6LoWPAN (IPv6 based Low Power WPAN)

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Nov. 19. 2007

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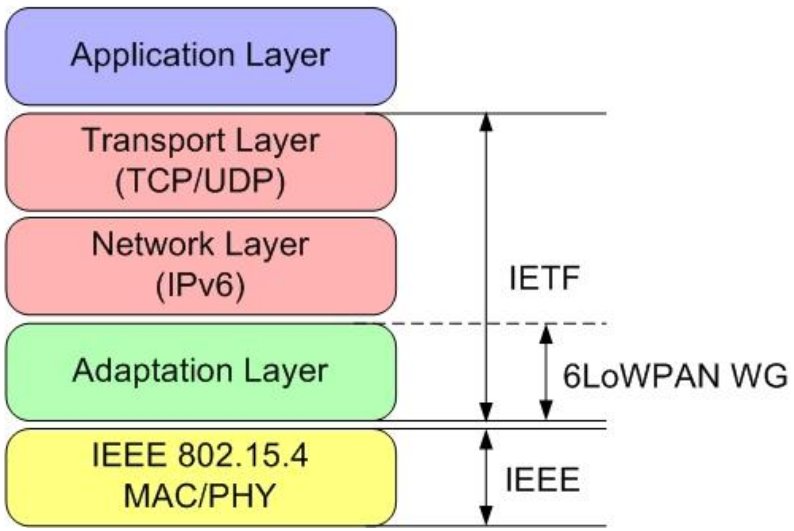
Outline

- Overview of 6LoWPAN
- Transmission of IPv6 Packets over IEEE 802.15.4 WPAN Networks
  - 6LoWPAN Header
  - Fragmentation
  - Mesh Routing
- Requirements of 6LoWPAN Technologies
  - 6LoWPAN Application + Architecture
  - 6LoWPAN Neighbor Discovery Optimizations
  - 6LoWPAN Routing
- Conclusion

Overview of 6LoWPAN

Overview of 6LoWPAN

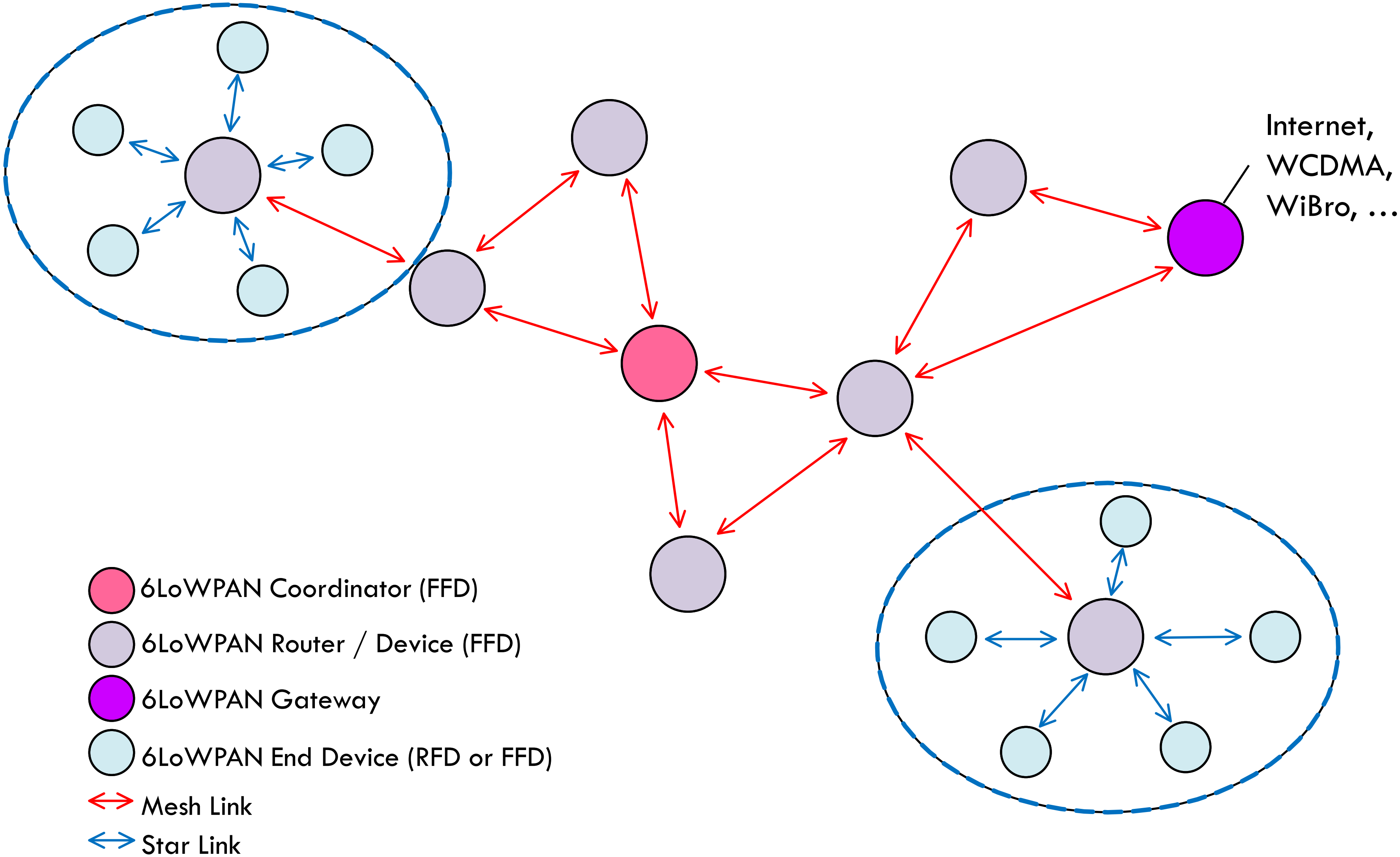
- **No method exists to make IP run over IEEE 802.15.4 networks**
  - Worst case: 802.15.4 PDU 81 octets, IPv6 MTU requirements 1280 octets
- **Stacking IP and above layers "as is" may not fit within one 802.15.4 frame**
  - IPv6 40 octets, TCP 20 octets, UDP 8 octets + other layers (security, routing, etc) leaving few bytes for data
- **Not all ad-hoc routing protocols may be immediately suitable for LoWPAN**
  - DSR may not fit within a packet, AODV needs more memory, etc



