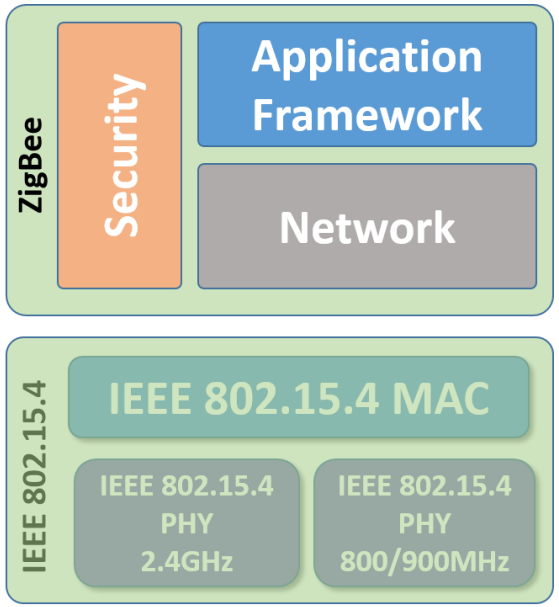
# ZigBee & 6LoWPAN

# IEEE 802.15.4

- **Mention on**
  - Physical Layer Specifications
    - Channels
    - Frequency Bands
    - Modulation
  - MAC layer specifications
    - Channel Access
    - Frames
  - Clustering
    - Management of devices
    - Topologies
  - Packet types
    - Data
    - MAC Command
    - Beacon
    - ACK
- **No-Mention on**
  - Network Formation
  - Neighbor discovery process
  - Managing Application Layer
  - Definition of Application Objects
  - Device Maintenance
  - Security at Higher Layers

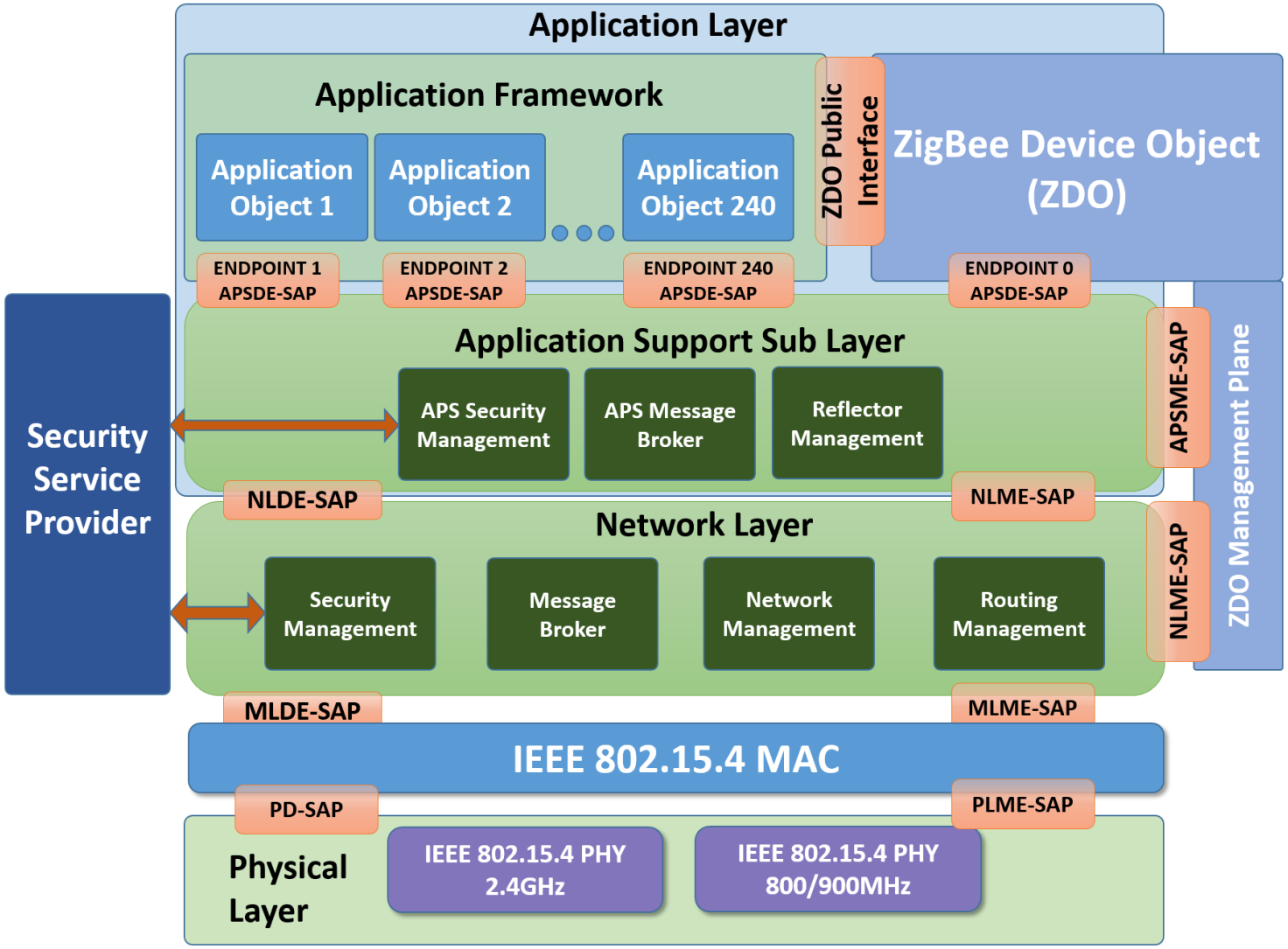
# ZigBee




- Consortium to Define Upper layer protocols on IEEE 802.15.4
- Defines scope for application development
- Strictly speaks about interoperability among different manufacturers
- Networks are separated based on services they offer

- Profiles
  - ➢Smart Home
  - ➢Utility
    - ❑Smart Energy
  - ➢Lighting
  - ➢Retail Services
- Network Specifications
- Compliance Specifications
- Certification Program

