IPv6 and Sensor Networks

Module 250 – IPv6 and Sensor Networks

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IPv6 Deployment and Support

- *Looking for a contact ?*
  - *Mail to : martin.potts@martel-consulting.ch*
  - *Or bernard.tuy@renater.fr*

Acknowledgements

IPv6 Deployment and Support

- Patrick Grossetete, Cisco (was Arch Rock)
- Socrates Varakliotis, UCL

Agenda

IPv6 Deployment and Support

- Introduction
- The Generic Components
- Standards and Technologies
- Conclusion

Background

- Different from most modules in this series
- Need first to define Wireless Sensor Networks and show why they are different
- Need to discuss their technology
- Then show where IPv6 technology kicks in
- Consider some applications
- Consider a specific product line as example

The Construction of the Module

- First we define the different components of Sensor Networks
- Then we list some of the standards that are being, or have been, defined for the need
- Then we consider a specific portfolio of products from a supplier, Cisco(Arch Rock), to meet the need
- Finally we consider some application environments that have been pursued

The Problem

IPv6 Deployment and Support

- **Sensors are often small devices, in large numbers, that need to be addressed**
  - **They are not powerful, and often have limited power because they are not wired**
- **Sensor networks are often wireless, with insufficient power to reach all nodes**
  - **They need wireless ad-hoc networks**
- **So far many are not even IP-enabled, but are changing**
  - **IPv6 is not the only solution for such nets**
  - **But recent protocols and systems have been developed for them**

What is a “sensor”?

IPv6 Deployment and Support

From Human senses to devices

Instruments are more precise. They give us an exact temperature, humidity, heart rate.

You feel COLD.

You feel WET.

You feel your heart pumping!

Thermometer

Exercise Heart Monitor

Rain Gauge

Humidity Meter

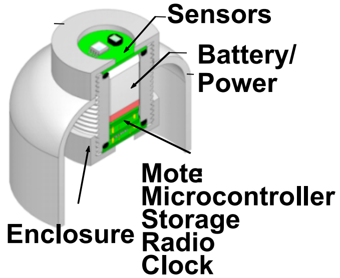
Wireless Sensor Node

IPv6 Deployment and Support

- The world is outfitted with **billions** of devices sensing their environment
- Homes, offices, factories, streets, hospitals, automobiles….people
- Issue:
  - Data is **dropped** or remains **“stranded”**

Wireless Sensor Node =

Sensor + tiny computer + radio + network



- **Sensors:** Temperature, humidity, light, vibration, etc.
- **Battery operated:** Lasts for months or years!
- **Tiny computer:** As little as you can afford
- **Radio communications:** No wires needed!
- **Internet connected:** As easy as opening a web page

Sensor Network Technology

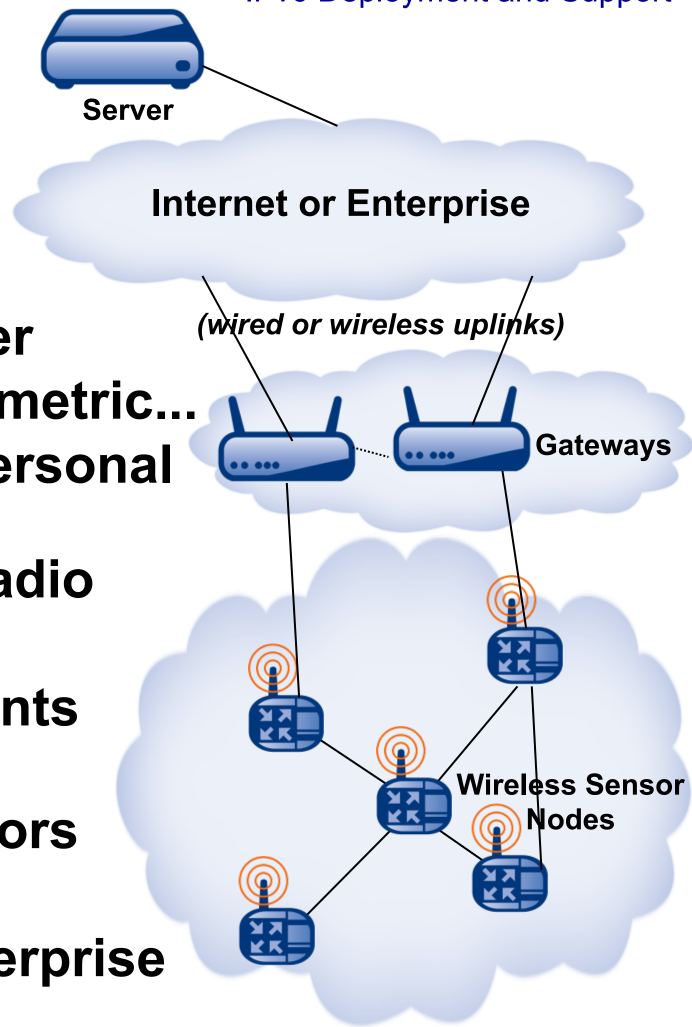
- Sensor nets often wireless towards sensors
  - May use Wifi – 802.11
  - Often use ZigBee – 802.15.4 (low-power)
  - Other technology under development and use
- Sensor net gateways often use Web access
  - Is good standard for heterogeneity
- Sensor net gateways may use different technologies towards Internet
  - Often wired – with normal technologies
  - Often wireless – e.g. cellular or Wifi

Wireless Sensor Network

IPv6 Deployment and Support

- Network of small-footprint computers
- Optimized for long-life on low power
- Equipped to sense physical data
- Networked using low-power radio

- Function:
  - Sense any measurable physical parameter
    - Light, motion, chemical, proximity, biometric…
  - Form "LoWPAN = Low power Wireless Personal Area Network" and communicate
    - Automatic meshing and routing over radio
  - Apply user-defined business logic
    - Sampling, summarizing, reporting events
- Form:
  - Node (Processor, Radio, Storage) + Sensors
  - Embedded OS, Networking, Applications
  - Servers and Routers interfacing with Enterprise IT systems



Sensor Network Characteristics

- Should have an open architecture
  - Needs to fit in with components and sensors from other suppliers
- Need wide range of Nets
  - Different reaches, characteristics, topologies
- Need efficient and low power packet handling – even of small packets
- Need security and ruggedness
- Need minimal external configuration
- Clearly use of an IP network vital!

IP Convergence

IPv6 Deployment and Support

Innovation

Converged Devices and Applications

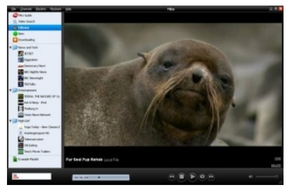
Web 2.0, P2P, VoIP, IP/TV, VoD, Sensors,...

IP Networks

Converged Networks

Data, Audio, Voice, Video, Sensors

Wired, Wireless – Fixed, Mobile



Sensor Network Architecture

- **Sensors come in many sizes and powers**
  - **Some can, but some cannot run IP stack**
- **If they can run stack, new protocols have been optimised for them**
  - **Need to address many, hence IPv6 desirable**
  - **6LoWPAN for optimal power and packet size**
  - **Is only defined for IPv6**
- **If they cannot run stack, then sensor gateway used**
  - **Addresses and controls data to/from sensors**
  - **Caches data between Sensor Net and WAN**
- **Topologies may be Star or Mesh**
- **Traditionally in fixed networks**
  - **Mobility patterns are emerging, i.e. Emergency responders**

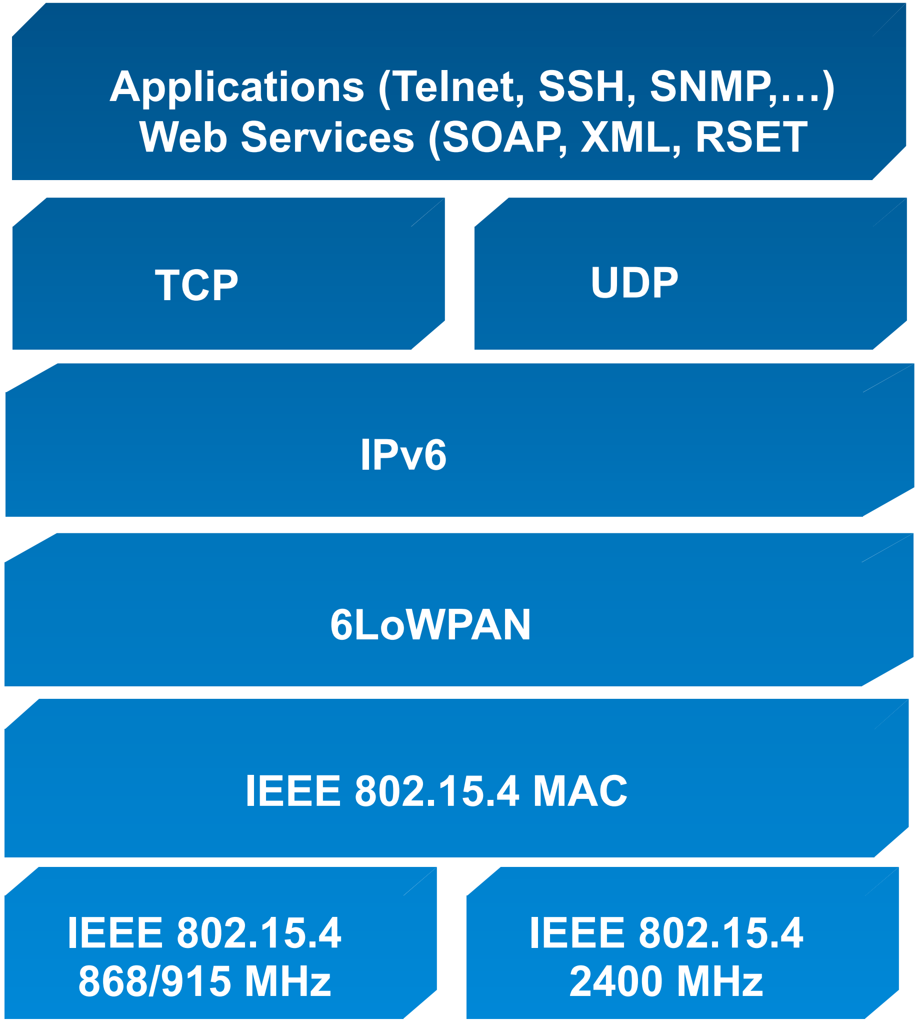
Agenda

IPv6 Deployment and Support

- Introduction
- The Generic Components
- <u>Standards and Technologies</u>
- An Example – the Arch Rock Portfolio
- Deployment Case Studies
- Conclusion

Open Architecture

IPv6 Deployment and Support



A Low-Power Standard Link

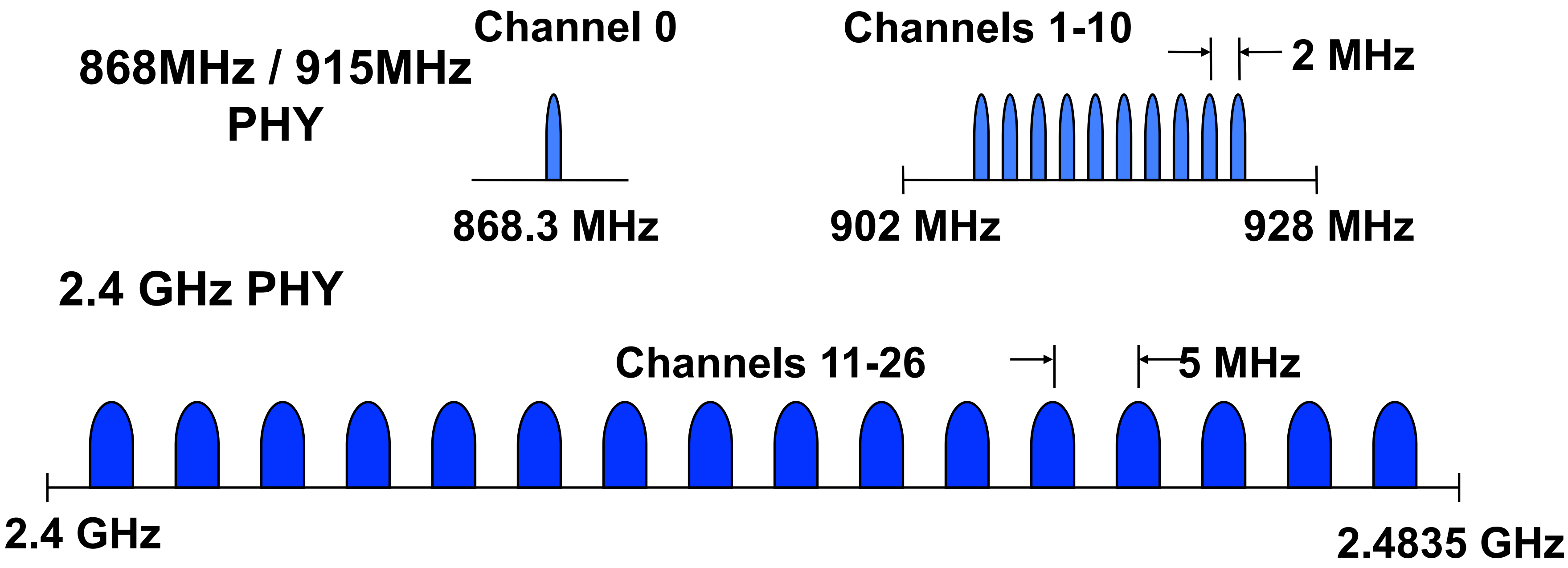
IPv6 Deployment and Support

IEEE	802.15.4	802.15.1 (Bluetooth)	802.16 (WiMax)	802.11	802.3
Class	**WPAN**	**WPAN**	**Metro Area**	**WLAN**	**LAN**
Lifetime (days)	**100-1000+**	**1-7**	**Powered**	**0.1-5**	**Powered**
Net Size	**65535**	**7**	**P2P, P-MP**	**30**	**1024**
BW	**20-250 Kb/s**	**720 Kb/s**	**75Mb/s**	**11(b)-108(n)Mb/s**	**10Mb/s-10Gb/s**
Range (m)	**1-100+**	**1-10+**	**50K**	**1-100+**	**185 (wired)**
Goals	**Low Power, Large Scale, Low Cost**	**Cable Replacement**	**Cable Replacement**	**Throughput**	**Throughput**