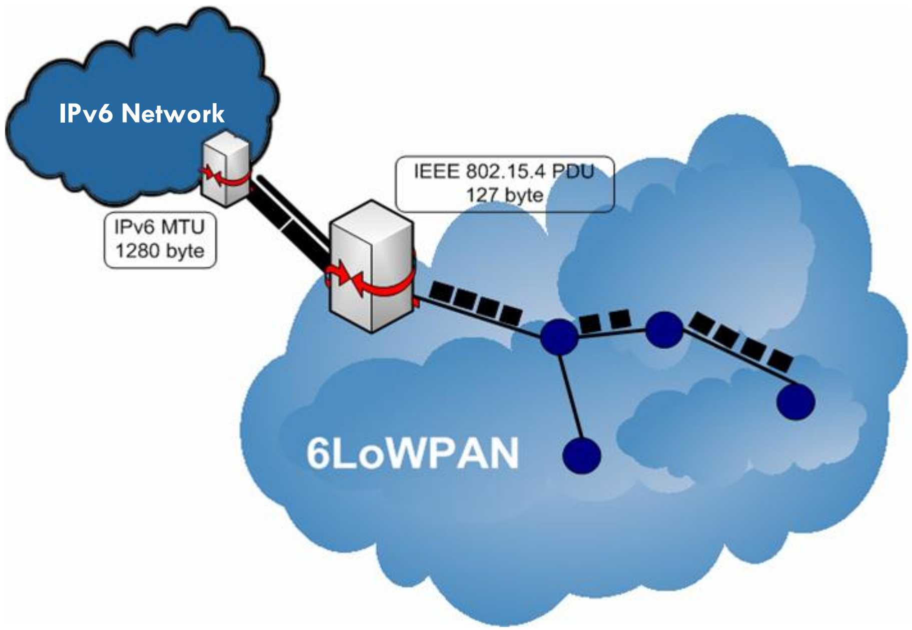
IETF 6LoWPAN

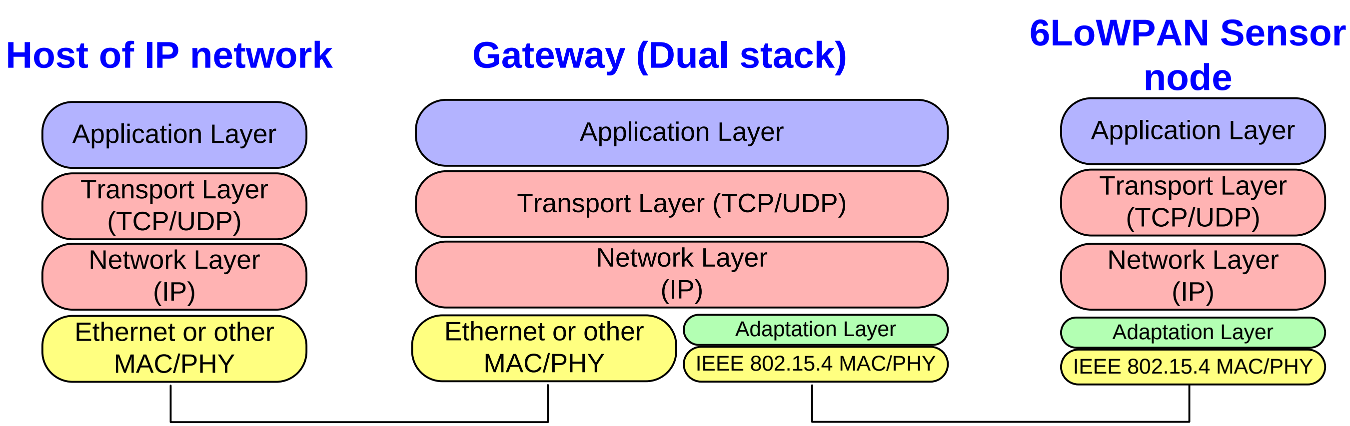
- LoWPANs
  - Low Cost, Low Power, Low Speed, Limited Distance
    - 900~2400MHz, 20~250kbit/s
    - FFD (Full-Function Device) vs. RFD (Reduced-Function Device)
  - Mesh network of interconnected devices
    - 10s to 1000s of nodes
  - Conforming to IEEE 802.15.4-2003 Standard
- Current Scope of 6lowPAN
  - Produce "Problems Statement, Assumptions and Goals for IPv6 for LoWPANs“ – RFC 4919
  - Produce "Transmission of IPv6 Packets over IEEE 802.15.4 WPAN Networks“ – RFC 4944
- Rechartering is on-going (IETF-68 Prague, IETF-69 Chicago)
  - Architecture (Bootstrapping), ND Optimization, etc ..
  - Routing, Mobility, Security, etc..

6LoWPAN Network Topology



6LoWPAN Gateway Architecture





Many Advantages of IP

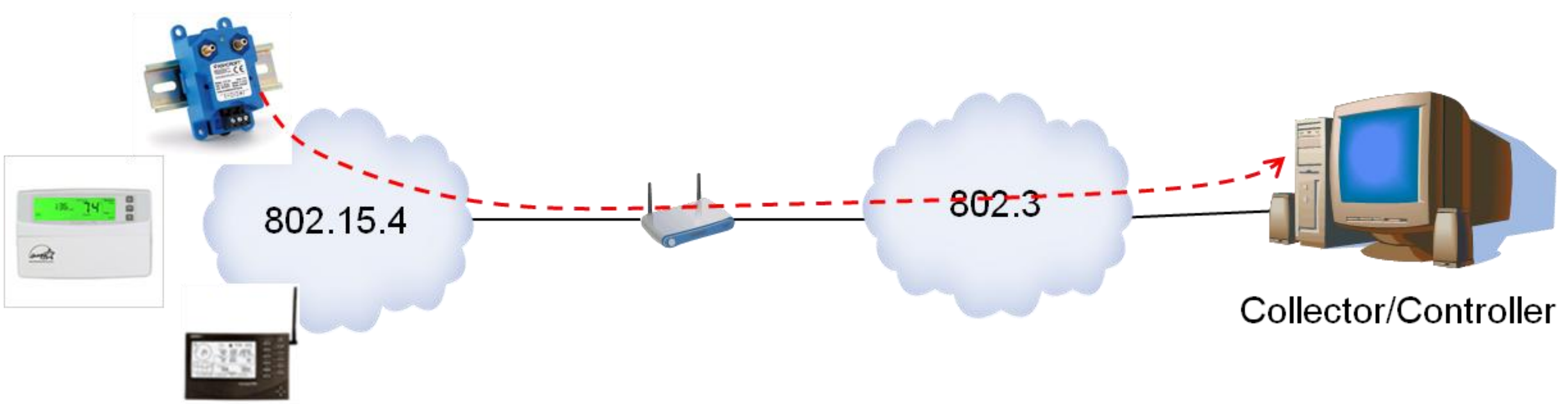
- **Extensive interoperability**
  - Other wireless embedded 802.15.4 network devices
  - Devices on any other IP network link (WiFi, Ethernet, GPRS, Serial lines, …)
- **Established security**
  - Authentication, access control, and firewall mechanisms
  - Network design and policy determines access, not the technology
- **Established naming, addressing, translation, lookup, discovery**
- **Established proxy architectures for higher-level services**
  - NAT, load balancing, caching, mobility
- **Established application level data model and services**
  - HTTP/HTML/XML/SOAP/REST, Application profiles
- **Established network management tools**
  - Ping, Traceroute, SNMP, … OpenView, NetManager, Ganglia, …
- **Transport protocols**
  - End-to-end reliability in addition to link reliability
- **Most "industrial" (wired and wireless) standards support an IP option**

Why global addresses

- Why global addresses
  - End-to-end communication in networks with heterogeneous links
    - *without* a stateful (possibly application specific) translation gateway
    - data collection point may be multiple IP hops away
- End-to-end communication across different PANs
- IP connects different subnetworks
  - ZigBee does not

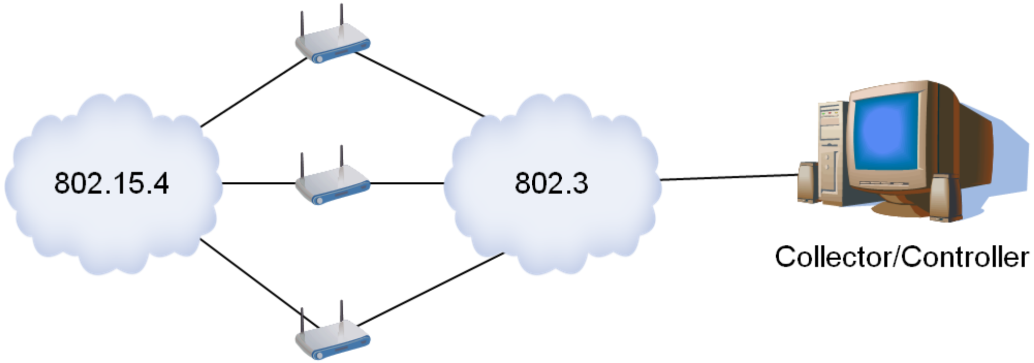
Why global addresses : example

- Monitoring and Control Applications
  - Collector OR controller generally not a 802.15.4 device
  - Conventional device on conventional link
  - Collector/controller often connected using other links

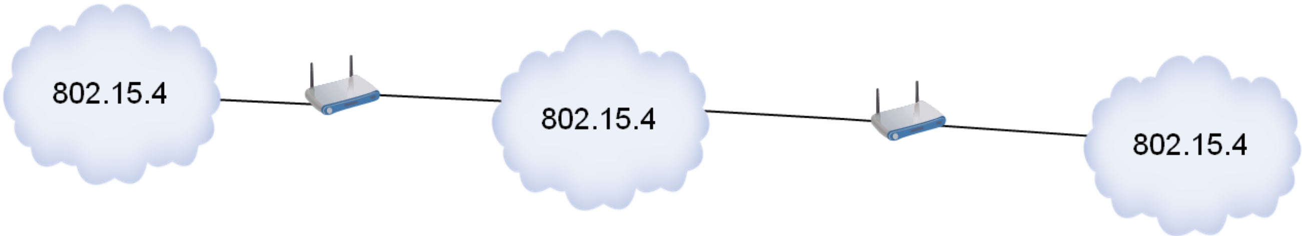


Why global addresses : example

- Route directly to the data collector
- Possibly through different egress points



- Multiple PANs may be different in PAN ID, channel, MAC, network-wide keys, etc.



6LoWPAN Format

- **Limited Packet Size**
  - Protocols for low-end (limited RAM and storage) LowPAN devices should be designed such that control packets fit within a single 802.15.4 frame(127 octets).
  - Given the limited packet size, headers for IPv6 and layers above must be compressed whenever possible.
  - Adding all layers for IP connectivity should still allow transmission in one frame, avoiding fragmentation and reassembly.