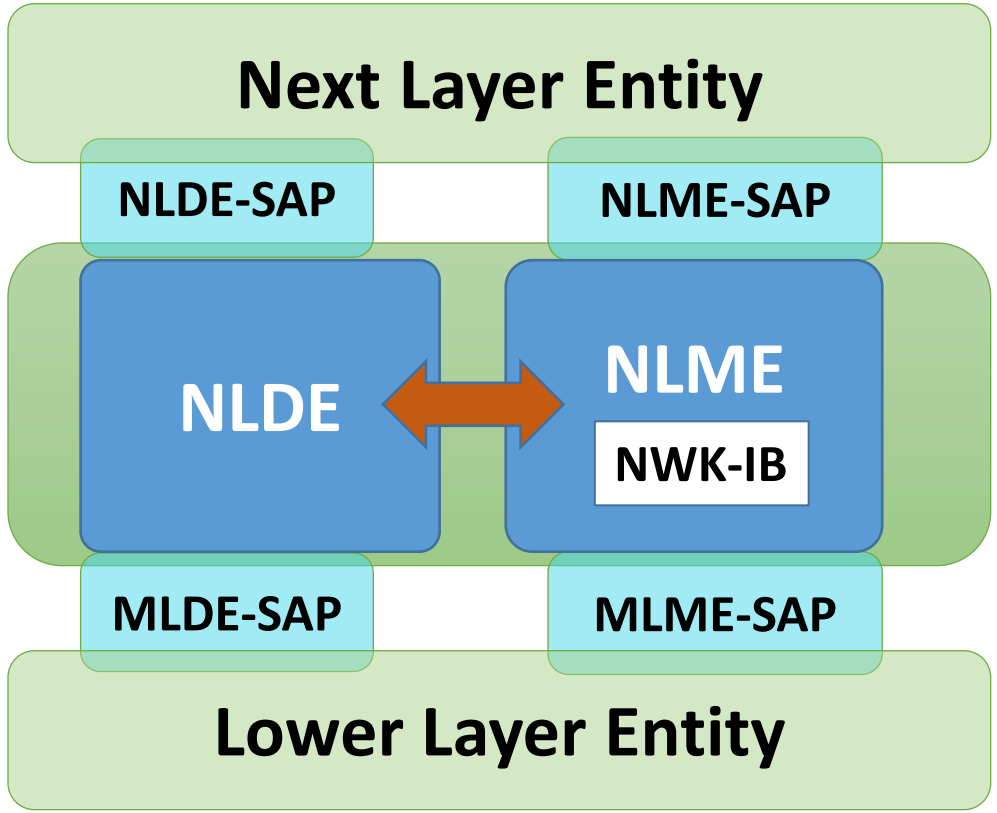
# Architecture



# Network Layer

- The network layer is required to provide functionality to ensure correct operation of the IEEE 802.15.4 MAC sub-layer and to provide a suitable service interface to the application layer
- Join and leave a network
- Apply security to Network Layer frames
- Route frames to their intended destinations
- Discovery and maintenance of routes among devices
- Discover one-hop neighbors
- Store of pertinent neighbor information
- Addressing Schemes
  - 16 Bit
  - PAN-ID
  - Node-ID

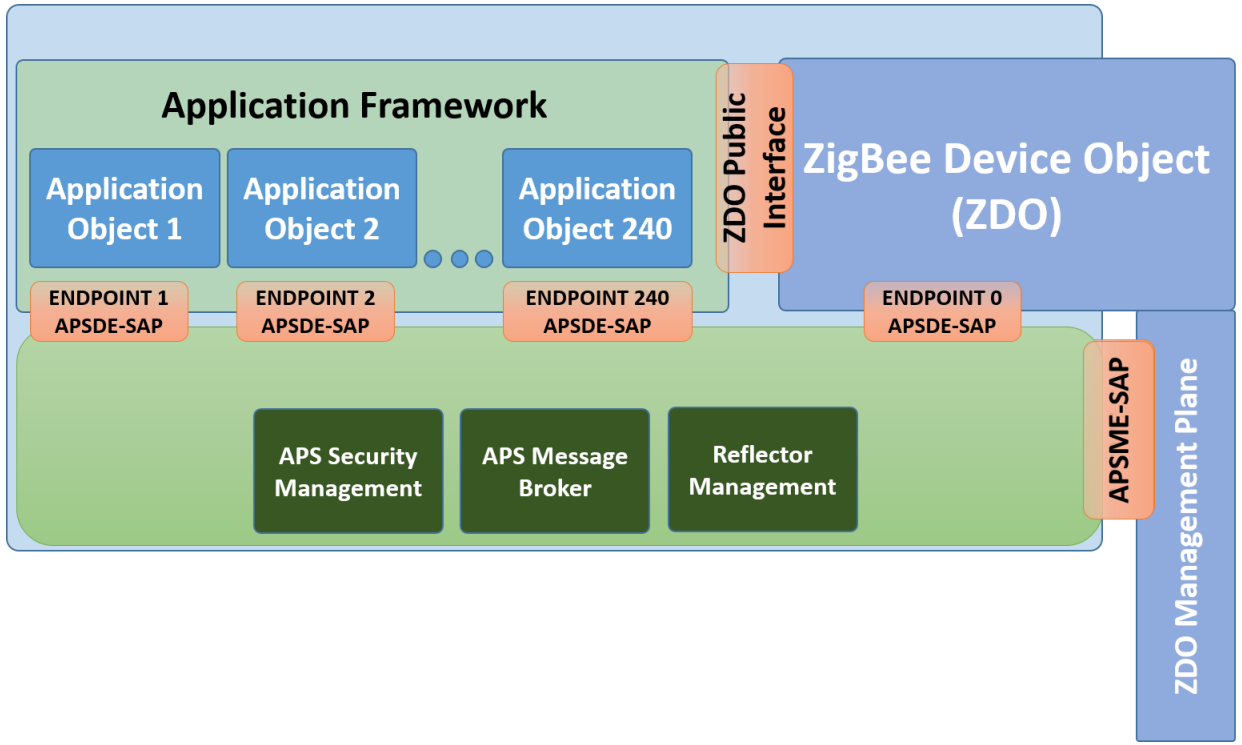
# Network Layer



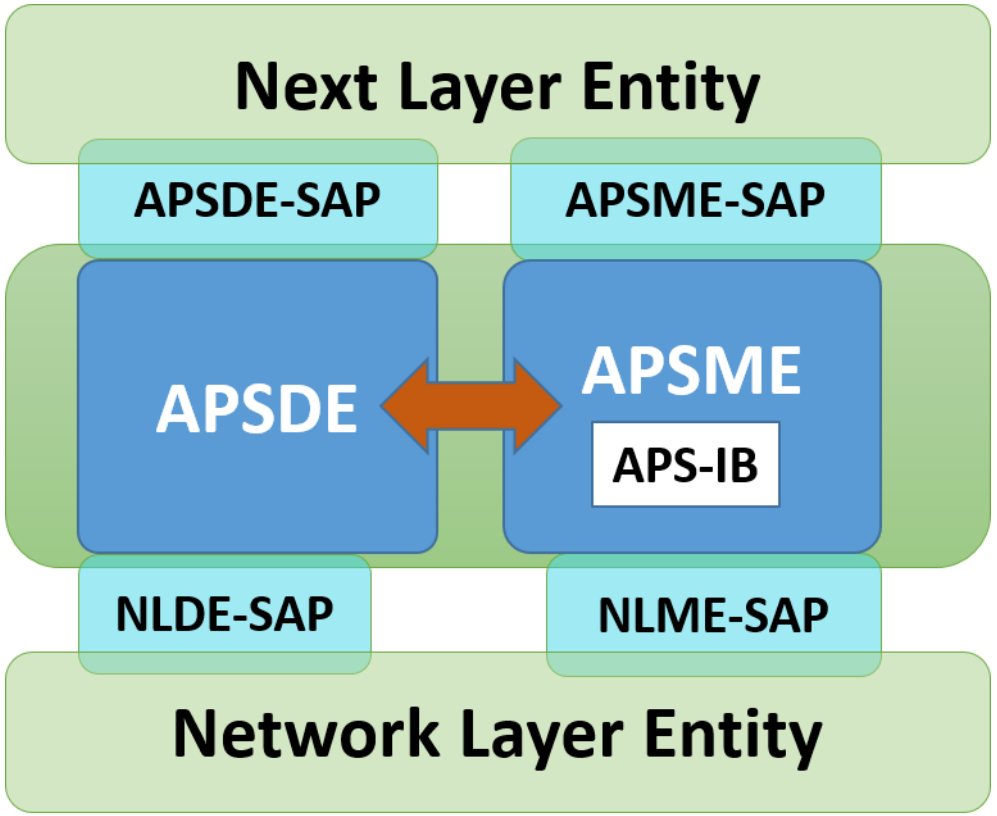

- NLDE-SAP
  - Generation of the Network level PDU (NPDU)
  - Topology specific routing
  - Security
- NLME-SAP
  - Configuring a new device
  - Starting a network
  - Joining and leaving a network
  - Addressing
  - Neighbor discovery
  - Route discovery
  - Reception control