- **Low T-power & SNR, modest BW, Little Frames**

IEEE 802.15.4 Physical Layer

IPv6 Deployment and Support



Frequency Bands of Operation

16 channels in the 2.4GHz ISM band

10 channels in the 915MHz ISM band

1 channel in the European 868MHz band

Transmit Power

- Capable of at least 1 mW

Receiver Sensitivity (PER Rate <1%)

- -85 dBm @ 2.4 GHz band
- -92 dBm @ 868/915 MHz band

IEEE 802.15.4 Physical Layer

Preamble	Start of Packet Delimiter	PHY Header	PHY Service Data Unit (PSDU)
6 Octets			0-127 Octets

- **PHY Packet Fields**

Preamble (32 bits) – synchronization

Start of Packet Delimiter (8 bits)

PHY Header (8 bits)

  Frame Length (7 bits)

  Reserved (1 bit)

PSDU (0 to 1016 bits) – Data field

- **Frequency Bands**

2.4 GHz PHY

  250 Kb/s (4 bits/symbol, 62.5 Kbaud)

868MHz/915MHz PHY

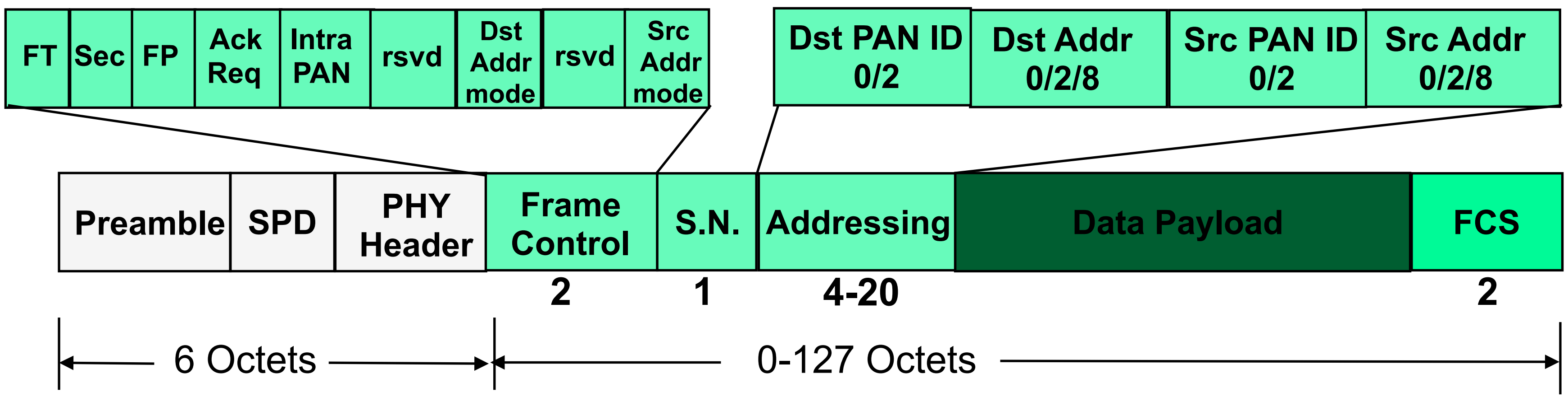
  868 MHz Band: 20 Kb/s (1 bit/symbol, 20 Kbaud)

  915 MHz Band: 40 Kb/s (1 bit/symbol, 40 Kbaud)

IEEE 802.15.4 MAC Layer

IPv6 Deployment and Support

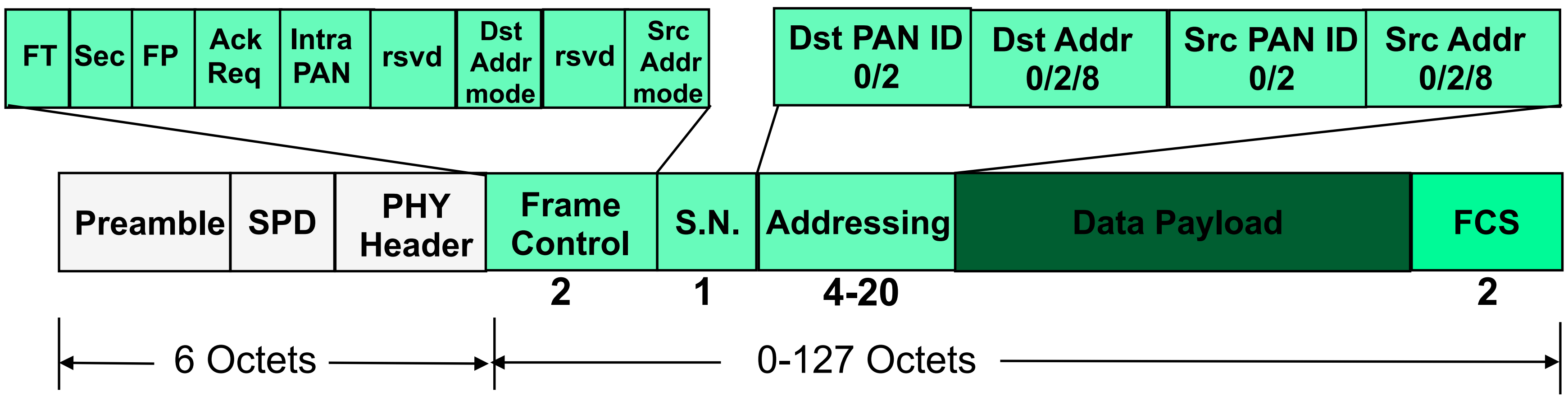
- Simple MAC allows for general use
  - Many TinyOS-based protocols (MintRoute, LQI, CENS Route), TinyAODV, ZigBee, SP100.11, Wireless HART, …
  - 6LoWPAN => IP
  - Choice among many semiconductor suppliers



IEEE 802.15.4 MAC Layer

IPv6 Deployment and Support

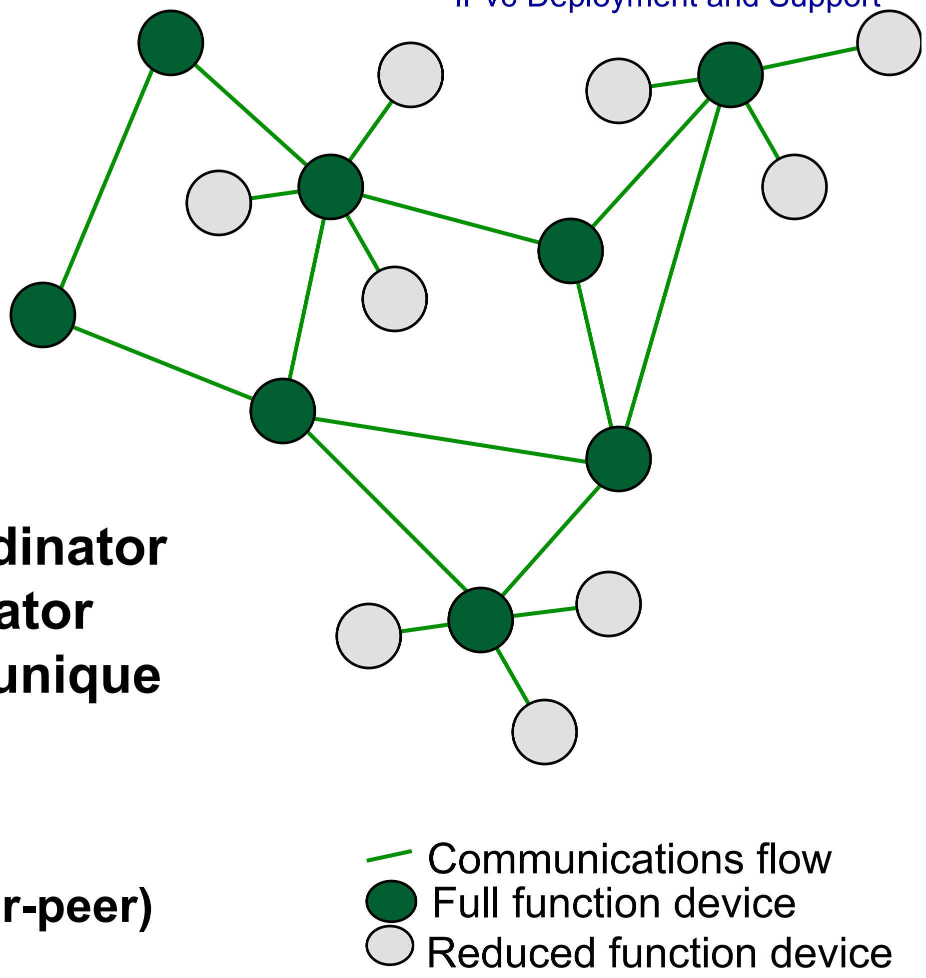
- Defines 4 Types of MAC Frame structure
  - A beacon frame, used by a coordinator to transmit beacons
  - A data frame, used for all transfers of data – ie: 6LoWPAN
  - An acknowledgment frame, used for confirming successful frame reception
  - A MAC command frame, used for handling all MAC peer entity control transfers



IEEE 802.15.4 MAC Overview

IPv6 Deployment and Support

- Network Topologies
  Star, Peer-to-Peer, combined
- Full function device (FFD)
  Any topology
  Network coordinator capable
  Talks to any other device
- Reduced function device (RFD)
  Limited to star topology
  Cannot become a network coordinator
  Talks only to a network coordinator
- Each independent PAN selects a unique identifier
- Addressing modes:
  - Network + device identifier (star)
  - Source/destination identifier (peer-peer)