6LoWPAN Format (con't)

- **Packet Overhead –Worst Case Scenario:**
  - The Maximum Transmission Unit (MTU) size for IPv6 packets over IEEE 802.15.4 is 1280 octets.
  - A full IPv6 packet does not fit in an IEEE 802.15.4 frame
    - max. PHY frame = 127 octets
  - E.g) 127 octets –(25 + 21 + 40 + 8) == 33 octets for UDP application data ?
    - The maximal PHY layer frame overhead is 25octets
    - Link-Layer security causes further overhead of max. 21octets →81 octets for MAC layer payload.
    - Since the IPv6 header size is 40octets
    - UDP uses 8 octets in the header
    - So only 33octets are left for UDP application data.

Transmission of IPv6 Packets over IEEE 802.15.4 WPAN Networks (RFC 4944)

1. 6LoWPAN Header

- Header Overhead
  - Standard IPv6 header is 40 bytes [RFC 2460]
  - Entire 802.15.4 MTU is 127 bytes [IEEE]
  - Often data payload is small

6LoWPAN Header (Adaptation Layer)

IPv6 Header

- **Basic Header (addressing, hops left, etc.)**
  - ✓ Hop-by-Hop Options
  - ✓ Routing
  - ✓ Fragment
  - ✓ Destination Options
- **Each header contains the type of the following header**

Addressing	HBH Options	Routing	Fragment	Dest Options	Payload…

6LowPAN Header (Adaptation Layer)

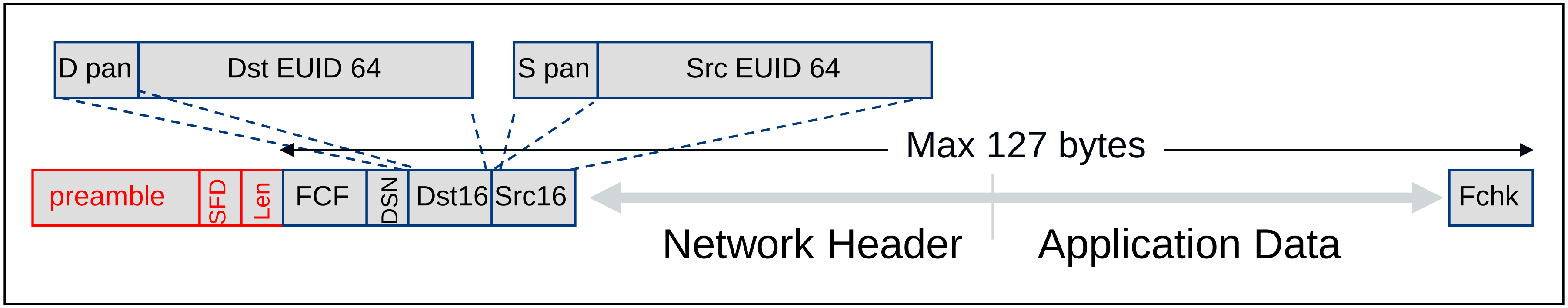
- **[Header Type] + [Header]**

Dispatch Type	Dispatch Header…
Mesh Type	Mesh Header…
Fragmentation Type	Fragmentation Header…

- **Typical Header Stacks (preserve IPv6 ordering)**

✓ Single Hop, No Fragmentation	HC1 Dispatch	HC1 Hdr…				
✓ Multi Hop, No Fragmentation	Mesh Dispatch	Mesh Hdr…	HC1 Dispatch	HC1 Hdr…		
✓ Single Hop, Fragmentation	Frag Dispatch	Frag Hdr…	HC1 Dispatch	HC1 Hdr…		
✓ Multi Hop, Fragmentation	Mesh Dispatch	Mesh Hdr…	Frag Dispatch	Frag Hdr…	HC1 Dispatch	HC1 Hdr…

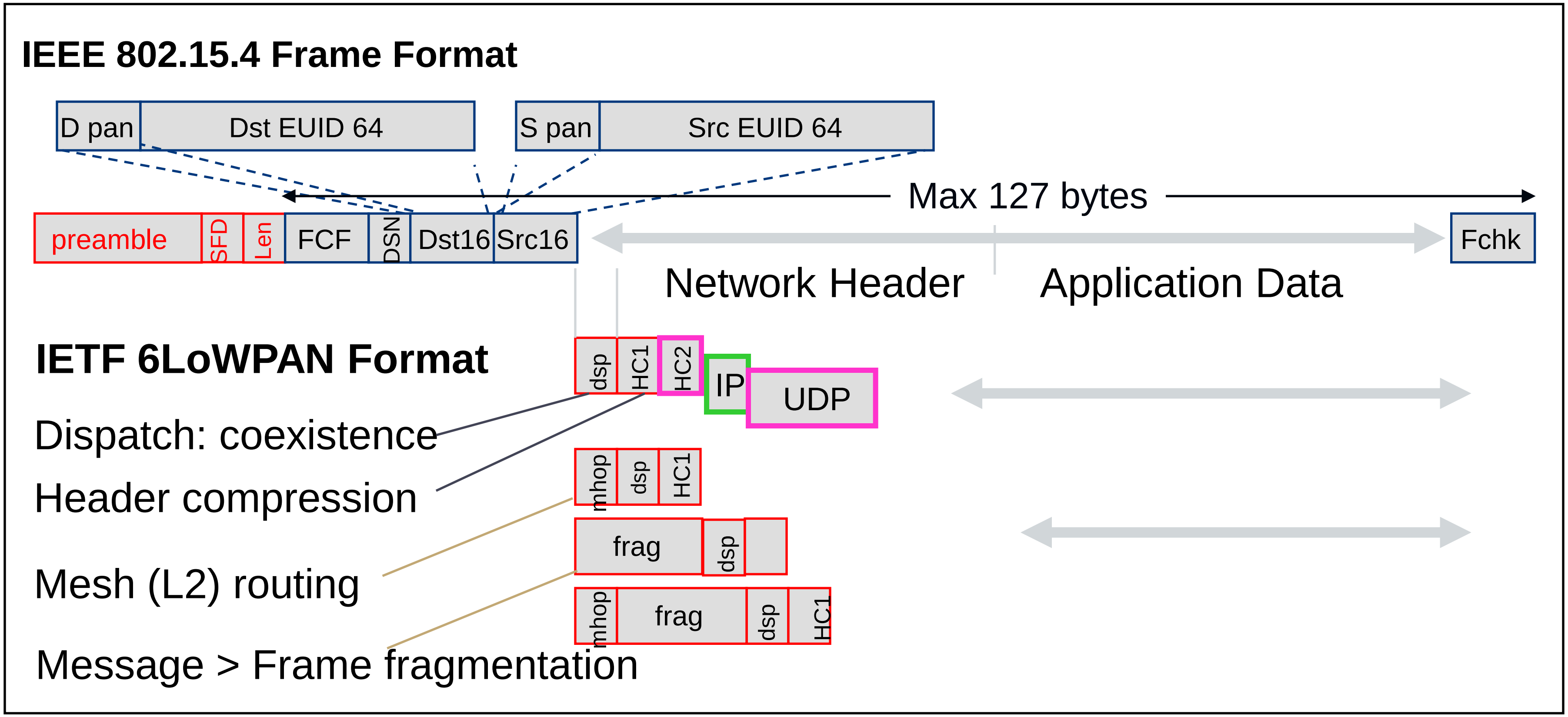
IEEE 802.15.4 Frame Format



- Low Bandwidth (250 kbps), low power (1 mW) radio
- Moderately spread spectrum (QPSK) provides robustness
- Simple MAC allows for general use
  - Many TinyOS-based protocols (MintRoute, LQI, BVR, …), TinyAODV, Zigbee, SP100.11, Wireless HART, …
  - 6LoWPAN => IP
- Choice among many semiconductor suppliers
- Small Packets to keep packet error rate low and permit media sharing