# Application Layer

- Application Support Sub Layer
- Application Objects
- ZigBee Device Object (ZDO) Layer
- ZDO Management Plane

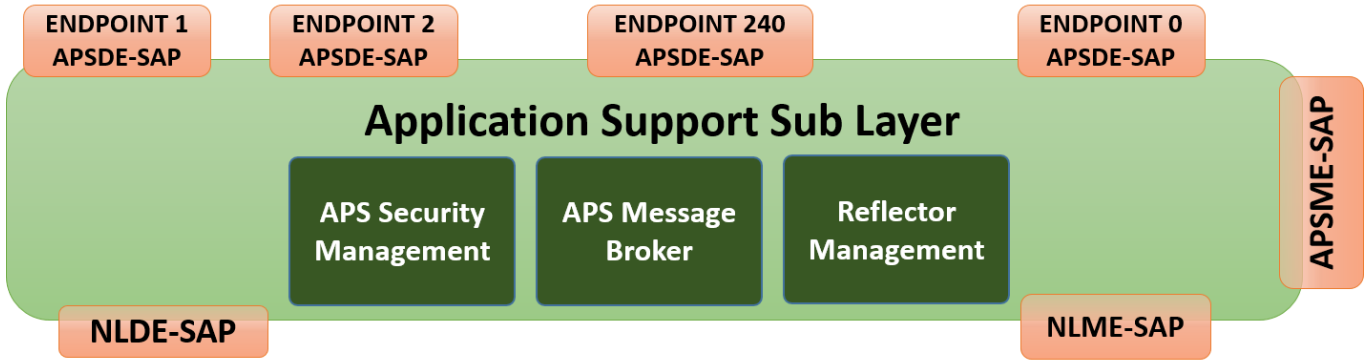


# Application Support Sub Layer (APS)



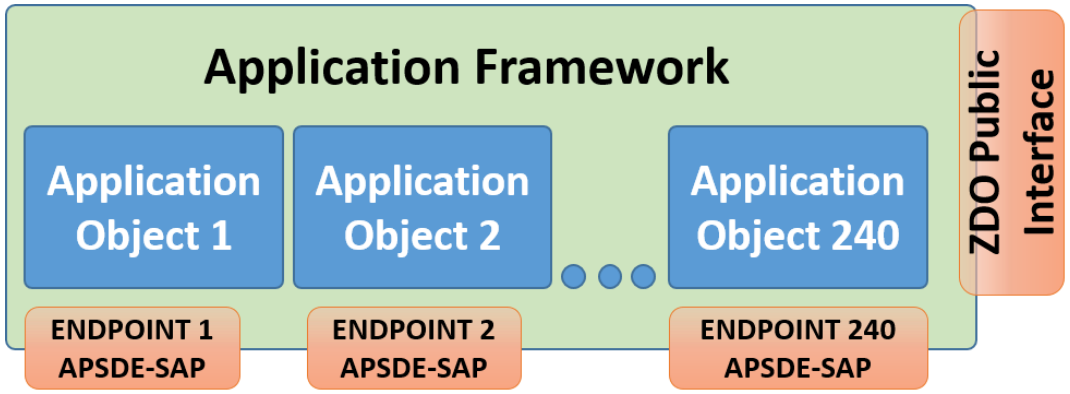

- Maintaining tables for binding, defined as the ability to match two devices together based on their services and their needs
- Forwarding messages between bound devices

# Application Support Sub Layer (APS)




- Security for application layer packets
- Message handling for Application Objects
- Connections to Application Objects
- Reflector Management
- Connections to ZDO

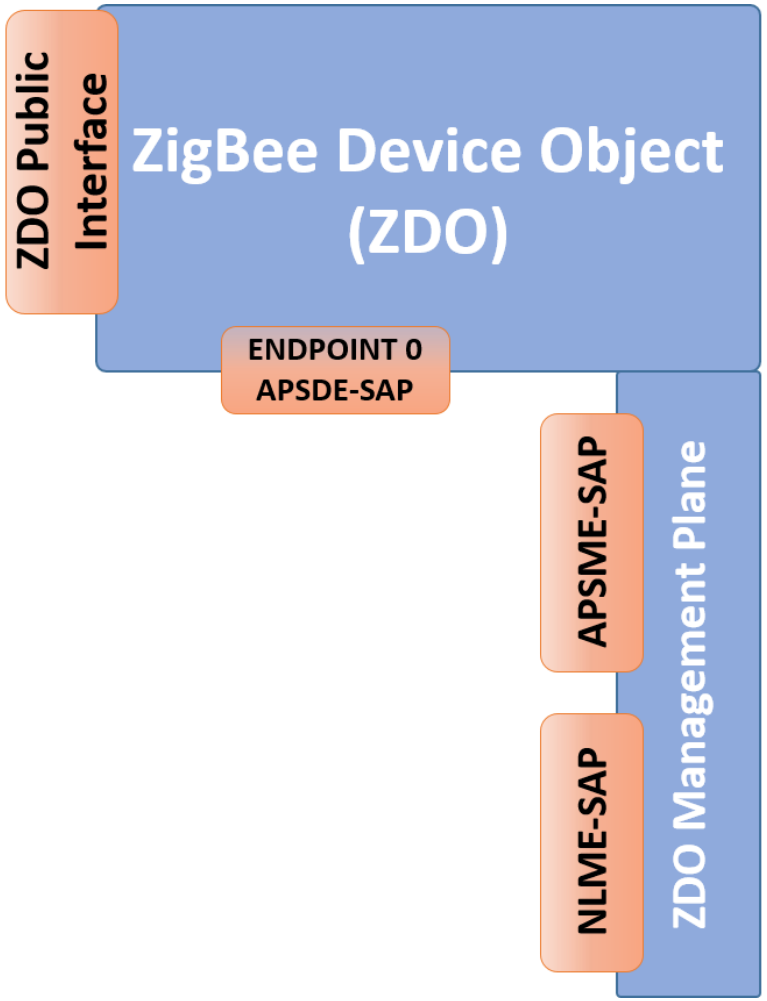
# Application Framework




- Connections from APS Sub Layer
- Application objects
  - Sensor Profiles
  - Actuator Profiles
- Upto 240 Object definitions
- A Device may have more than one Application Object
- Interface to ZDO Layer

# ZigBee Device Object (ZDO)

- Initializing the Application Support Sublayer (APS), Network Layer (NWK), Security Service Provider (SSP) and any other ZigBee device layer other than the end applications residing over Endpoints 1-240
- Defines the role of the device within the network (e.g., ZigBee coordinator or end device)
- Initiating and/or responding to binding requests
- Establishing a secure relationship between network devices