IETF IPv6 Standards

IPv6 Deployment and Support

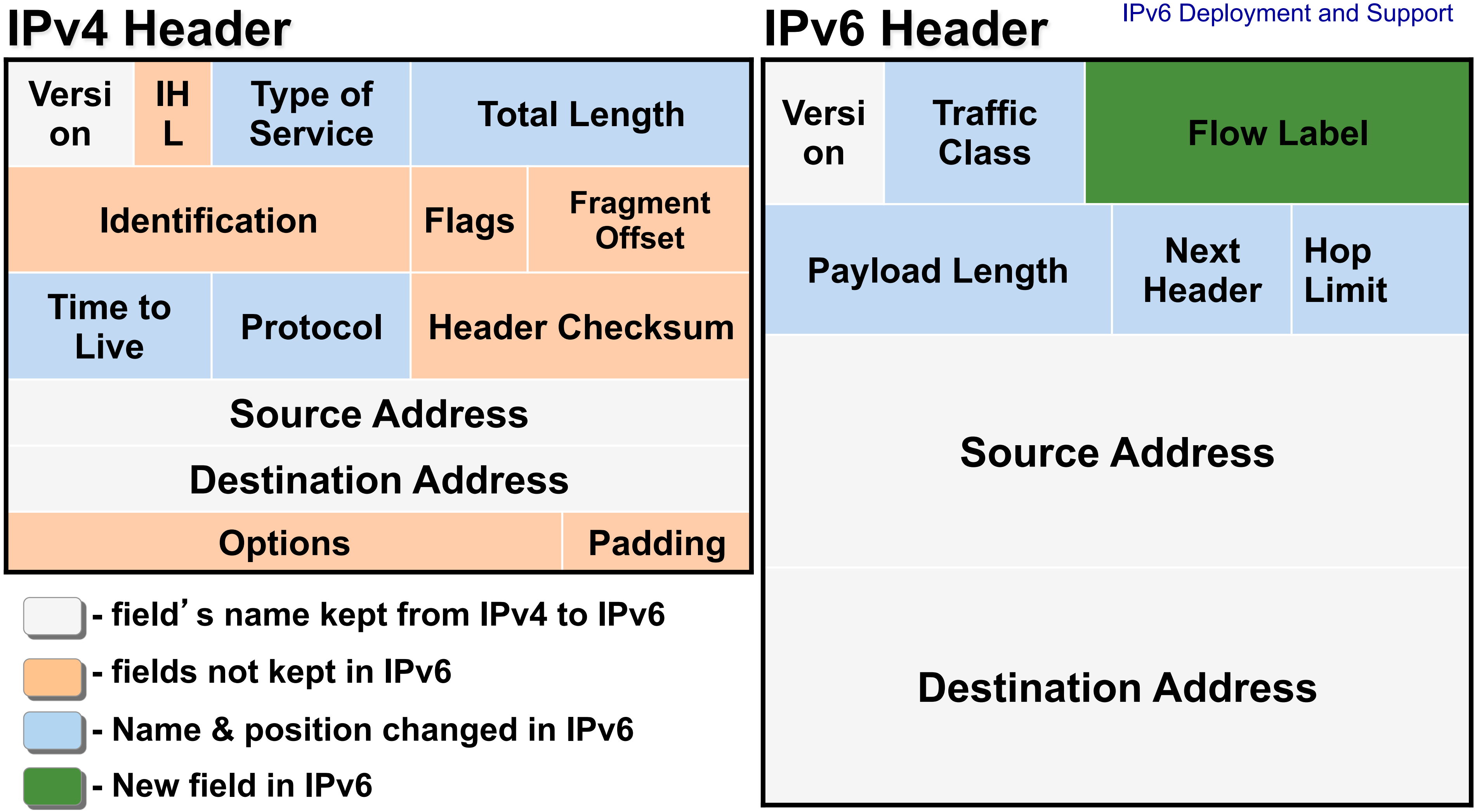
- Core IPv6 specs are stable and well tested IETF Draft Standards
  - IPv6 Addressing Architecture, ICMPv6, Neighbour Discovery, Stateless Auto-configuration, IPv6 over "Data Link Layers", DNS Record, Routing Protocols, Tunneling, MIB's, Header Compression, MLD, etc.
- 2007: IPv6 WG now closed – replaced by 6MAN (Maintenance) WG
- IPv6 Transition then, now Operations focused, WGs
  - NGTrans WG (closed), v6ops (active)
- WGs focusing on Wireless Sensor Networks
  - 6LoWPAN - http://www.ietf.org/html.charters/6lowpan-charter.html
  - RoLL - http://www.ietf.org/html.charters/roll-charter.html

IPv6 Technology Overview

IP Services	IPv4 solution	IPv6 Solution
Addressing	32 bits, Network Address Translation	128 bits, multiple scopes (global, private, link,…)
Auto-configuration	DHCP	Stateless, DHCP, renumbering
Data Link layers	Ethernet, WiFi, ATM, FR, PPP, Sonet/SDH,…	Ethernet, WiFi, ATM, FR, PPP, Sonet/SDH, 6LoWPAN, …
Routing	RIP, OSPF, IS-IS, E-IGRP, MP-BGP	RIP, OSPF, IS-IS, E-IGRP, MP-BGP, *RoLL*
IP Network layer Security	IPsec	IPsec
Multicast	IGMP/PIM/Multicast MP-BGP	MLD/PIM/Multicast MP-BGP, Scope Identifier
QoS	Differentiated Service, Integrated Service	Differentiated Service, Integrated Service
Mobility	Mobile IP	Mobile IP with Direct Routing, NEMO

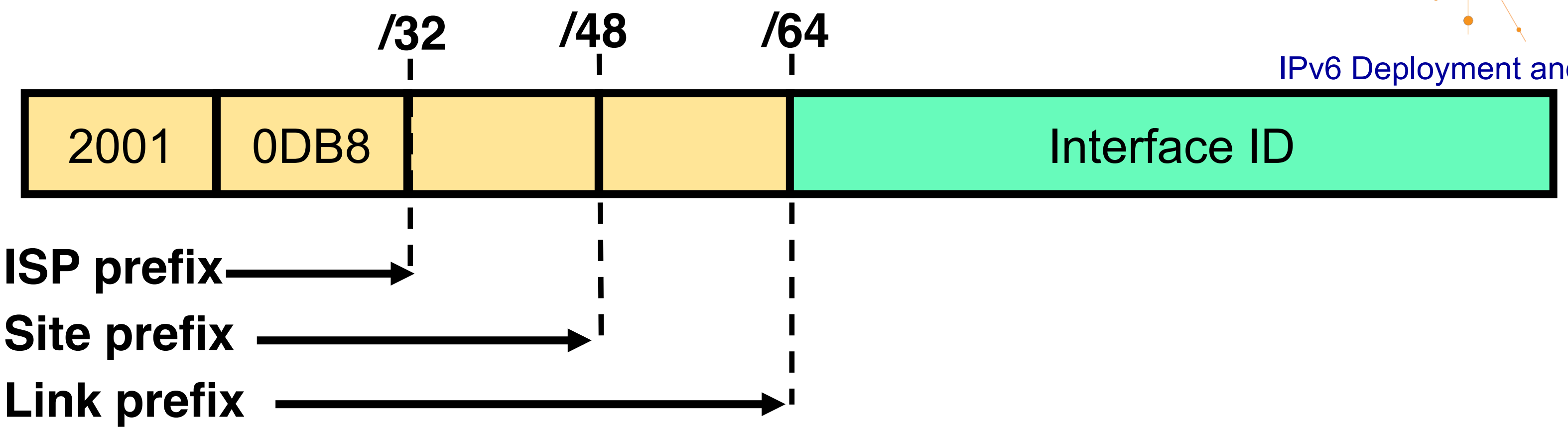
IPv4 – IPv6 Header Comparison

IPv6 Deployment and Support



IPv6 Address Format

IPv6 Deployment and Support



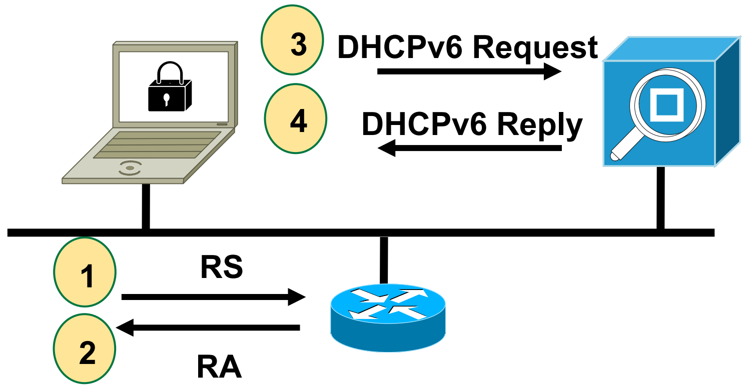
- **The allocation process is defined by the 5 Registries:**
  - **IANA allocates 2000::/3 as Global Unicast [RFC 4291]**
  - **Registries get ::/12 prefix(es) from IANA [formerly /23] under new policy http://www.icann.org/announcements/announcement-12oct06.htm**
  - **Registry allocates a /32 prefix [formerly /35] to IPv6 ISP and others large organizations or a /48 for Provider Independent (PI) request (*but RIPE*)**
  - **Then policies recommend that the ISP allocates a /48 prefix to each customer but it may be /56 or /60 – should avoid /64 per site or will require IPv6 NAT later**
  - **http://www.ripe.net/ripe/docs/ipv6policy.html**
  - **http://www.icann.org/announcements/ipv6-report-06sep05.htm**

IPv6 Address Configuration

IPv6 Deployment and Support

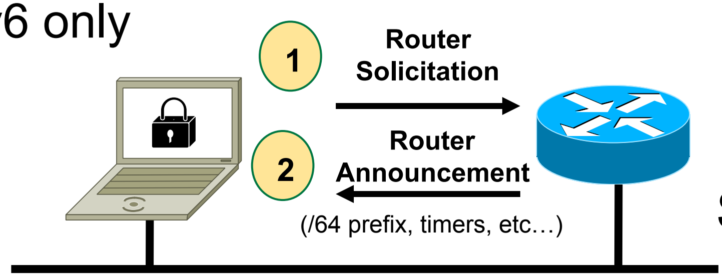
- IPv4 and IPv6

Manually configured



Assigned via DHCP

- IPv6 only



Stateless configuration

IPv6 Address = /64 prefix + Interface ID

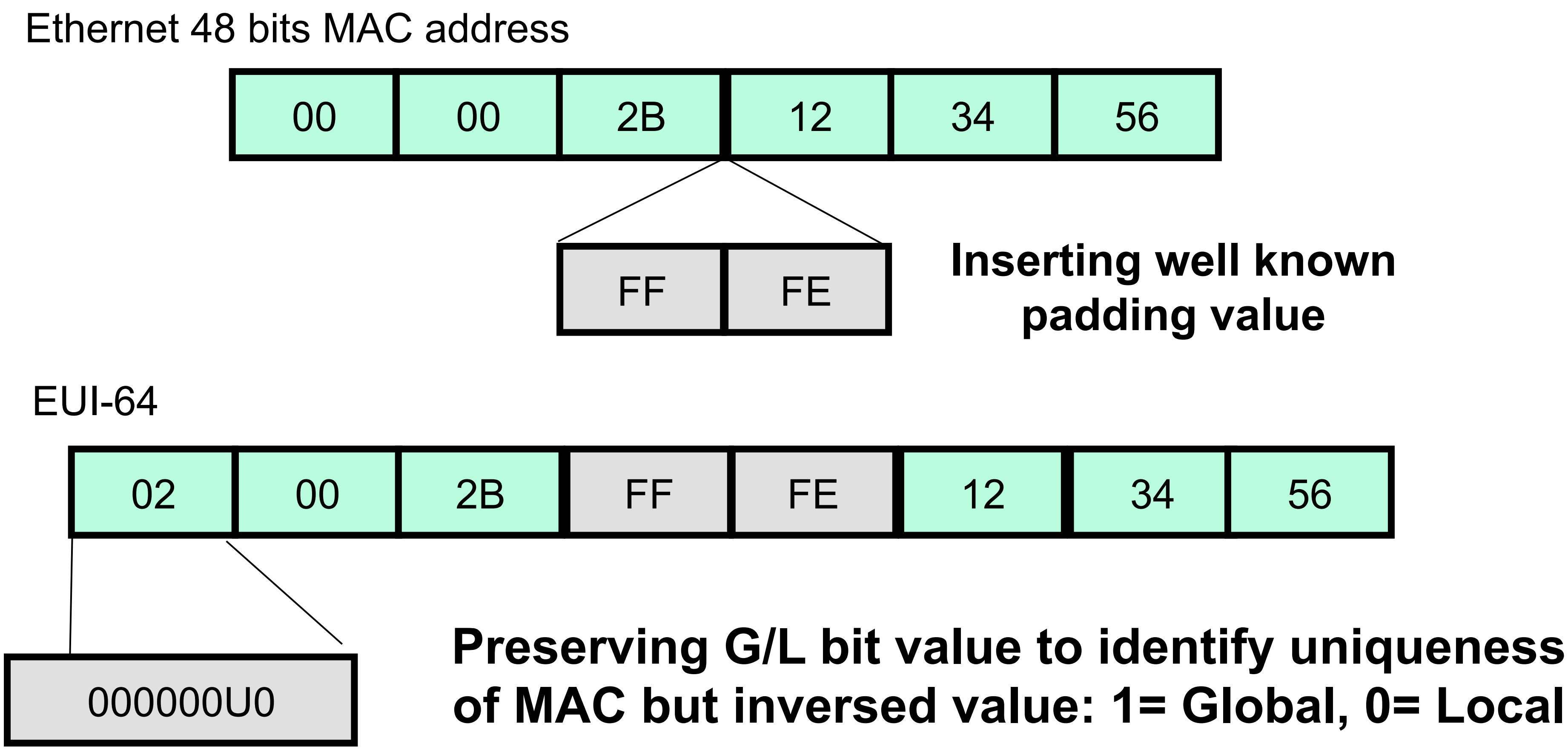
- **Interface ID field of an Unicast address may be assigned in several different ways, eg. 6LoWPAN**