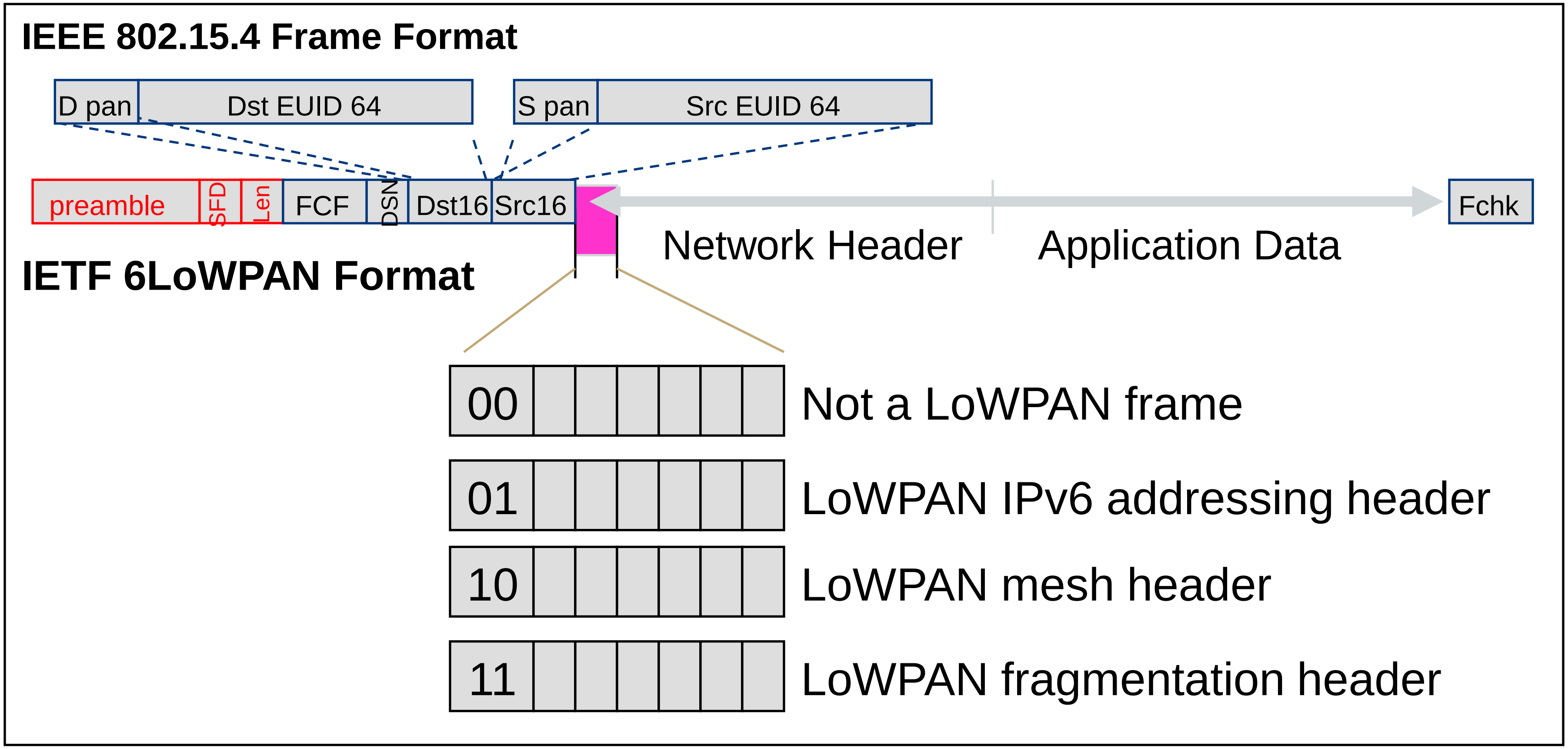
6LoWPAN Format Design

- Orthogonal stackable header format
- Almost no overhead for the ability to interoperate and scale.
- Pay for only what you use

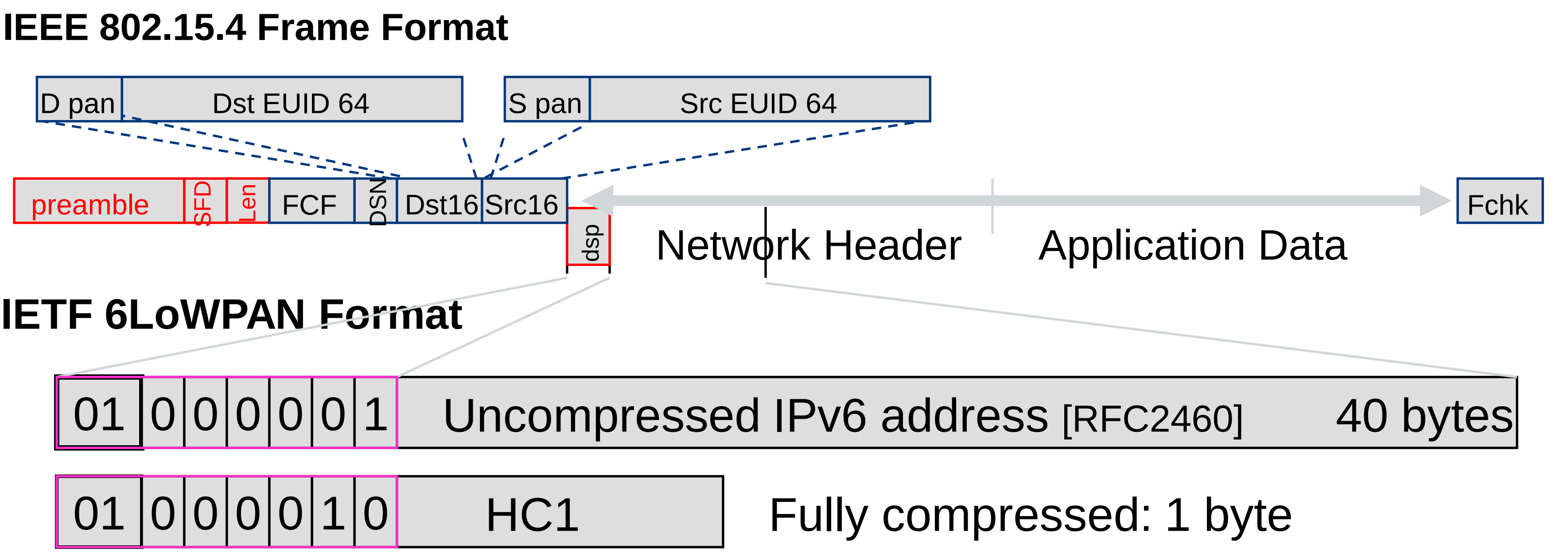


6LoWPAN – The First Byte

- Coexistence with other network protocols over same link
- Header dispatch - understand what's coming