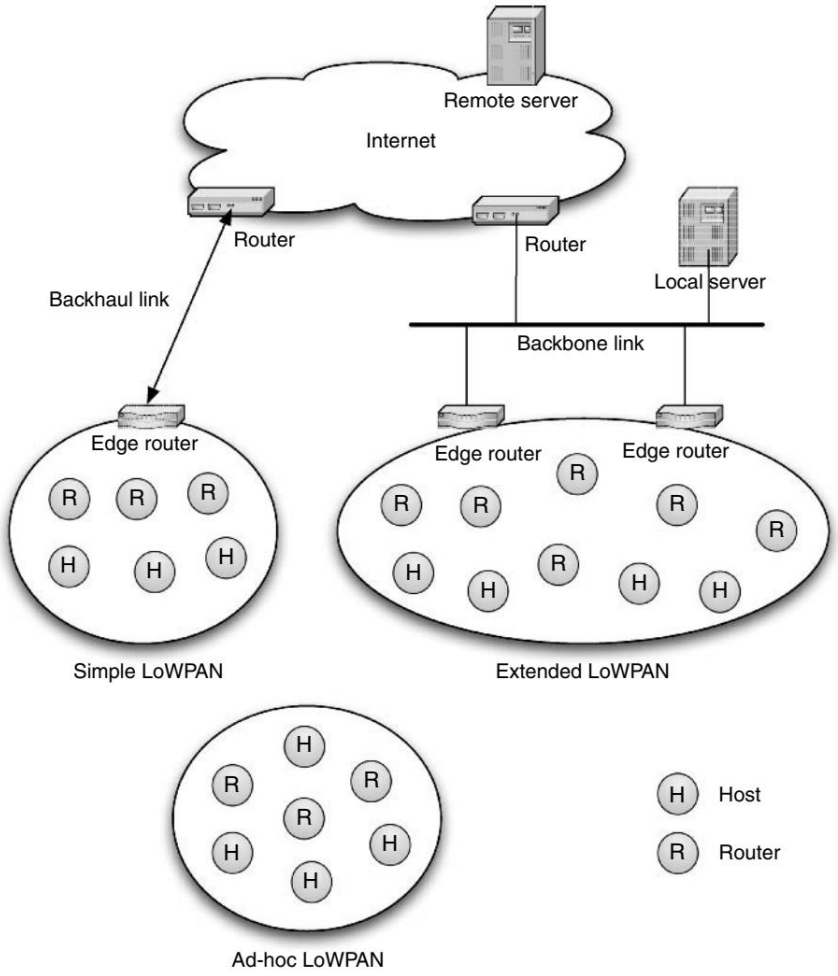
# ZDO

- Device & Service discovery
- Security Manager
  - Establish Key
  - Transport Key
  - Request Key
  - Update Device
  - Remove Device
  - Switch Key
- Network Manager
  - ZigBee Coordinator (ZC)
  - ZigBee Router (ZR)
  - ZigBee End Device (ZED)
  - Dynamic selection if cluster head
- Clustering
  - Binding
  - Reducing Load on Co-ordinator
  - …

# 6LoWPAN

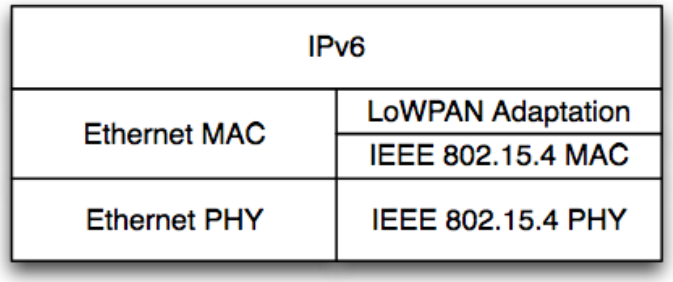
- IPv6 over Low power Personal Area Networks
- IETF’s initiative
- Extending the scope of IEEE 802.15.4 for Global connectivity
- RFC 4944

# Architecture

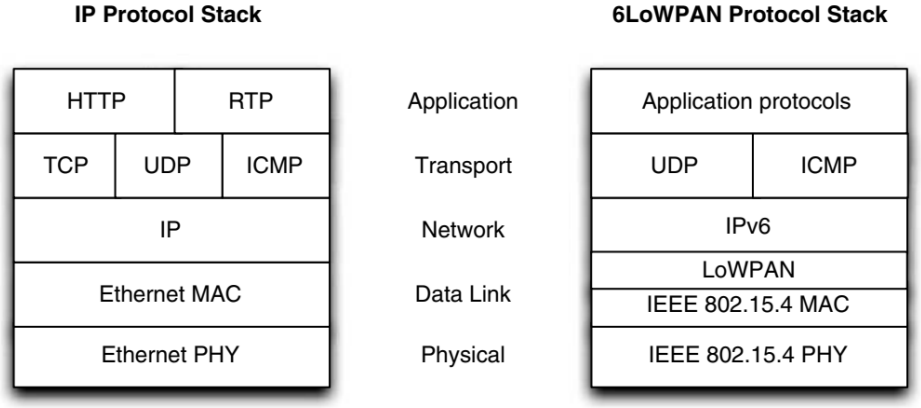



- LoWPANs are stub networks
- Simple LoWPAN
  - Single Edge Router
- Extended LoWPAN
  - Multiple Edge Routers with common backbone link
- Ad-hoc LoWPAN
  - No route outside the LoWPAN
- Internet Integration issues
  - Maximum transmission unit
  - Application protocols
  - IPv4 interconnectivity
  - Firewalls and NATs
  - Security

# 6LoWPAN

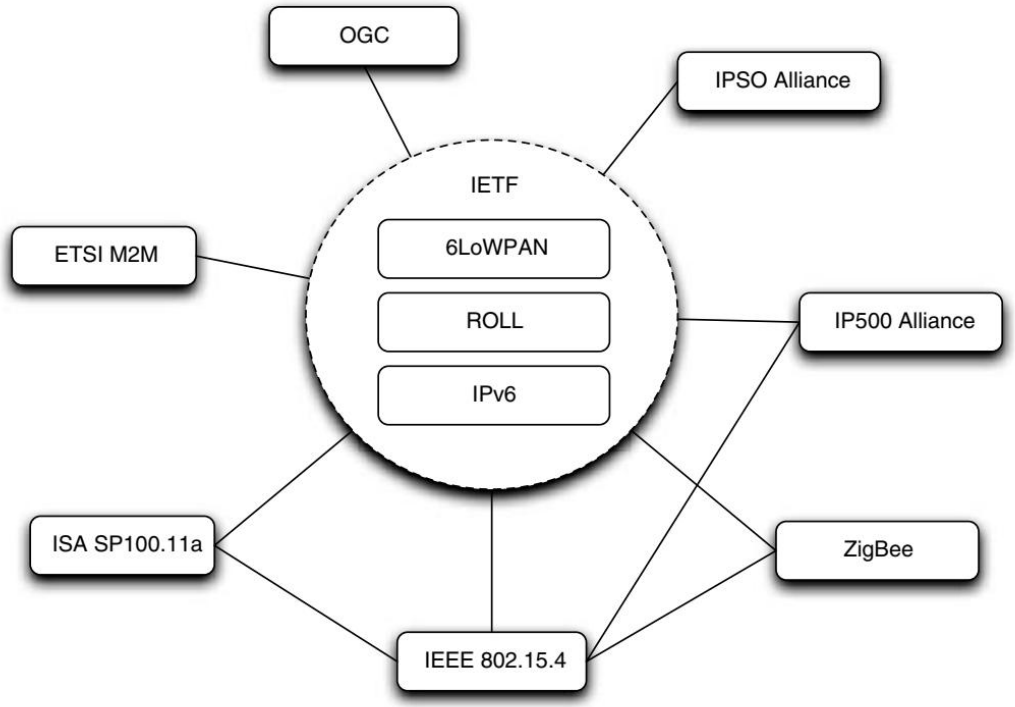



**IPv6-LoWPAN Router Stack**




- Addressing
- Tunneling
- Header
- Transport Layer Protocols
- Application Layer Protocols

# Motivation & Adoption




- Open Geospatial Consortium
- IP for Smart Objects
- ISA 100 (industry automation consortium)
- M2M