IPv6 transport in 6LowPAN

- IPv6 standard specifies minimum MTU of 1280 bytes
  - However LOWPANs have MTU of max 127
    - Available space of only 81 bytes
- Need to fit IPv6 packets on to LOWPAN
  - Need to specify representation
  - Typically need to compress headers
    - IPv6 Header 40 Bytes
  - Require link layer fragmentation as MTU is below 1280
    - Though not always as packets are usually small

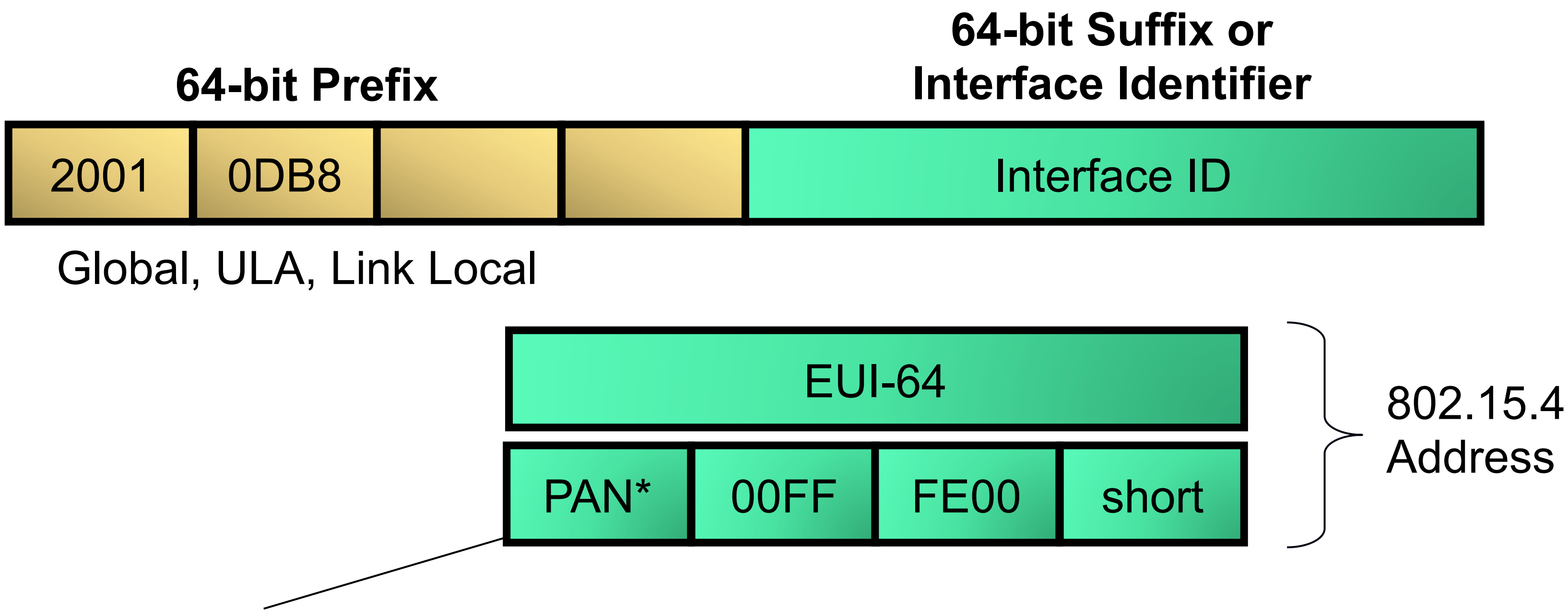
EUI-64 Format

IPv6 Deployment and Support



IPv6 Address in 6LoWPAN

IPv6 Deployment and Support



PAN* - complement the "Universal/Local" (U/L) bit, which is the next-to-lowest order bit of the first octet

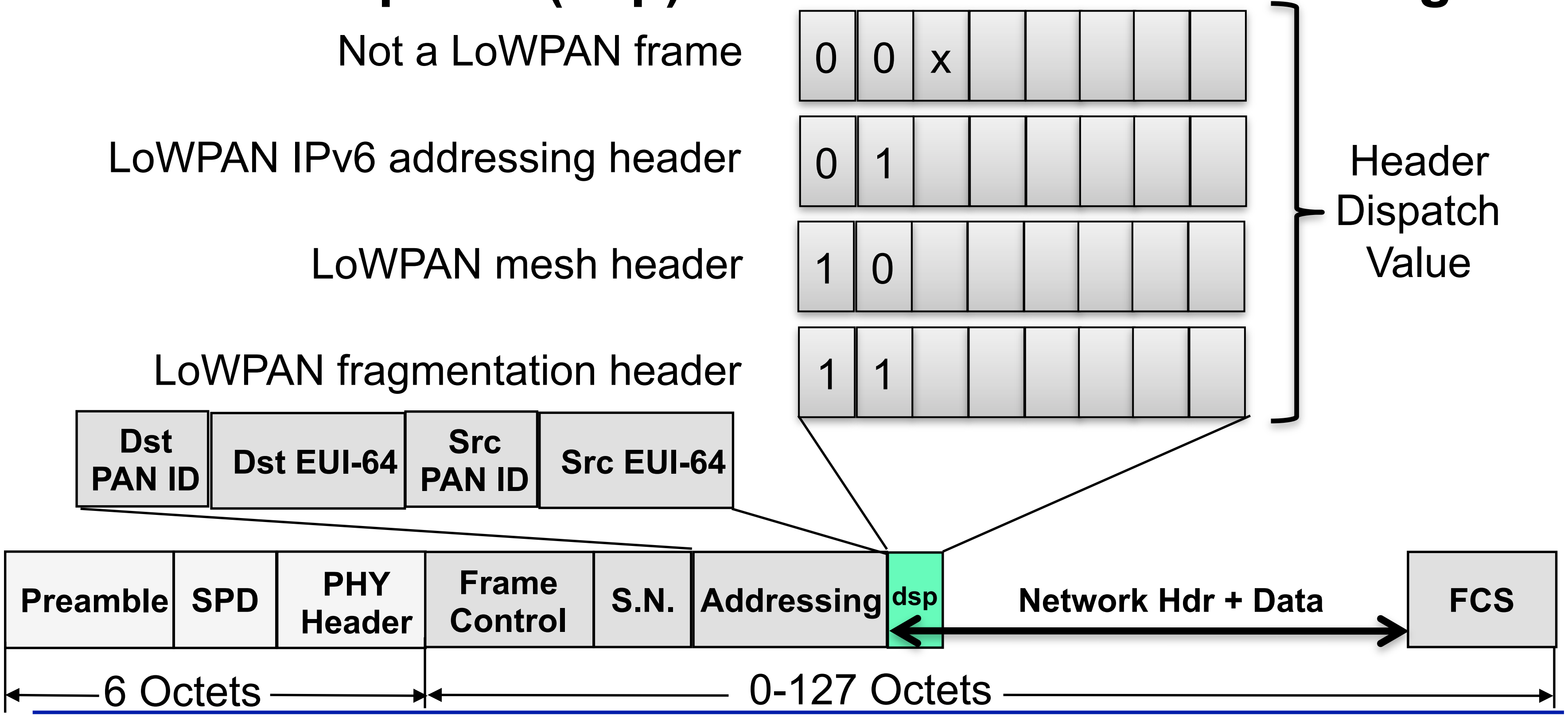
Allow IP routing over a mesh of 802.15.4 nodes

Localised internet of overlapping subnets

6LoWPAN – The First Byte

IPv6 Deployment and Support

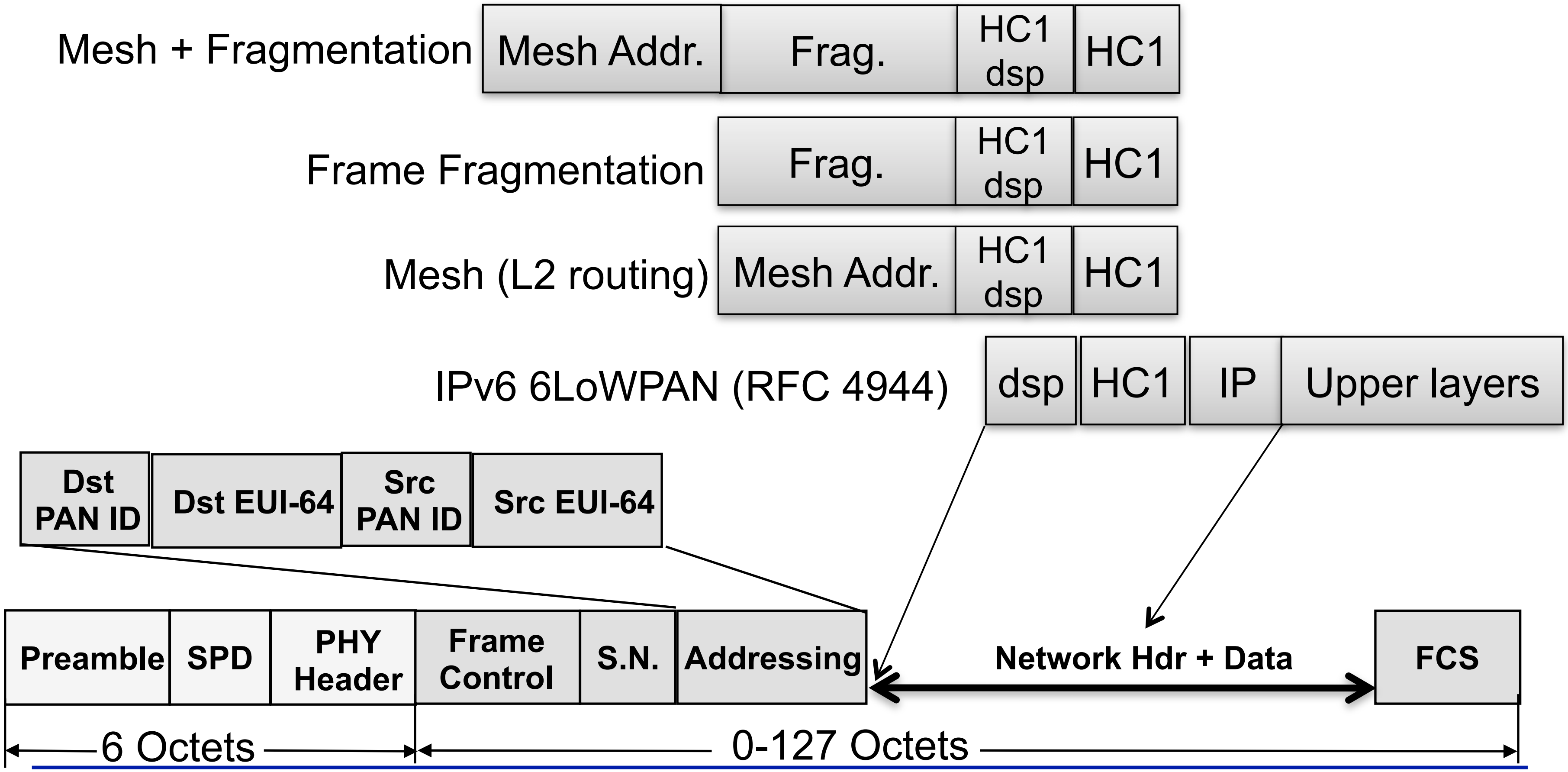
- **Coexistence with other network protocols over same link**
- **Header dispatch (dsp) - understand what's coming**