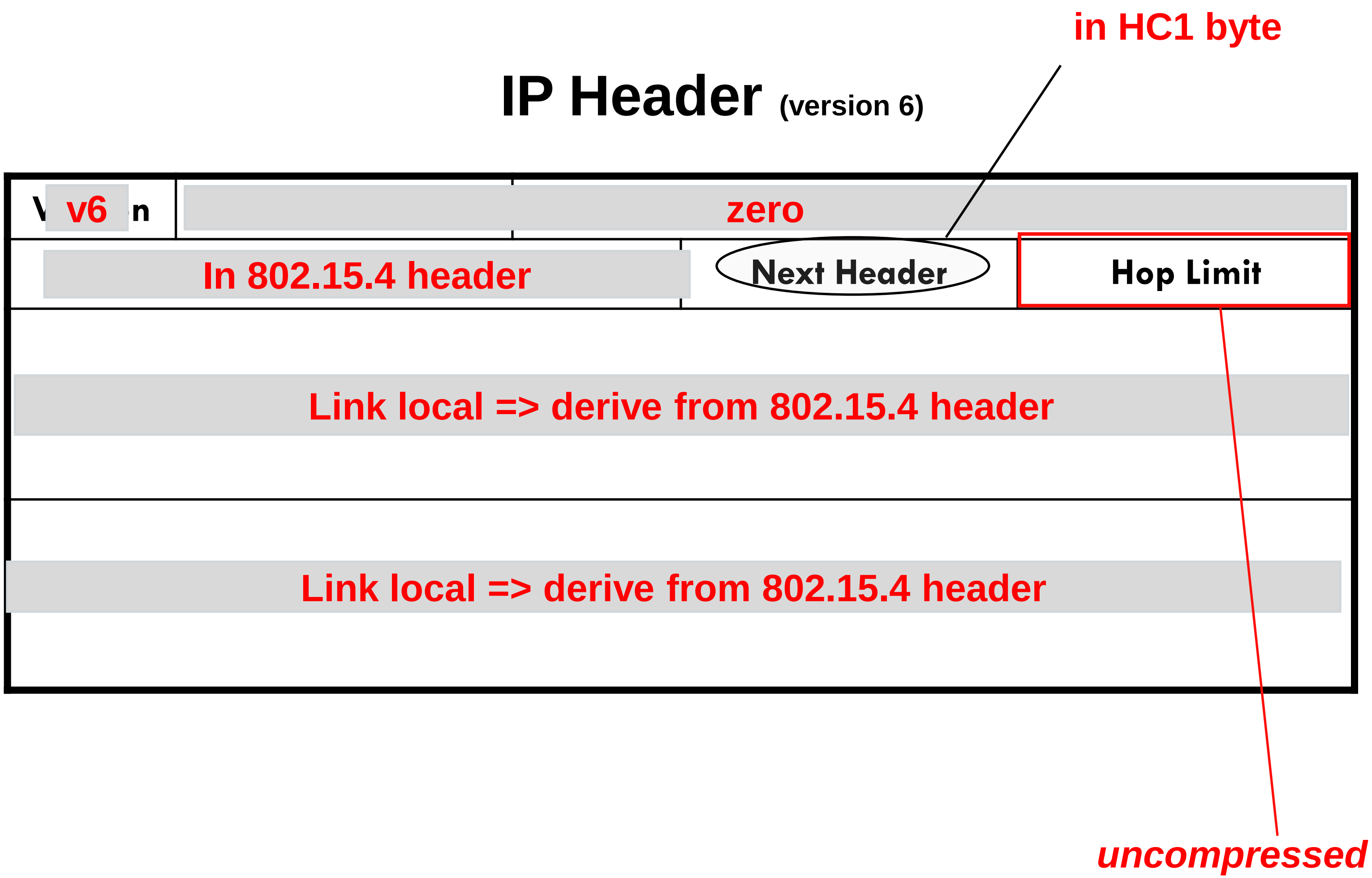


6LoWPAN – IPv6 Header

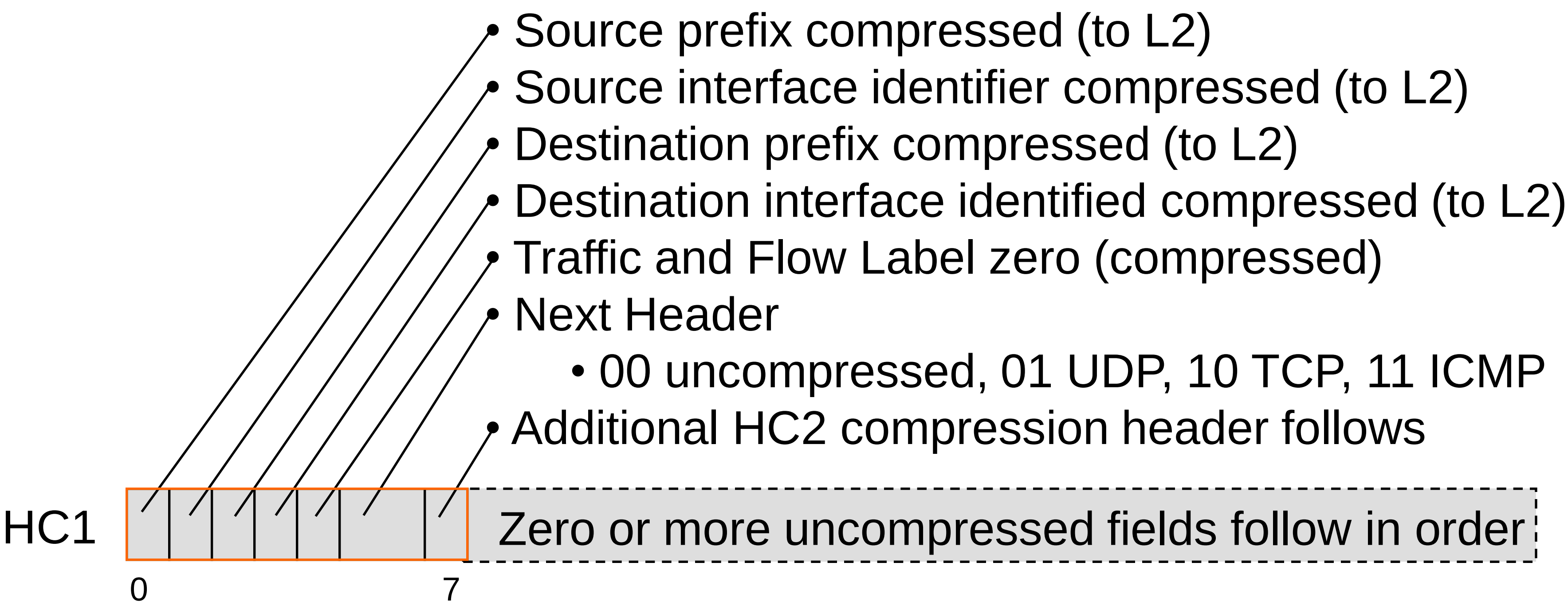


Source address	: derived from link address
Destination address	: derived from link address
Traffic Class & Flow Label	: zero
Next header	: UDP, TCP, or ICMP

IPv6 Header Compression

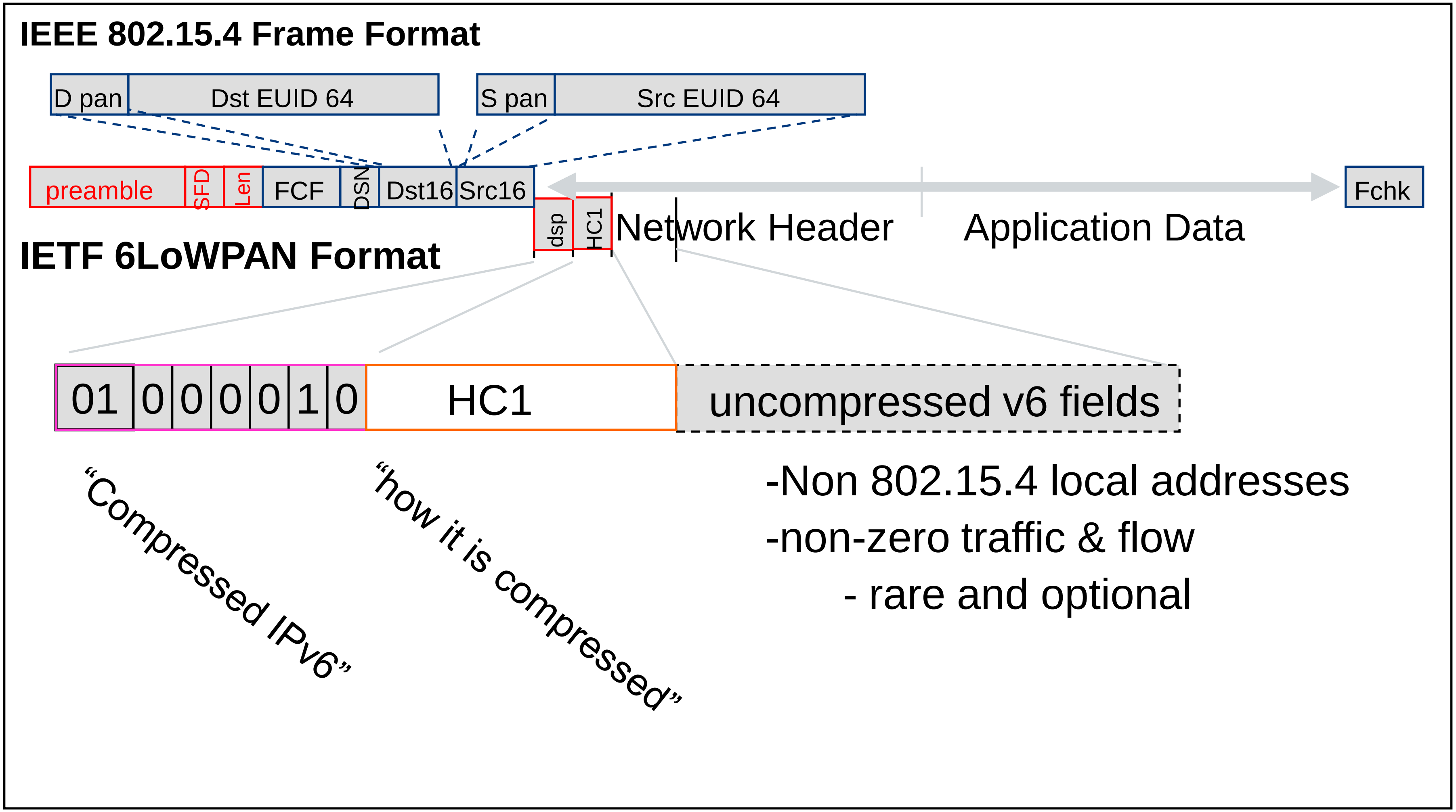


HC1 Compressed IPv6 Header



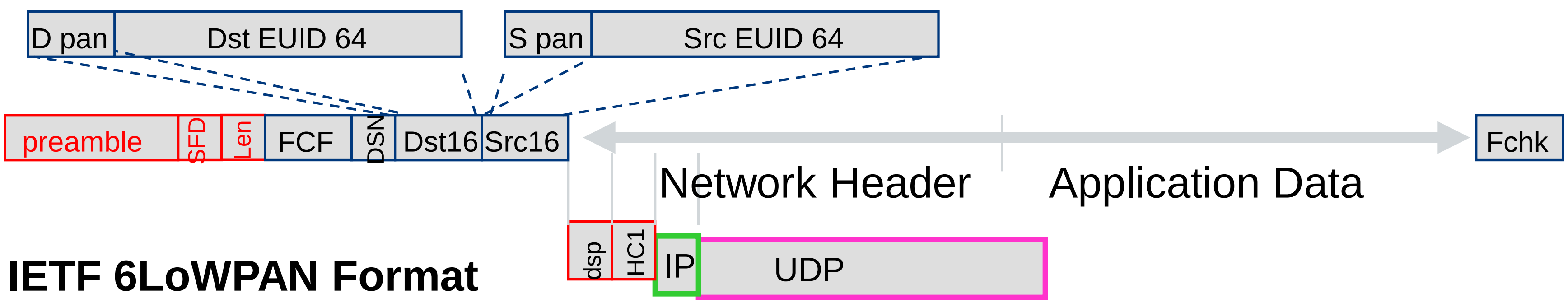
- IPv6 address <prefix64 || interface id> for nodes in 802.15.4 subnet derived from the link address.
  - PAN ID maps to a unique IPv6 prefix
  - Interface identifier generated from EUID64 or Pan ID & short address
- Hop Limit is the only incompressible IPv6 header field