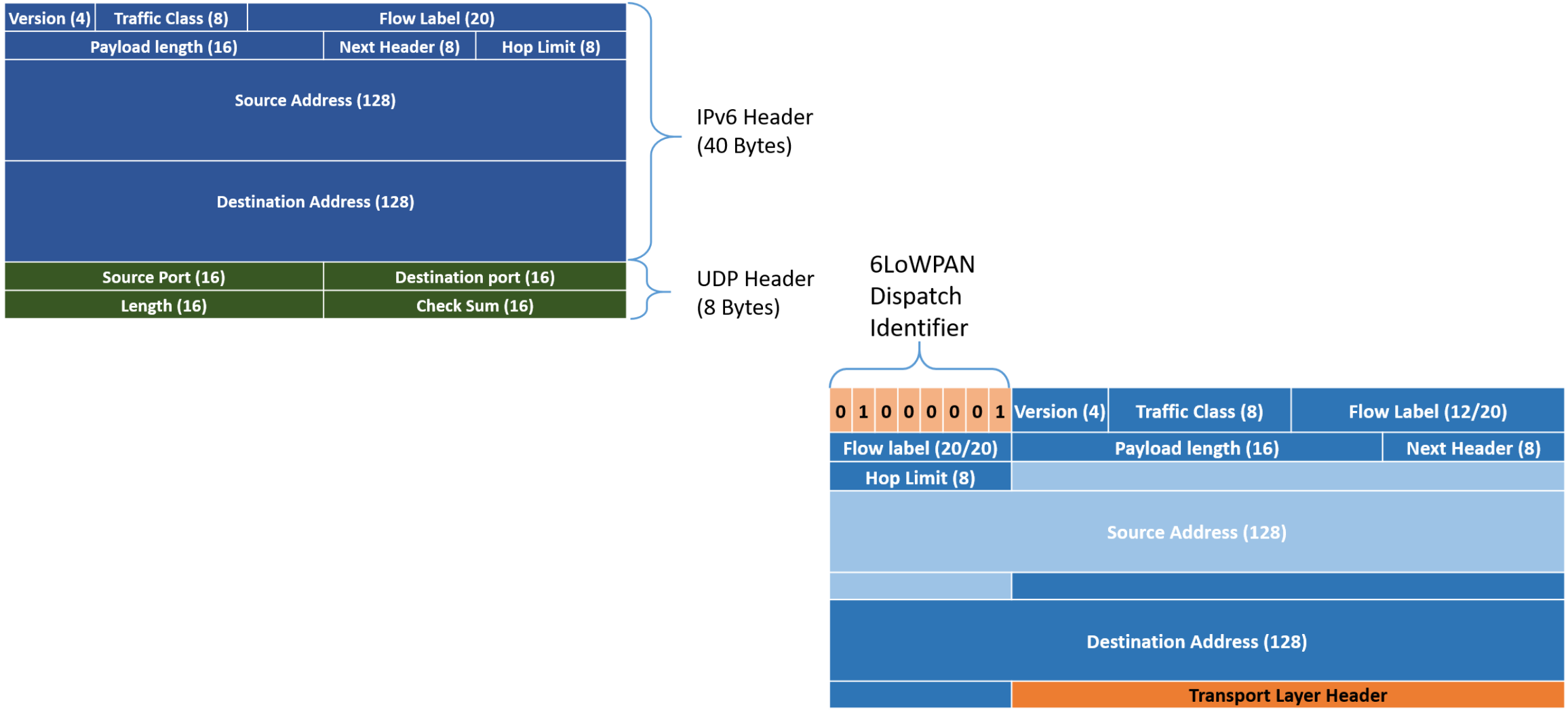
# Features

- Support for e.g. 64-bit and 16-bit 802.15.4 addressing
- Useful with low-power link layers such as IEEE 802.15.4
- Narrowband ISM and power-line communications
- Efficient header compression
  - IPv6 base and extension headers, UDP header
- Network Auto-configuration using Neighbour Discovery
- Unicast, multicast and broadcast support
  - Multicast is compressed and mapped to broadcast
- Fragmentation
  - 1280 byte IPv6 MTU -> 127 byte 802.15.4 frames
- Support for IP routing (e.g. IETF RPL)
- Support for use of link-layer mesh (e.g. 802.15.5)

# Addressing

- 8 bit addressing
- 16 bit addressing
- 128 bit addressing
- 64 bit Interface identifier

# Header

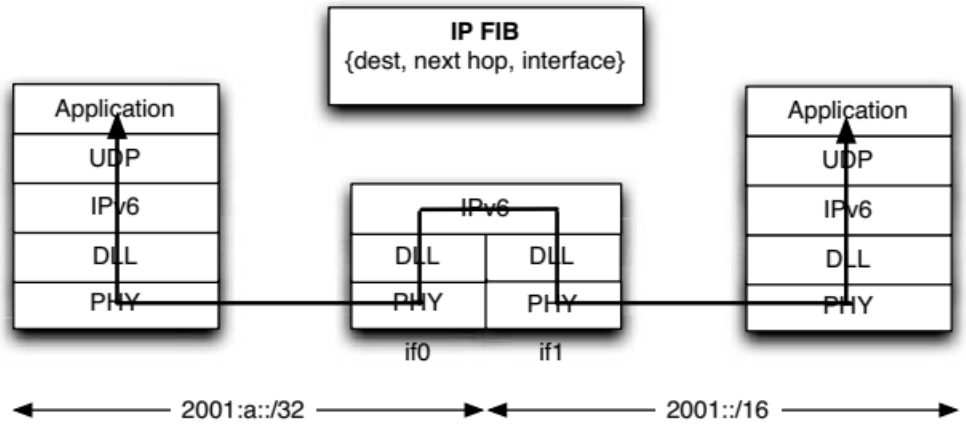

Version (4)
Traffic Class (8)
Flow Label (20)
Payload length (16)
Next Header (8)
Hop Limit (8)
Source Address (128)
Destination Address (128)
Source Port (16)
Destination port (16)
Length (16)
Check Sum (16)
IPv6 Header
(40 Bytes)
UDP Header
(8 Bytes)
6LoWPAN
Dispatch
Identifier
0 1 0 0 0 0 0 1
Version (4)
Traffic Class (8)
Flow Label (12/20)
Flow label (20/20)
Payload length (16)
Next Header (8)
Hop Limit (8)
Source Address (128)
Destination Address (128)
Transport Layer Header

# Header

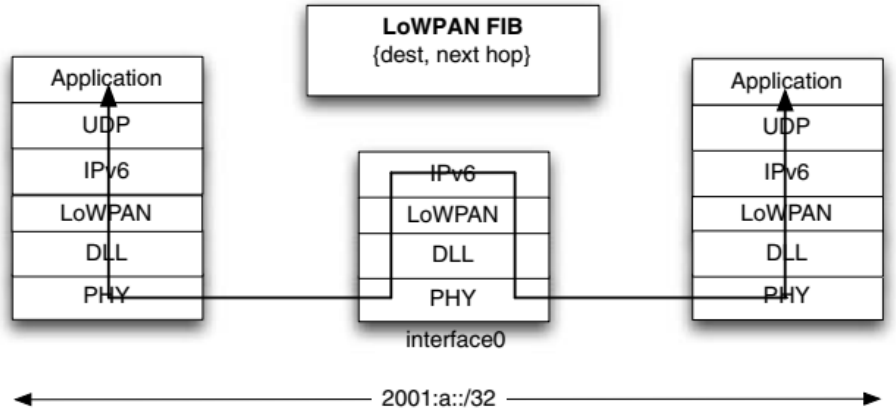
| From | To | Allocation |
|---|---|---|
| 00 000000 | 00 111111 | NALP – Not a LoWPAN frame (NALP) |
| 01 000000 | | reserved for future use |
| 01 000001 | | IPv6 – uncompressed IPv6 packets |
| 01 000010 | | LOWPAN_HC1 – compressed IPv6, see Section 2.6.1 |
| 01 000011 | 01 001111 | reserved for future 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 |