6LoWPAN – Adaptation Layer

IPv6 Deployment and Support

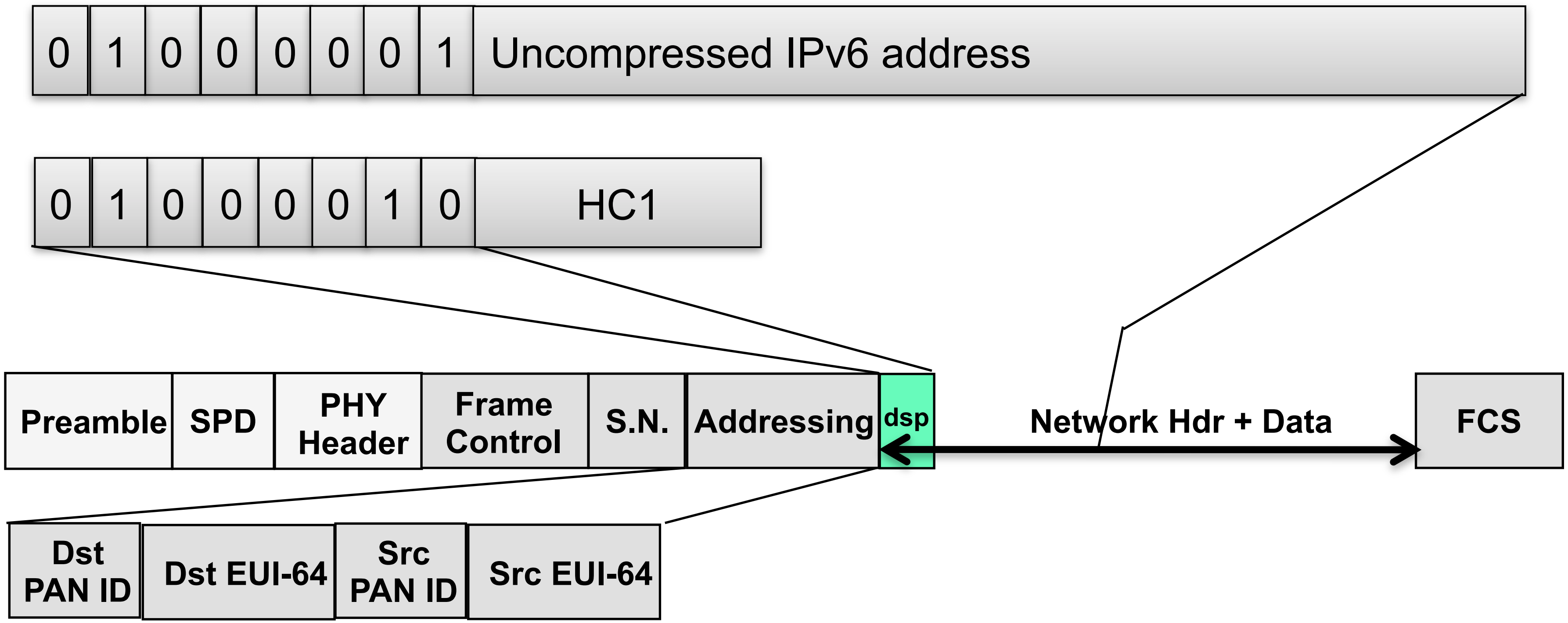
- RFC 4944 – Almost no overhead for the ability to interoperate and scale
- Standard IPv6 header (40 bytes) vs Entire 802.15.4 MTU (127 bytes)



6LoWPAN – IPv6 Header

IPv6 Deployment and Support

- Uncompressed IPv6 header = 40 Bytes (RFC 2460)
- LoWPAN_HC1: Compressed Header = 2 Bytes



6LoWPAN – Header Compression

IPv6 Deployment and Support

- Standard IPv6 header (40 bytes) vs. Entire 802.15.4 MTU (127 bytes)
  - Often data payload is small,
  - Pay for only what you use

- By virtue of having joined the same 6LoWPAN network, devices share some state.

- The IPv6 header values are expected to be common on 6LoWPAN networks, so the HC1 header has been constructed to efficiently compress them from the onset

- Next header: UDP, TCP, or ICMP in a compressed IPv6 Header

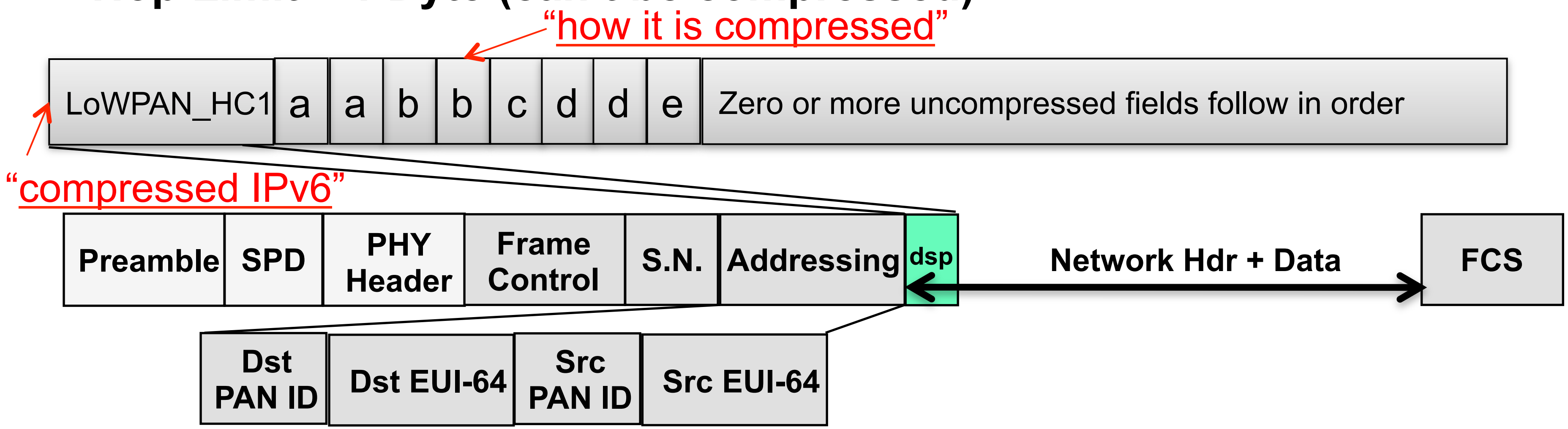
IPv6 Header Compression

Version = IPv6	Traffic Class = 0	Flow Label = 0	
Payload Length In 802.14.4 header or fragment header		Next Header In HC1 byte	Hop Limit = uncompressed
Source Address Link Local + EUI-64 derived from 802.15.4 header			
Destination Address Link Local + EUI-64 derived from 802.15.4 header			

HC1 Compressed IPv6 Header

IPv6 Deployment and Support

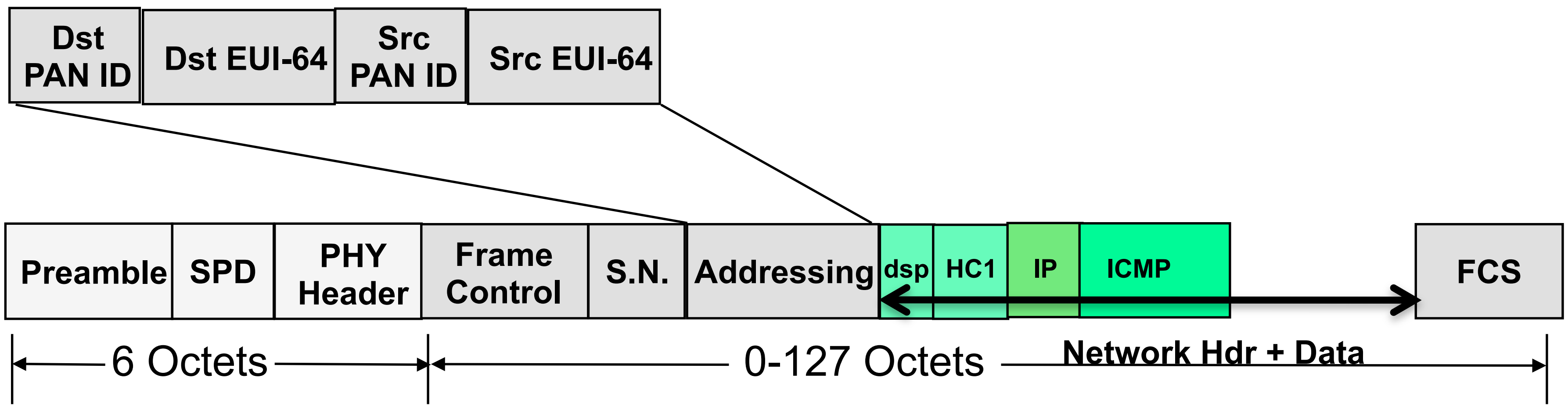
- LoWPAN_HC1: Compressed Header – 1 Byte
  - a=IPv6 source address (bits 0-1), b=IPv6 destination address (bits 2-3)
    - IPv6 Prefix Carried-in-line/compressed, Interface Identifier Carried-in-line/Elided
  - c=Traffic Class and Flow Label (bit 4): 0-compressed, 1=Traffic class and Flow label = 0
  - d=Next Header (bits 5-6): 00=Not compressed, 10=ICMP, 01=UDP, 11=TCP
  - e=HC2 encoding (bit 7): 0=no more compression header, 1= HC2, type determined by "d"
- Hop Limit – 1 Byte (can't be compressed)



6LoWPAN – Compressed/ICMP

IPv6 Deployment and Support

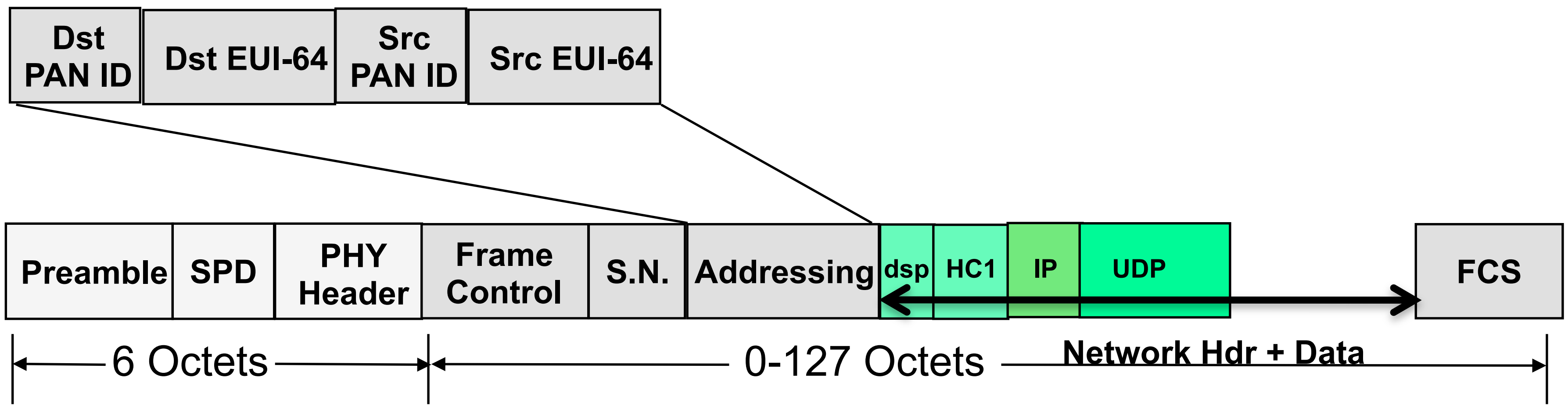
- Header Dispatch = compressed
- HC1 = Source & Dest Local, next hdr=ICMP
- IP = Hop Limit
- ICMP = 8-byte header



6LoWPAN – Compressed/UDP

IPv6 Deployment and Support

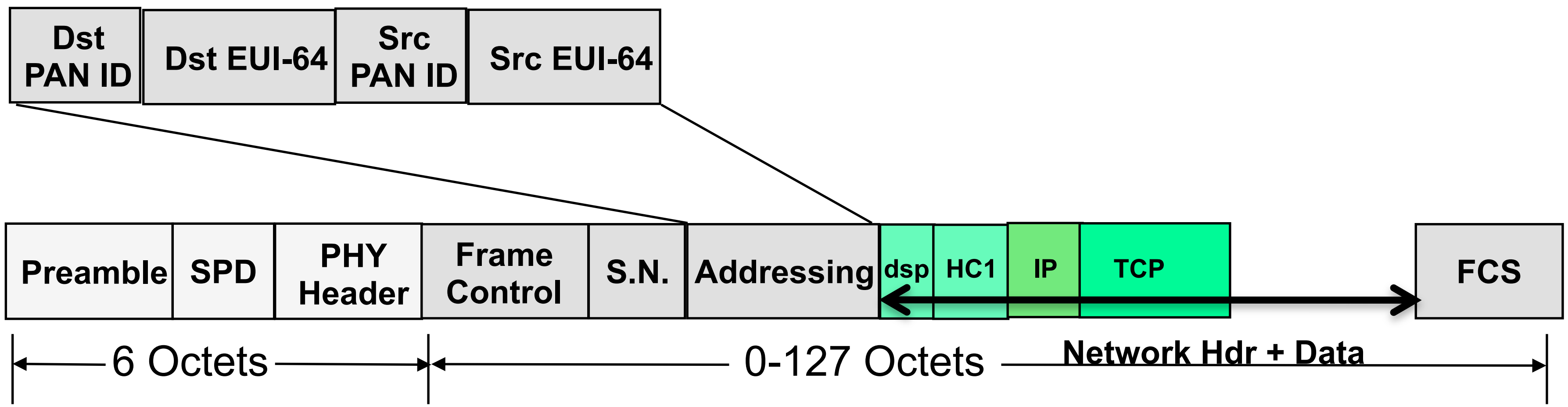
- Header Dispatch = compressed
- HC1 = Source & Dest Local, next hdr=UDP
- IP = Hop Limit
- UDP = 8-byte header