6LoWPAN: Compressed IPv6 Header



6LoWPAN – Compressed / UDP

IEEE 802.15.4 Frame Format



IETF 6LoWPAN Format

Dispatch: Compressed IPv6

HC1: Source & Dest Local, next hdr=UDP

IP: Hop limit

UDP: 8-byte header (uncompressed)

L4 – UDP/ICMP Headers (8 bytes)

UDP Header (version 6)

P + [0..15] (Source Port)

P + [0..15] (Destination Port)

Source Port	Destination Port
Length	Checksum

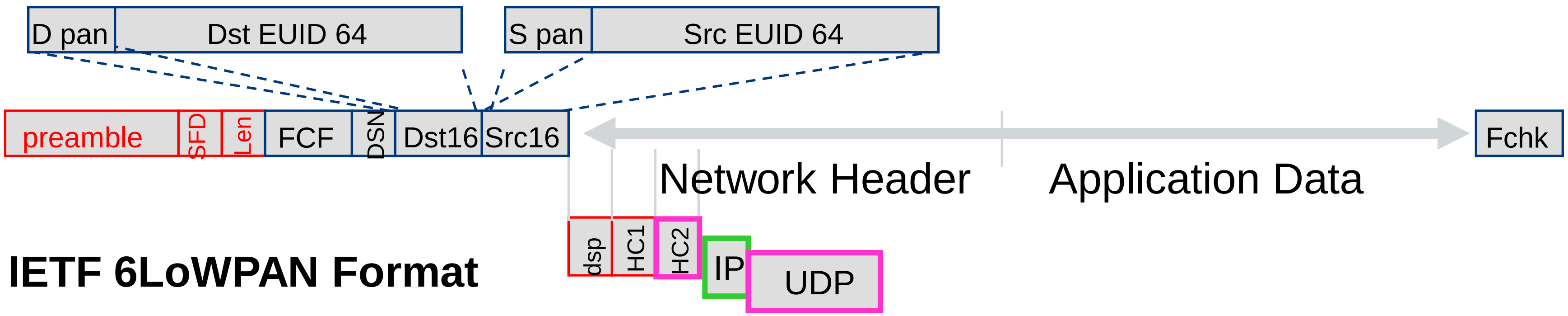
from 15.4 header (Length)

ICMP Header (version 6)

Type	Code	Checksum
Other message specific Information		

6LoWPAN – Compressed / Compressed UDP

IEEE 802.15.4 Frame Format



IETF 6LoWPAN Format

Dispatch: Compressed IPv6

HC1: Source & Dest Local, next hdr=UDP

IP: Hop limit

UDP: HC2+3-byte header (compressed)

source port = P + 4 bits, P = 61616 (0xF0B0)

destination port = P + 4 bits

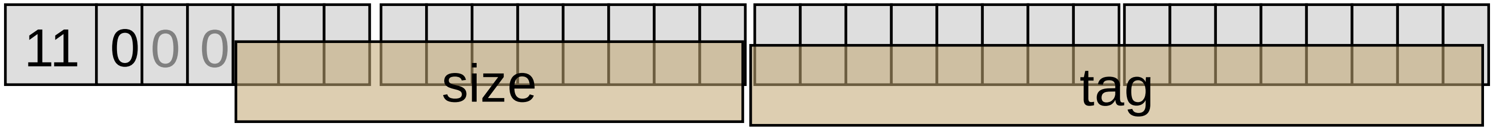
Fragmentation of 6LoWPAN Packet

- Fragmentation
  - Interoperability means that applications need not know the constraints of physical links that might carry their packets
  - IP packets may be large, compared to 802.15.4 max frame size
  - IPv6 requires all links support 1280 byte packets [RFC 2460]

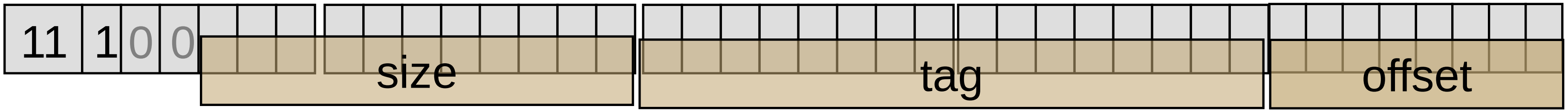
Fragmentation

- All fragments of an IP packet carry the same "tag"
  - Assigned sequentially at source of fragmentation
- Each specifies tag, size, and position
- Do not have to arrive in order
- Time limit for entire set of fragments (60s)