**Modified Dispatch Identifier**

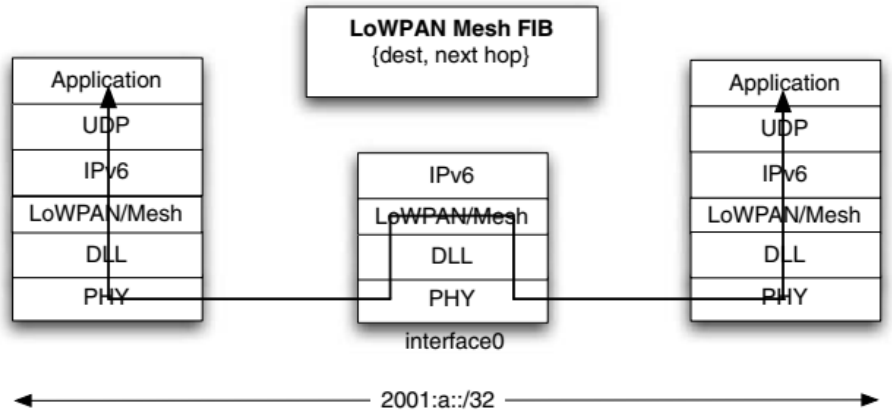
# Routing



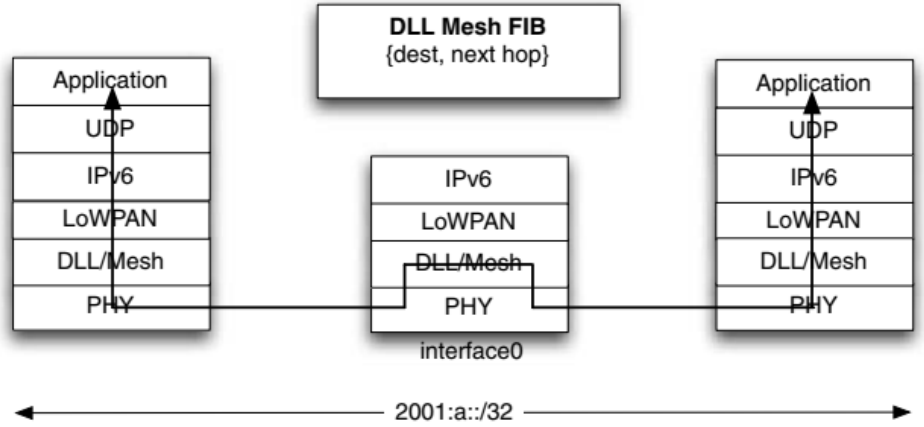

**IP Routing**




**L3, Route Over**

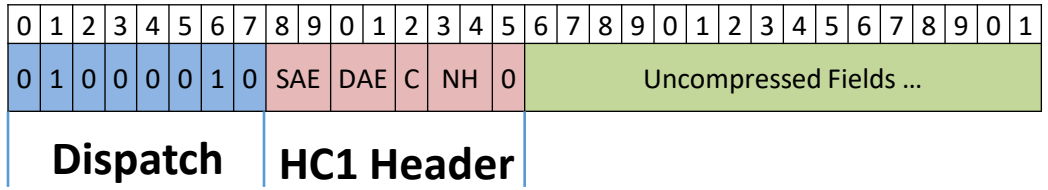


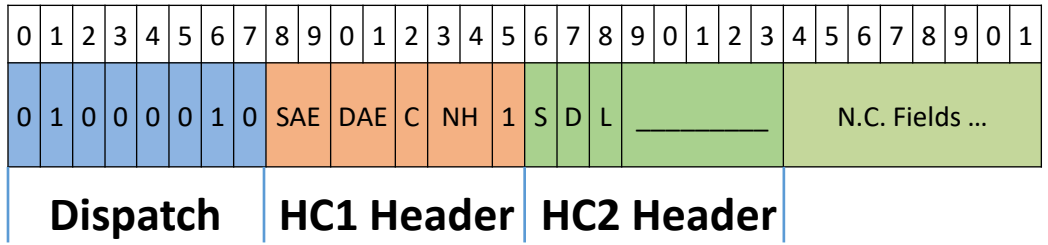

**L2, Mesh Under**




**L2, Mesh Under**

# Header Compression



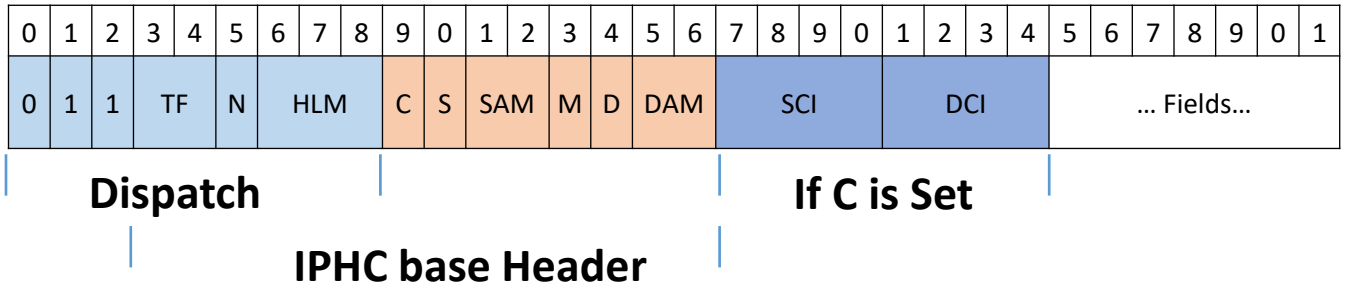




| SAE or DAE value | Prefix | IID |
|---|---|---|
| 00 | sent in-line | sent in-line |
| 01 | sent in-line | elided and derived from L2 or mesh address |
| 10 | elided and assumed to be link-local (FE80::/64) | sent in-line |
| 11 | elided and assumed to be link-local (FE80::/64) | elided and derived from L2 or mesh address |

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

# IPHC (IPv6 Header compression)

- 6LoWPAN Context has increased demand
  - While joining a Node
  - Performing a Neighbor Discovery
- Context based header compression is inevitable
- LoWPAN Nodes should use context-based header compression
  - only when a higher-layer protocol is in use
  - Protects the IPv6 addresses using some form of pseudo-header-based checksum and/or authenticator, such as UDP, TCP or some application-specific integrity protocol



# Networking

- Bootstrapping
  - Establishing a network (Commissioning)
    - new node joining
    - Network re-organizing
  - Uses
    - Service Set ID (WLAN)
    - Security (Wireless Protected Access)
  - Prefix match -- Home network
  - Neighbor Discovery
    - DHCPv6 (Stateless Address Auto configuration)
    - Registration
    - Reg. collision
    - Multi-hop registration
    - Various operations (node, router, edge router)