6LoWPAN – Compressed/TCP

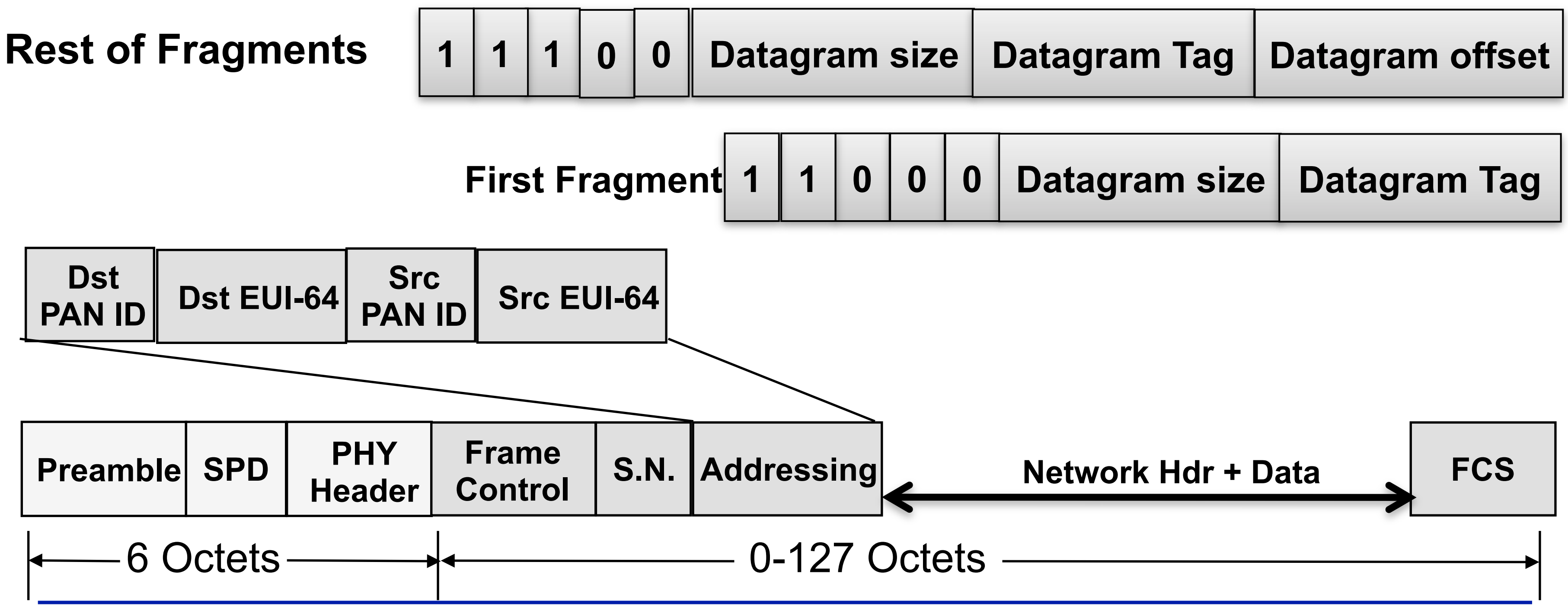
IPv6 Deployment and Support

- Header Dispatch = compressed
- HC1 = Source & Dest Local, next hdr=TCP
- IP = Hop Limit
- TCP = 20-byte header



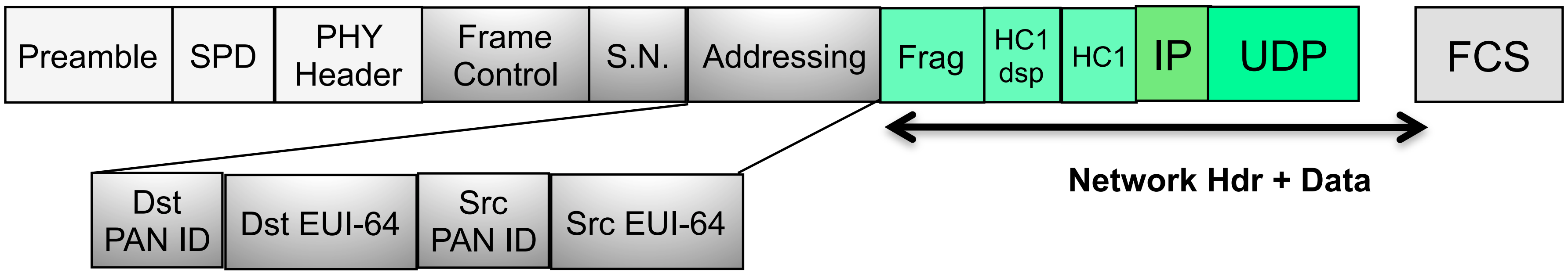
6LoWPAN – Fragmentation

- All fragments of an IP packet carry the same "tag"
    - Assigned sequentially at source of fragmentation
- Each subsequent fragment specifies tag, size, and position
- Do not have to arrive in order
- Time limit for set of fragments (Reassembly Timeout = 60s [RFC 2460])



6LoWPAN – Fragmentation Example

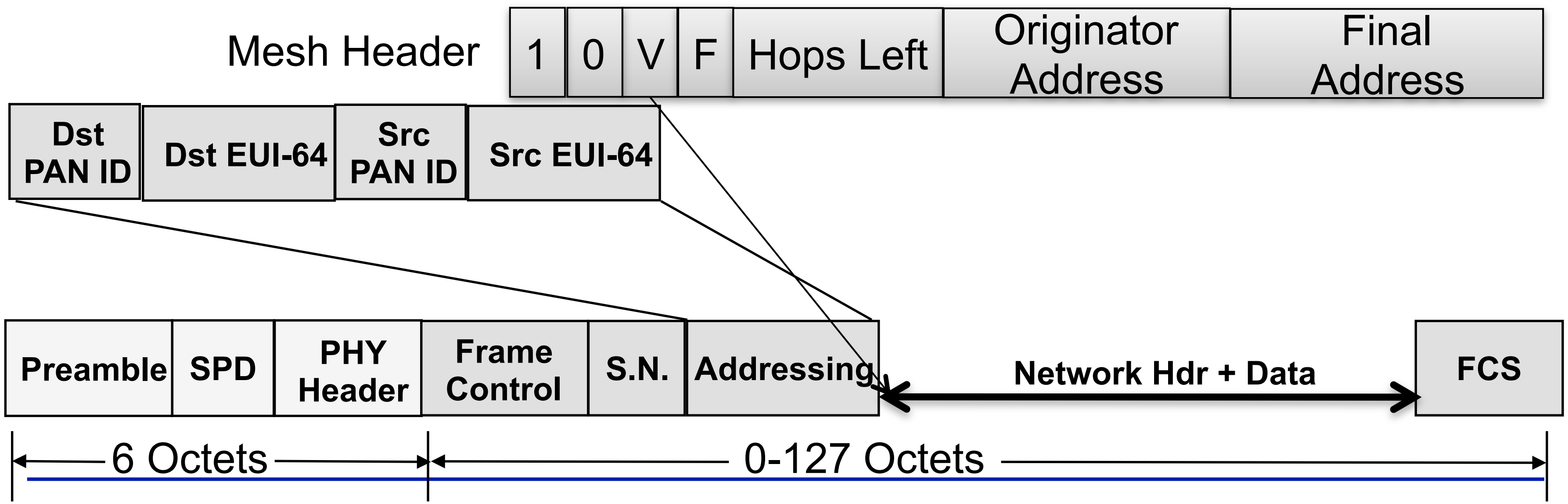
- **Interoperability means that applications need not know the constraints of physical links that might carry their packets**
  - **IP packets may be large, compared to 802.15.4 max frame size**
  - **IPv6 requires all links support 1280 byte packets [RFC 2460]**
- **Example of Fragmented/Compressed/UDP packet**
  - **Dispatch: Fragmented, First Fragment, Size, Tag**
  - **Dispatch = compressed IPv6**
  - **HC1 = Source & Dest Local, next hdr=UDP**
  - **IP = Hop Limit**
  - **UDP = 8-byte header**



6LoWPAN – "Mesh Under"

IPv6 Deployment and Support

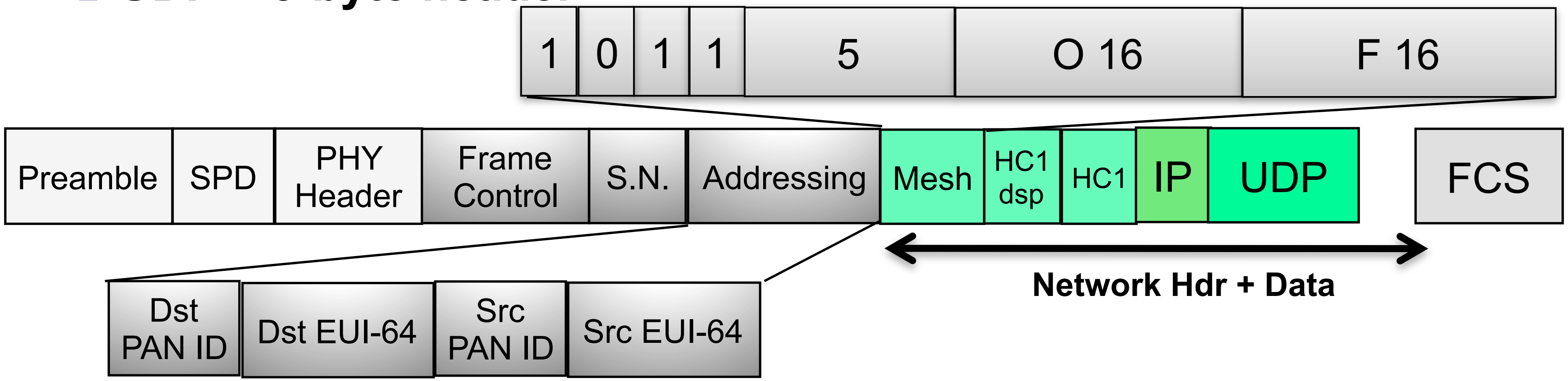
- Allow link-layer mesh routing under IP topology
  802.15.4 subnets may utilize multiple radio hops per IP hop
  Similar to LAN switching within IP routing domain in Ethernet
- Originating node and Final node specified by either short or EUI-64 address
  - In addition to IP source and destination
  - V = Very First, F = Final – 0= EUI-64, 1= short
- Hops Left (4 bits) – up to 14 hops, then add byte (indicated by 0xF) if more hops
- Mesh protocol determines node at each mesh hop



6LoWPAN – Mesh Example

IPv6 Deployment and Support

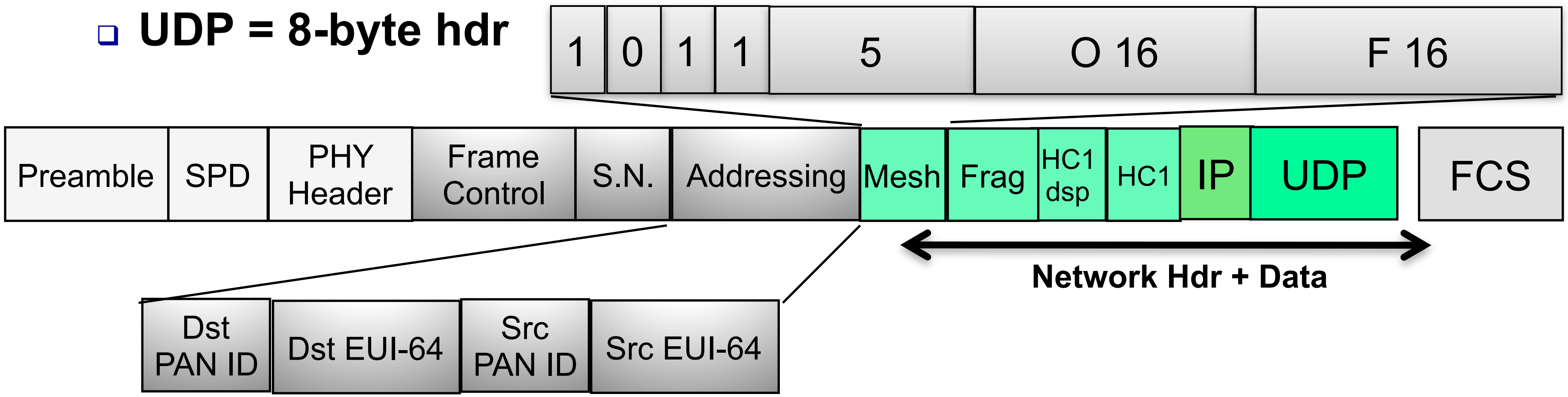
- **Example of Mesh/Compressed/UDP packet**
  - **Dispatch: Mesh Under, Very First=short, Final=short**
    - **Mesh= Originator Address, Final Address**
    - **Hops Left = 5**
  - **Dispatch = compressed IPv6**
  - **HC1 = Source & Dest Local, next hdr=UDP**
  - **IP = Hop Limit**
  - **UDP = 8-byte header**