First fragment

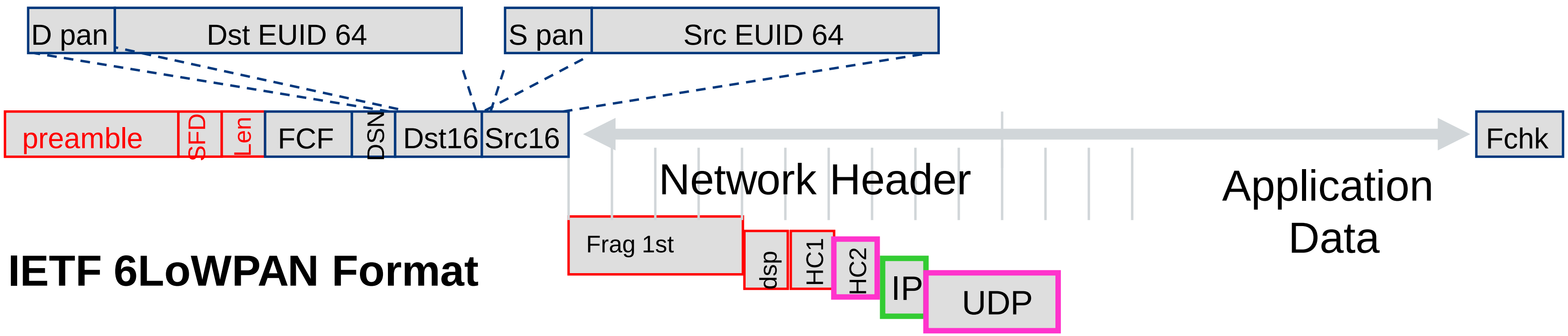


Rest of the fragments



6LoWPAN – Example
Fragmented / Compressed / Compressed UDP

IEEE 802.15.4 Frame Format



Dispatch: Fragmented, First Fragment, Tag, Size

Dispatch: Compressed IPv6

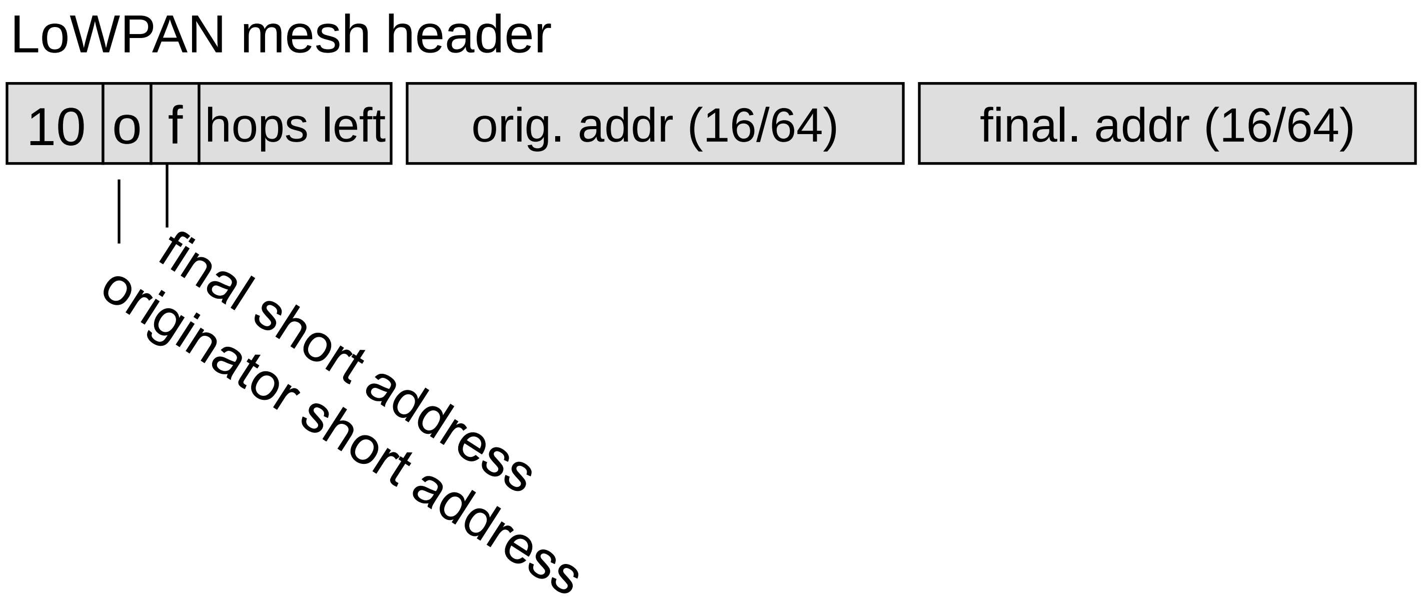
HC1: Source & Dest Local, next hdr=UDP
IP: Hop limit
UDP: HC2+3-byte header (compressed)

6LoWPAN Mesh Routing

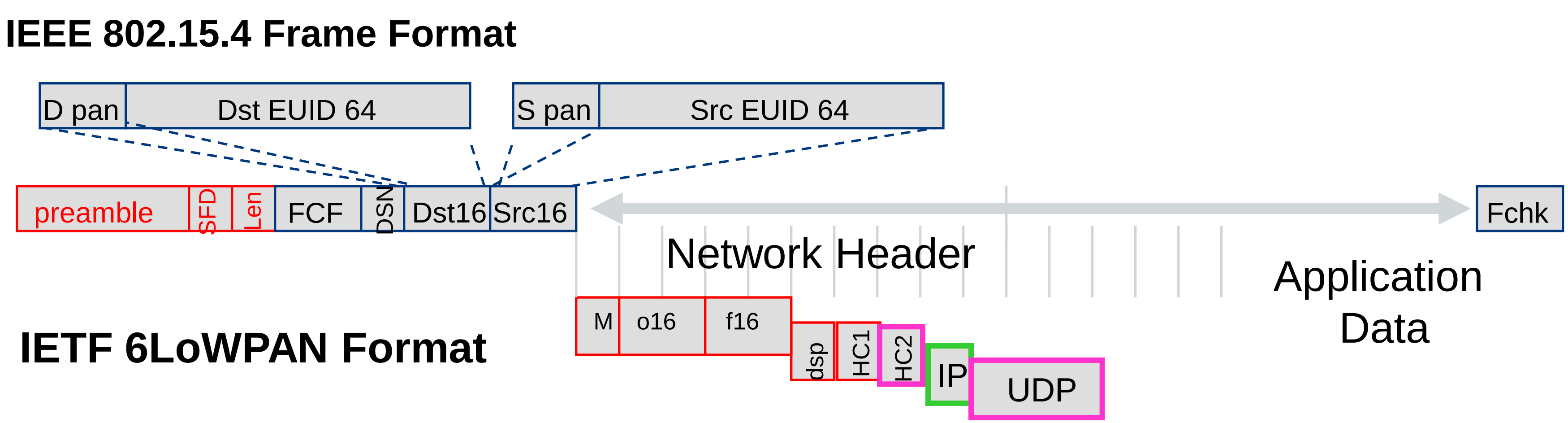
- Allow link-layer mesh routing under IP topology
  - 802.15.4 subnets may utilize multiple radio hops per IP hop
  - Similar to LAN switching within IP routing domain in Ethernet

“Mesh Under” Header

- Originating node and Final node specified by either short (16 bit) or EUID (64 bit) 802.15.4 address
  - In addition to IP source and destination
- Hops Left (up to 14 hops, then add byte)
- Mesh protocol determines node at each mesh hop



6LoWPAN – Example
Mesh / Compressed / Compressed UDP



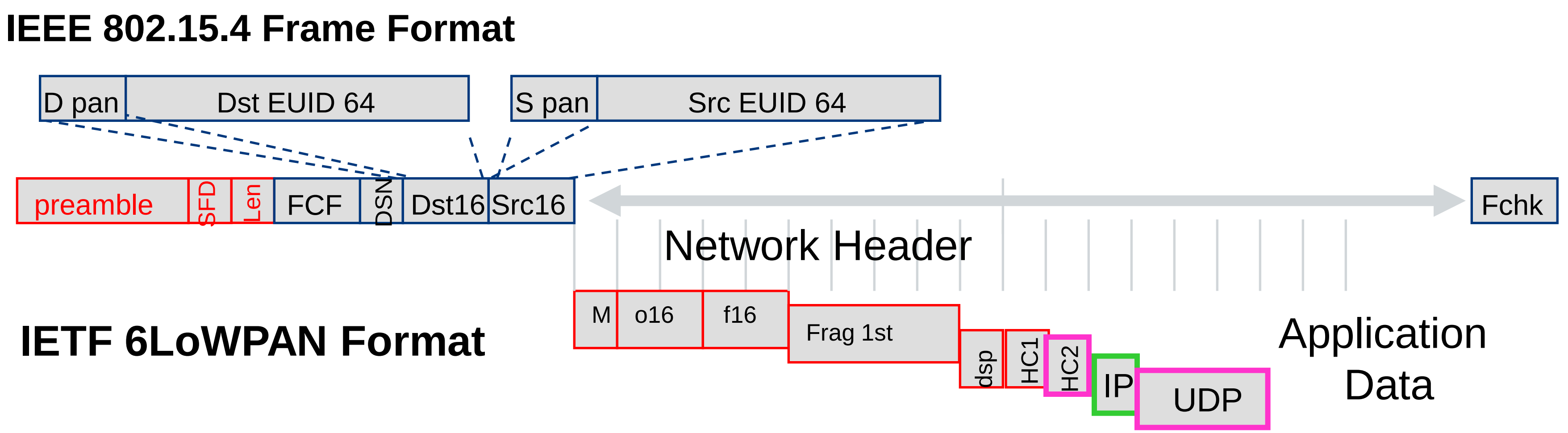
Dispatch: Mesh under, orig short, final short

Mesh: orig addr, final addr

Dispatch: Compressed IPv6

HC1: Source & Dest Local, next hdr=UDP
IP: Hop limit
UDP: HC2+3-byte header

6LoWPAN – Example
Mesh / Fragmented / Compressed / UDP



Dispatch: Mesh under, orig short, final short

Mesh: orig addr, final addr

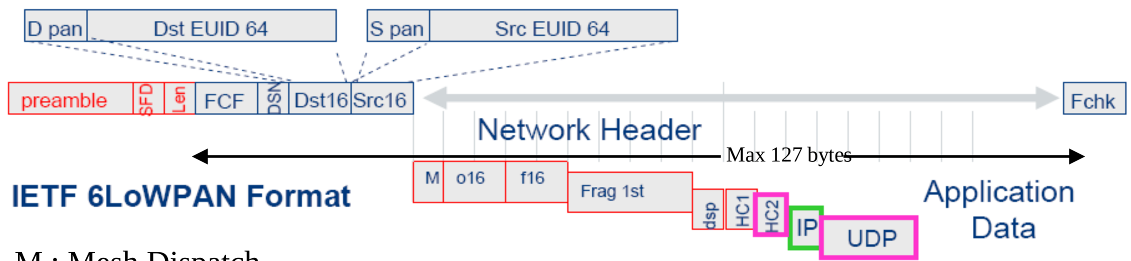
Dispatch: Fragmented, First Fragment, Tag, Size

Dispatch: Compressed IPv6

HC1: Source & Dest Local, next hdr=UDP
IP: Hop limit
UDP: HC2 + 3-byte header

6LoWPAN Header Summary

6LoWPAN Packet Format



M : Mesh Dispatch
O16 : Originate 16bits address
F16 : Final Destination 16bits address
Frag 1st : Fragmentation Header
DSP : Dispatch Header (Compressed IPv6)
HC1 : Source & Destination address = Local, next header = UDP
HC2 : Compressed UDP
IP : Hop Limit
UDP : HC2 + 3bytes header (compressed)