# Networking

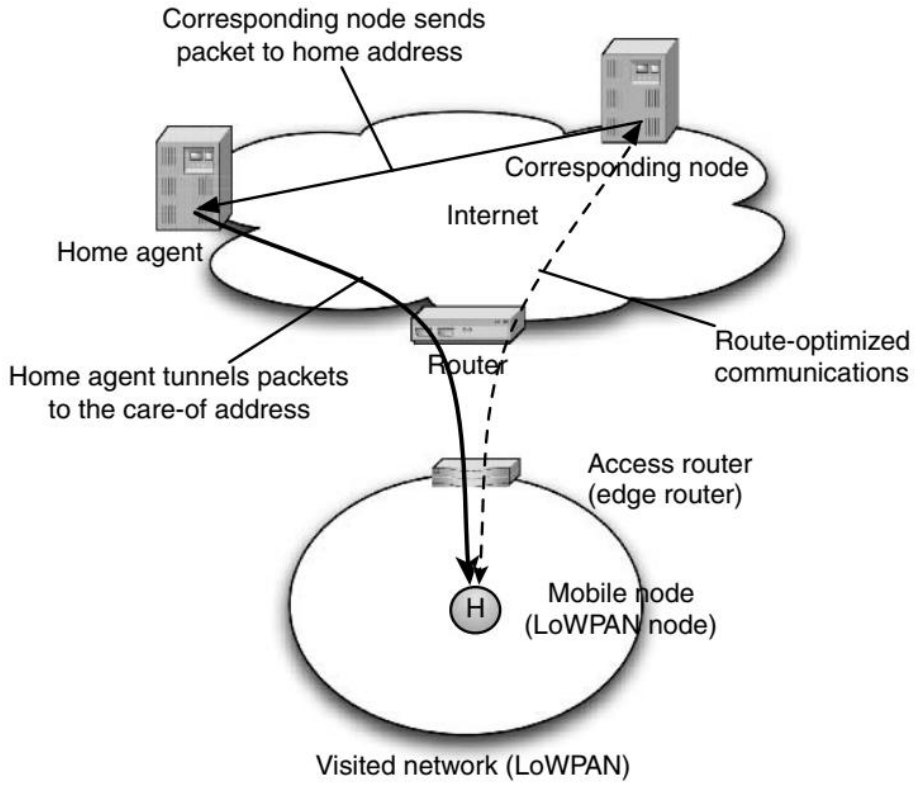
- Security
  - Objectives
    - Confidentiality
    - Integrity
    - Availability
  - Layer2 mechanisms
    - As 802.15.4 implements AES(CCM, RFC 3610)
    - 13 byte key based on 8 byte MAC Id
    - 2^22= 7 weeks of key repetition
  - Layer3 mechanisms (Internet Key Exchange [RFC 2409])
    - IPSec
    - Doesn’t suit for LoWPANs
  - Key Management (Enhanced L3)
    - Username & Password
    - Long, Short, Group, Pair wise keys

# Mobility

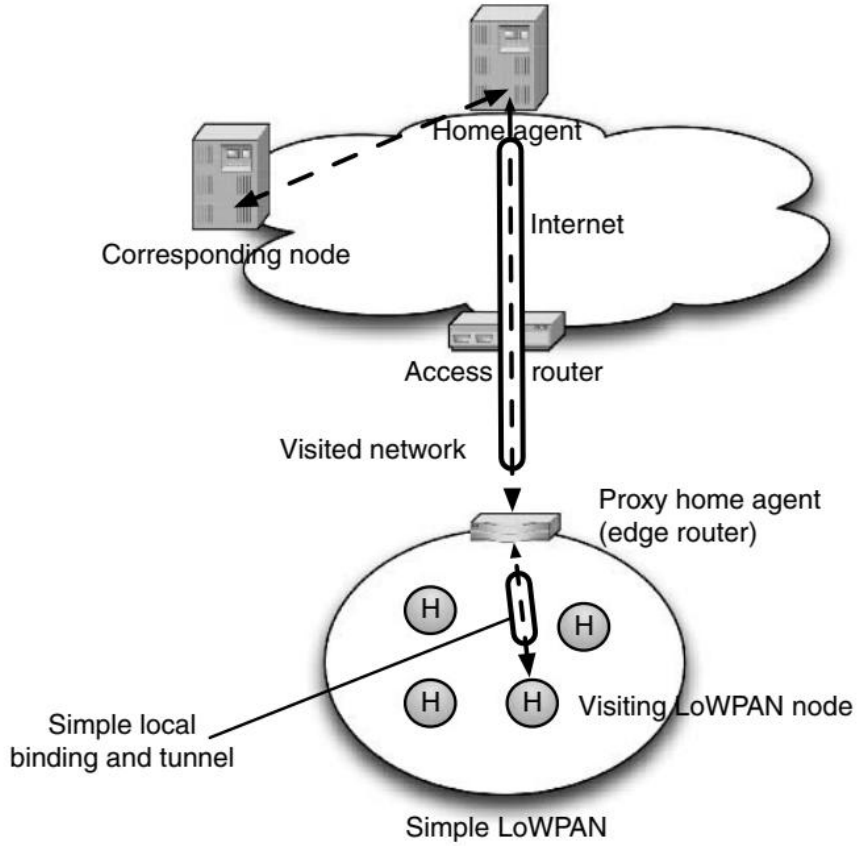
- So far nodes are considered stationary
  - Mobility
    - Roaming (macro)
    - Handover (micro)
  - Causes
    - Physical movement
    - Radio channel
    - Network performance
    - Sleep schedules
    - Node failure
  - Node & Network controlled (Wi-Fi, cellular systems)
  - Solutions for Mobility
    - Commissioning
    - Bootstrapping
    - Security
    - Updating DNS
    - Notifying upper layers