6LoWPAN – Mesh Example

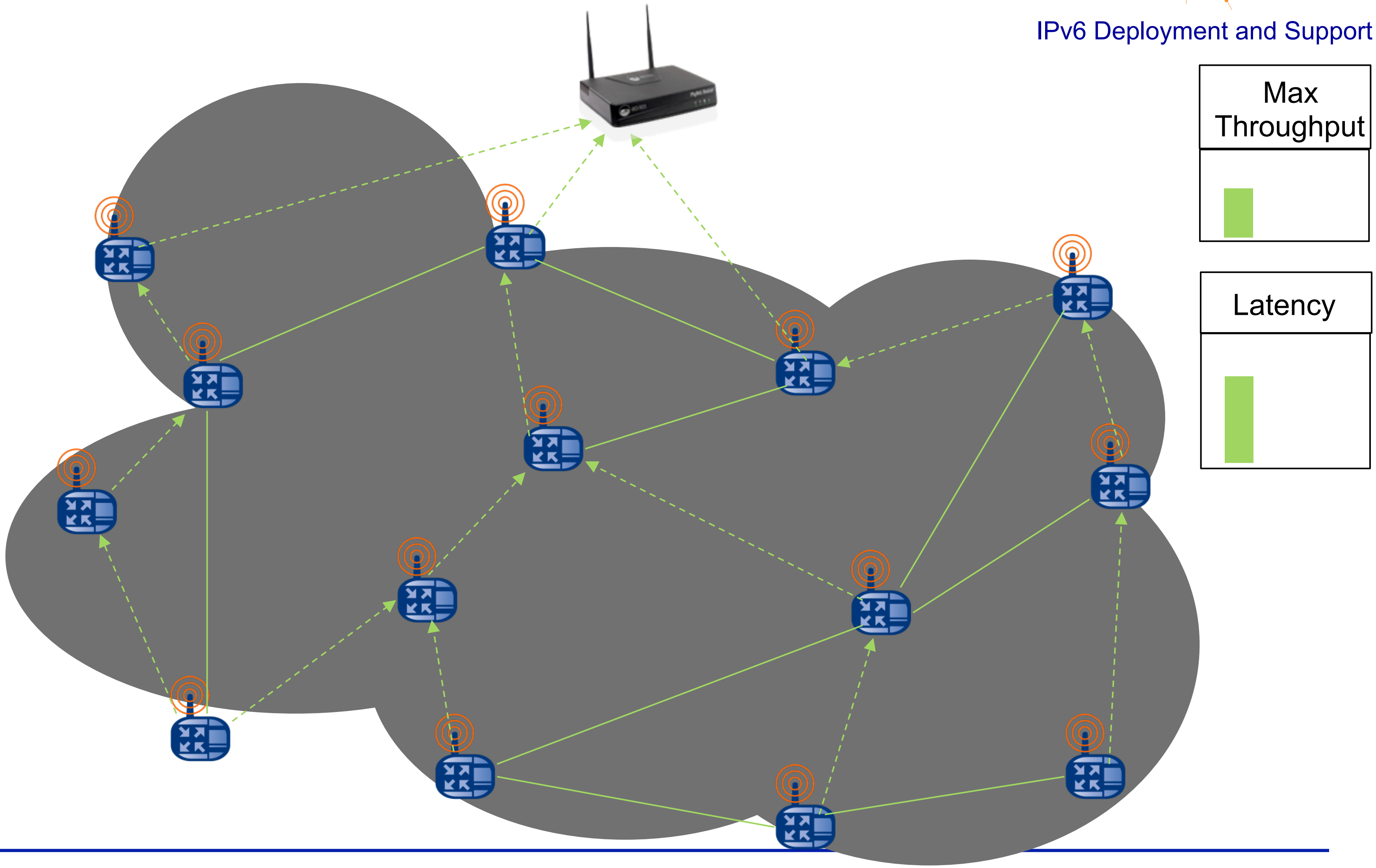
IPv6 Deployment and Support

- **Example of Mesh/Fragmented/Compressed/UDP packet**
  - **Dispatch: Mesh Under, Very First=short, Final=short**
    - **Mesh= Originator Address, Final Address**
    - **Hops Left = 5**
  - **Dispatch: Fragmented, First Fragment, Size, Tag**
  - **Dispatch = compressed IPv6**
  - **HC1 = Source & Dest Local, next hdr=UDP**
  - **IP = Hop Limit**
  - **UDP = 8-byte hdr**