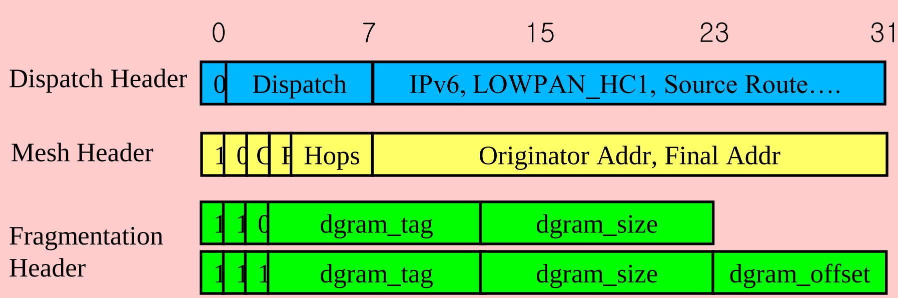
SFD : start-of-frame delimiter
FCF : Frame Control Field
DSN : data sequence number

IPv6 Compressed Scheme

LOWPAN_HC1 DISPATCH								HC1 Compressed IPv6 header							
0	1	0	0	0	0	1	0	0	1	2	3	4	5	6	7

0 : Source prefix compressed
1 : Source interface identifier compressed
2 : Destination prefix compressed
3 : Destination interface identified compressed
4 : Traffic and Flow Label zero
5,6 : Next Header
 00:uncompressed, 01:UDP, 10:TCP, 11:ICMP
7 : Additional HC2 compression header follows

6LoWPAN Headers



Requirements of 6LoWPAN Technologies

- 6LoWPAN Application + Architecture
- 6LoWPAN Neighbor Discovery Optimizations
- 6LoWPAN Routing

6LoWPAN Architecture

- 6LoWPAN Solutions might be dependent on how to define 6LoWPAN Architecture
  - Application Scenarios should be defined first.
    - u-City, u-Health, u-Defense, MANEMO, etc
    - Bootstrapping
- Architecture and Solutions
  - Basic Stack
    - 6LoWPAN Adaptation Layer & Format (Done !!)
    - ND Optimizations
  - Scenarios-Dependent
    - Mesh Routing
    - Mobility Support
    - Security Support

6LoWPAN Neighbor Discovery Optimizations

- draft-chakrabarti-6lowpan-ipv6-nd-03
- Goal
  - Minimizing Multicast messages such as:
    - Reduce or avoid multicast for Duplicate Address Detection.
    - Limit multicast Router Solicitations and Router Advertisements.
    - Avoid/Reduce Multicast Neighbor Solicitations.
  - Reduce or avoid (unicast) Neighbor Unreachability Detection messages.

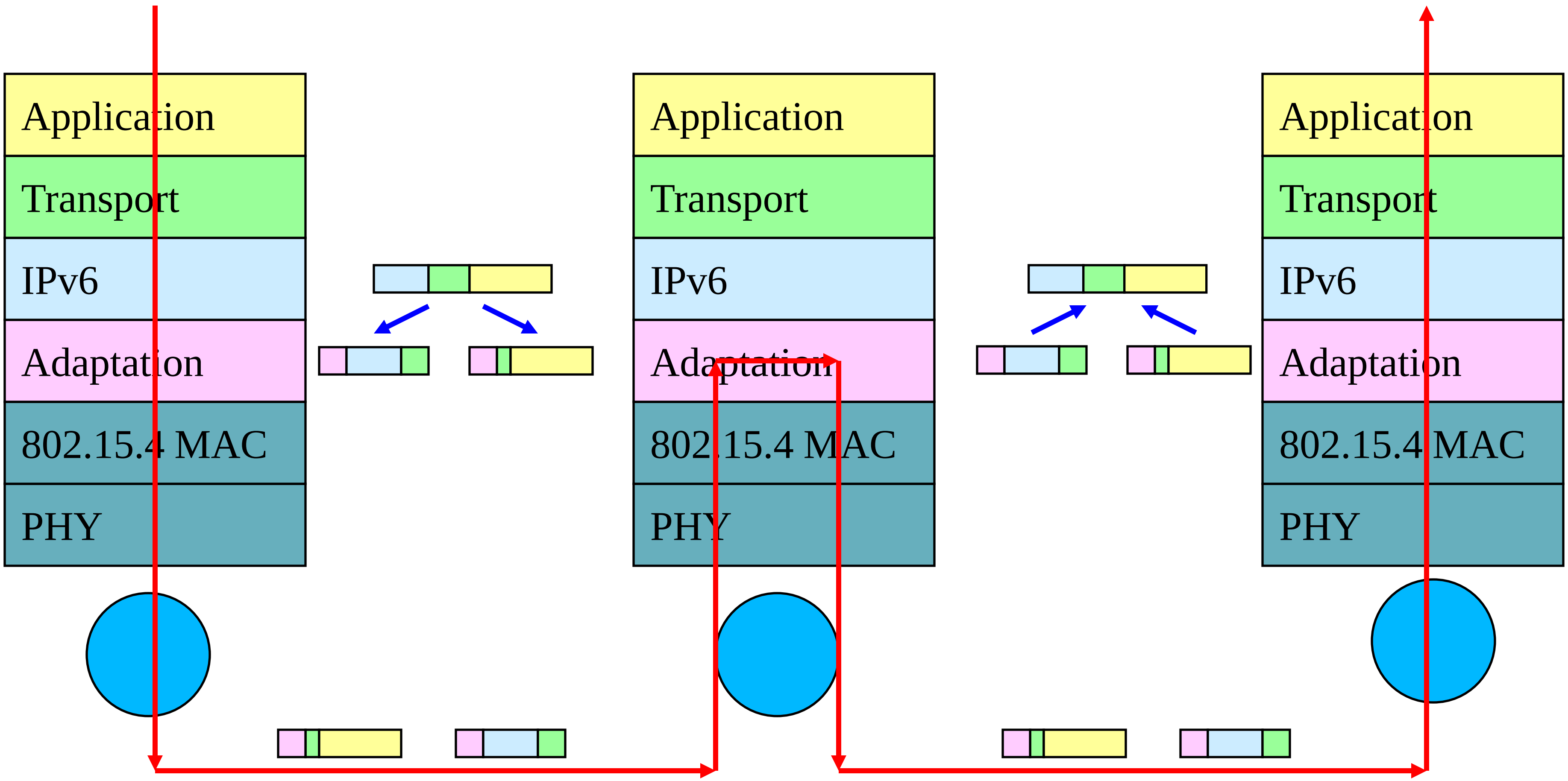
6LoWPAN Routing Requirement

- draft-dokaspar-6lowpan-routreq-02
- General Requirements:
  - Layer Transparency, Gateways
  - Robustness despite hibernating nodes
  - Local and Global Mobility
  - High Scalability
  - Secured control messages
  - Bootstrapping
- Special to 6LoWPAN:
  - Reusing MANET Protocols
  - Adaptation Layer Routing
  - No PHY frame fragmentation of control messages
  - 16 bit and 64 bit Addressing
  - Local repair MAY be omitted
  - ND without “Hello”Messages (L2-mechanisms)
  - Low Protocol Complexity
  - Low Routing State
  - Short code length
- Common requirements or guidelines for 6lowpan routing will lead to design refined routing solutions.

MANET Routing and Optimization

- **Mobile Ad-hoc Routing Protocols**
  - The MANET WG will develop two Standards track routing protocol specifications:
    - Reactive MANET Protocol (RMP) -On-demand
    - Proactive MANET Protocol (PMP) -Exchanges topology information
  - Already provides a number of (experimental) mesh routing protocols
    - RFC 3561: AODV –Ad-Hoc On-Demand Distance Vector Routing
    - RFC 3626: OLSR –Optimized Link State Routing -<OLSRv2>
    - Dynamic MANET On-demand (DYMO) Routing (I-D)
- **For 6LoWPAN :**
  - Shares same goal, but for ultra-low performance devices (i.e. sensor nodes).
    - Simplification and Optimization Required

Mesh Routing underneath to IPv6 Layer



Conclusion

- 6LoWPAN will be a one of drivers for IPv6 Deployment
- 6LoWPAN turns IEEE 802.15.4 into the next IP-enabled link
- Provides open-systems based interoperability among low-power devices over IEEE 802.15.4
- Provides interoperability between low-power devices and existing IP devices, using standard routing techniques
- Paves the way for further standardization of communication functions among low-power IEEE 802.15.4 devices
- Offers watershed leverage of a huge body of IP-based operations, management and communication services and tools
- Great ability to work within the resource constraints of low-power, low-memory, low-bandwidth devices like WSN

Q & A

Thank you