# Mobility

- MIPv6

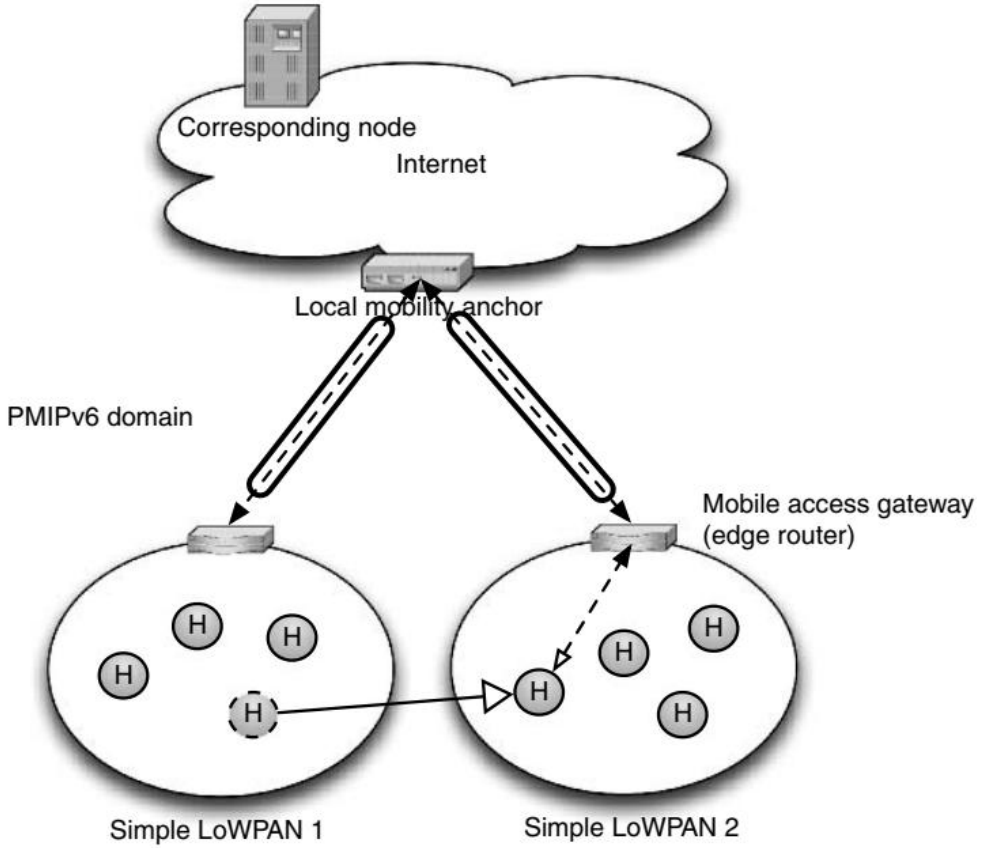



- Proxy Home Agent

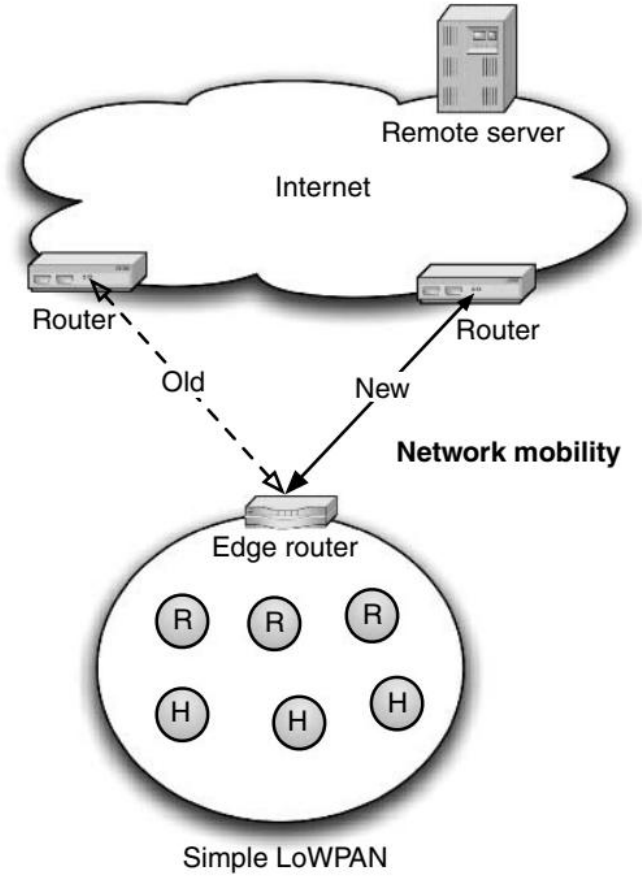


# Mobility

- Proxy MIPv6




- Network Mobility



# Routing

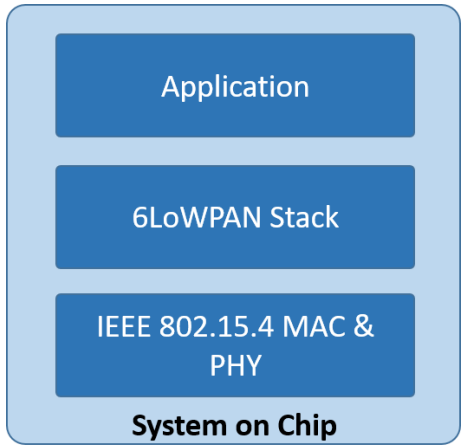
- ROLL – Routing Over Low Power Lossy networks
- Traffic patterns
  - peer-to-peer unicast flows
  - point-to multipoint
  - multipoint-to-point flows
- Routers in 6LoWPANs have a limited memory
- 6LoWPANs must be optimized for energy consumption.
- 6LoWPANs will be deployed over links with a limited frame size.
- Security and manageability are extremely important as 6LoWPANs are typically autonomous.
- Tunneling
- Dual Stack Devices

# Application Protocols

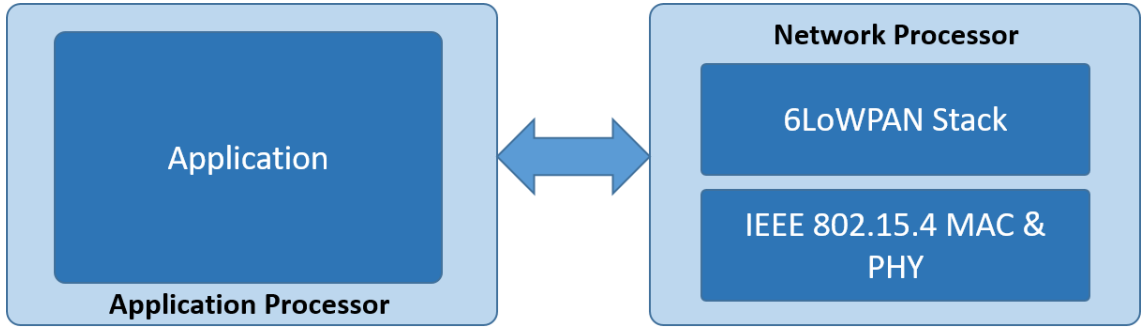
- People's internet
  - HTTP/HTTPS
  - FTP
  - RTP
  - SNMP
- As 6LoWPANs are Stateless
  - SOAP
  - REST
- Protocol paradigms
  - End to End
  - Real Time Streaming / Session
  - Pub/ Sub
- Common Protocols
  - Web service protocols
  - MQTT (MQTT-S)
  - ZIGBEE Compact Application Protocol
  - Service Discovery
    - SLP, UPnP, DPWS
  - Industry Specific (BACnet, oBIX, ANSI c12.19)
- ZCAP, MQTT has own discovery features

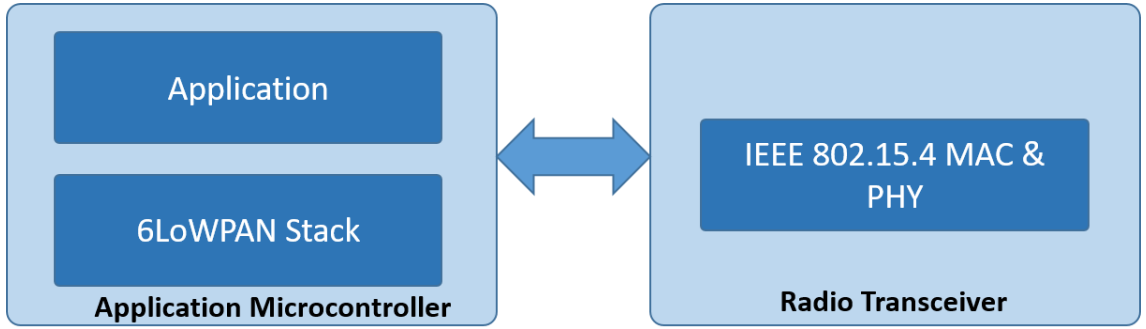
# Hardware Platforms

- Suited for Host, Routers




- Suited for Gateways



# Software Stacks

- TinyOS
- ContikiOS
- RIoT
- Jennic 6LoWPAN
- Sensinode NanoStack
- Nivis ISA100

# Software Stacks

- ContikiOS
  - C
  - MSP430, AVR, HC12, Z60, etc..
  - 2kB RAM, 40kB ROM
  - LoWPAN Support
  - Multitasking
  - Event driven kernel
  - uIP stack
  - Thread based
  - COOJA Simulator
  - Tmote, TelosB, Ubimote etc…
- TinyOS
  - nesC
  - MSP430, AVR
  - 0.4kB RAM
  - LoWPAN Support
  - BLIP
  - TOS Simulator
  - FIFO
  - OS merges with Program
  - TelosB, Imote, Smartmote etc..