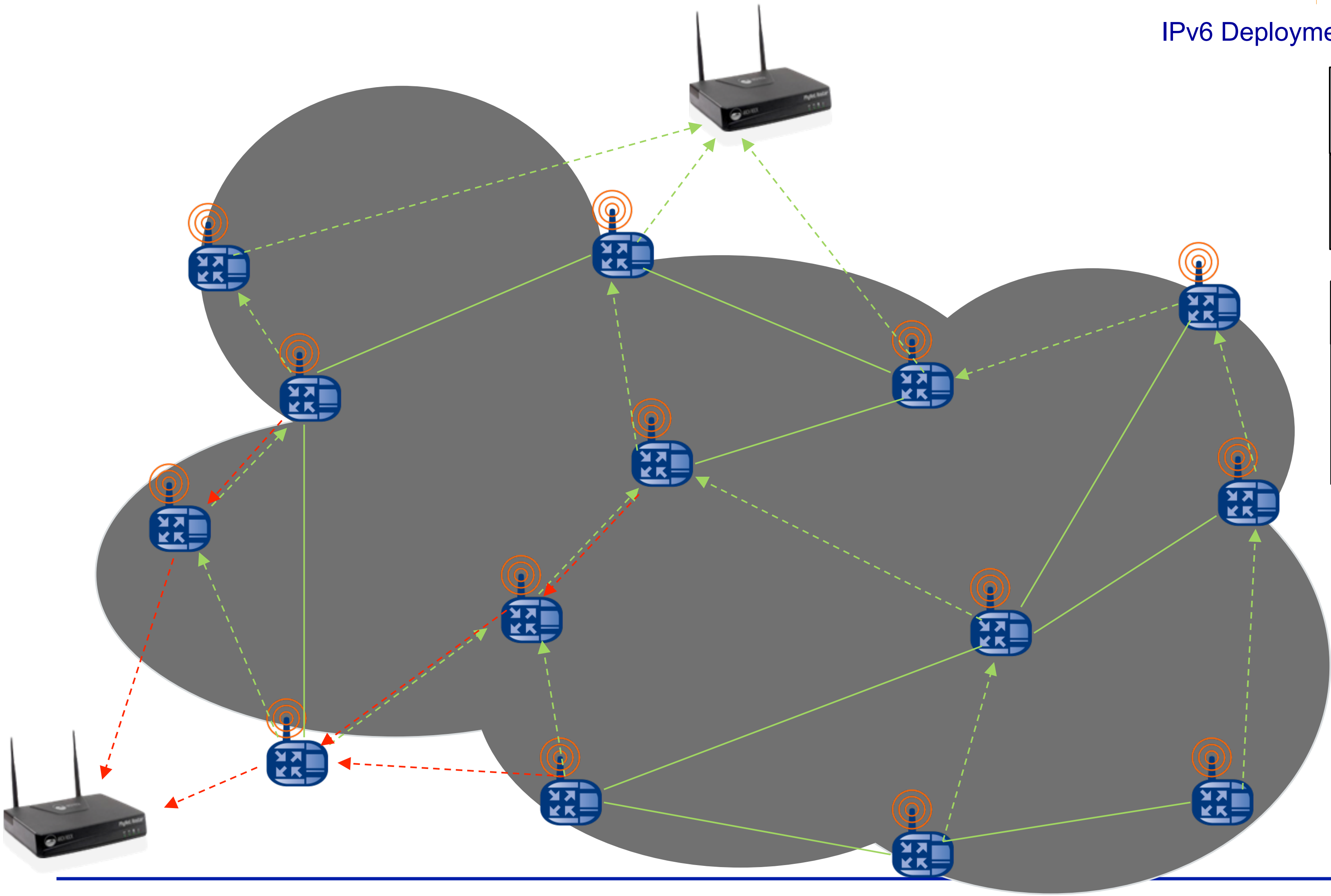
Self-Configuring WSN

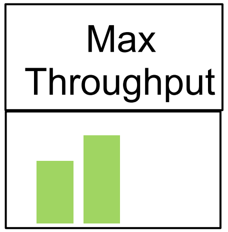
IPv6 Deployment and Support

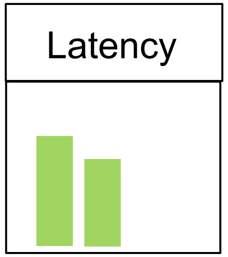


Scaling the WSN

IPv6 Deployment and Support

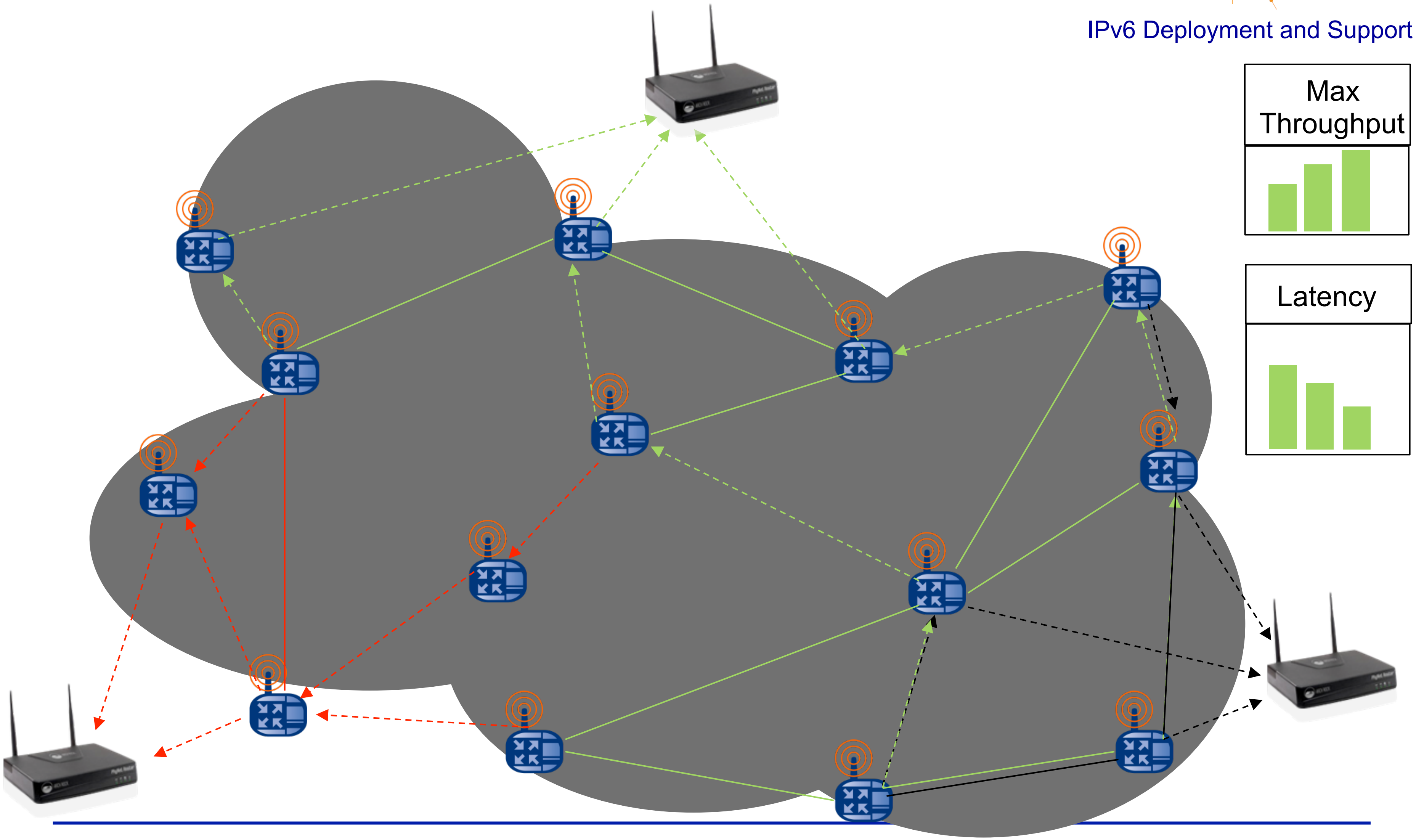






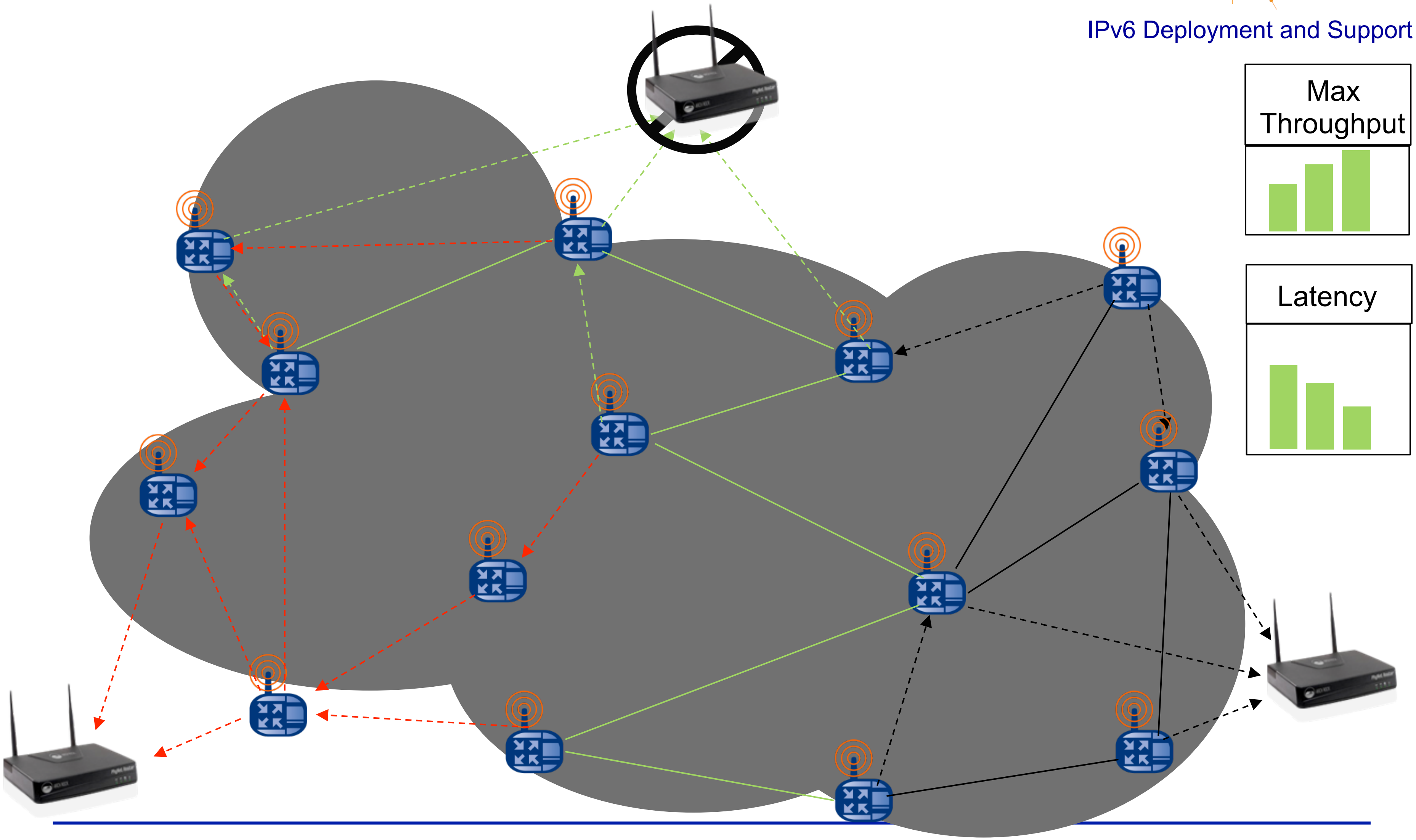
Scaling the WSN

IPv6 Deployment and Support



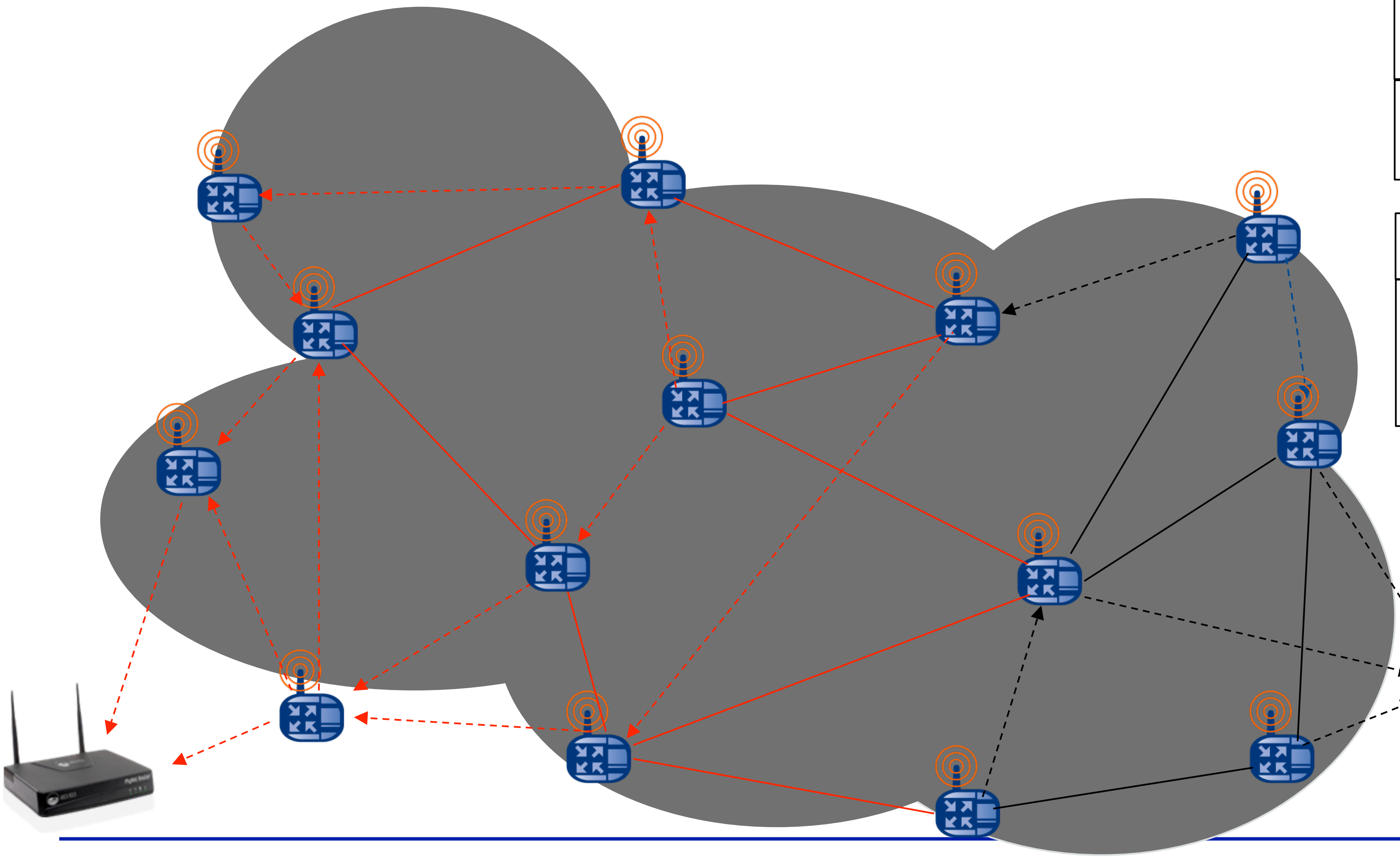
Resiliency of the WSN

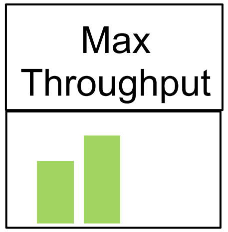
IPv6 Deployment and Support

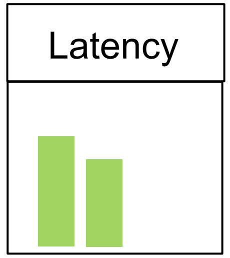


Resiliency of the WSN

IPv6 Deployment and Support







Compact Application Protocol

- ZigBee does not support IP
- To talk to IP devices it needs modification
- CAP: proposed to IETF and ZigBee Alliance
  - Modifies ZigBee protocol with UDP/IP adaptation layer
  - Can bridge diverse types of devices across large application domains:
    - Legacy industrial sensors, wireless/wired
    - 802.15.4 / LoWPAN
    - Emerging powerline communication networks

Mobility in WSN

- Most WSN applications assume fixed networks, or limited mobility of nodes within the WSN
- Emerging mobility patterns (see RUNES/U-2010)
  - PANs for emergency responders (firemen with uniform-attached sensors, etc.)
  - Dynamically deployed nodes
- Network Mobility (NEMO) scenarios apply
- Mobile Ad-hoc Network Mobility (MANEMO) often more suitable
  - Avoid nested tunneling

Node Operating Systems

IPv6 Deployment and Support

- Various compact operating systems developed for sensor nodes
  - Small memory size
  - Power saving facilities
  - Reduced IPv6 Stack
- Examples:
  - Contiki, http://www.sics.se/contiki
  - TinyOS, http://www.tinyos.net
- Common smart sensor node is MOTES

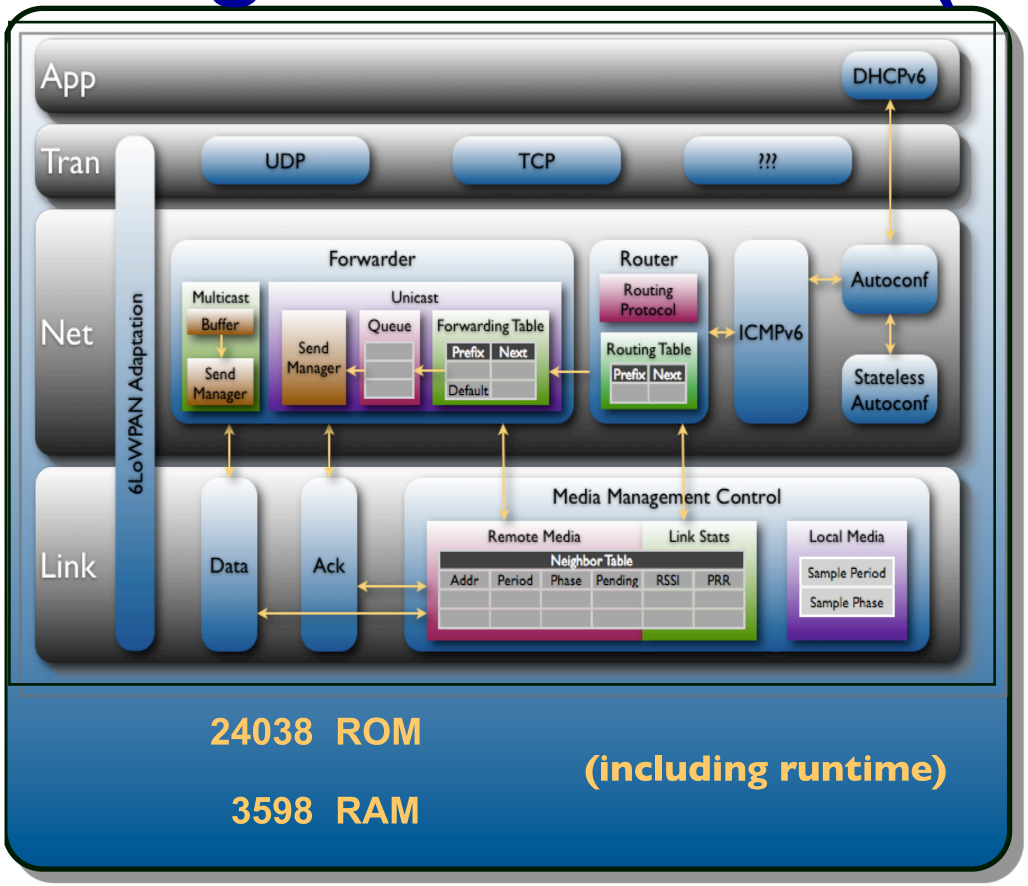
Agenda

IPv6 Deployment and Support

- Introduction
- The Generic Components
- Standards and Technologies
- <u>An Example – the Arch Rock Portfolio</u>
- Deployment Case Studies
- Conclusion

e.g. IP on motes (Arch Rock)

IPv6 Deployment and Support

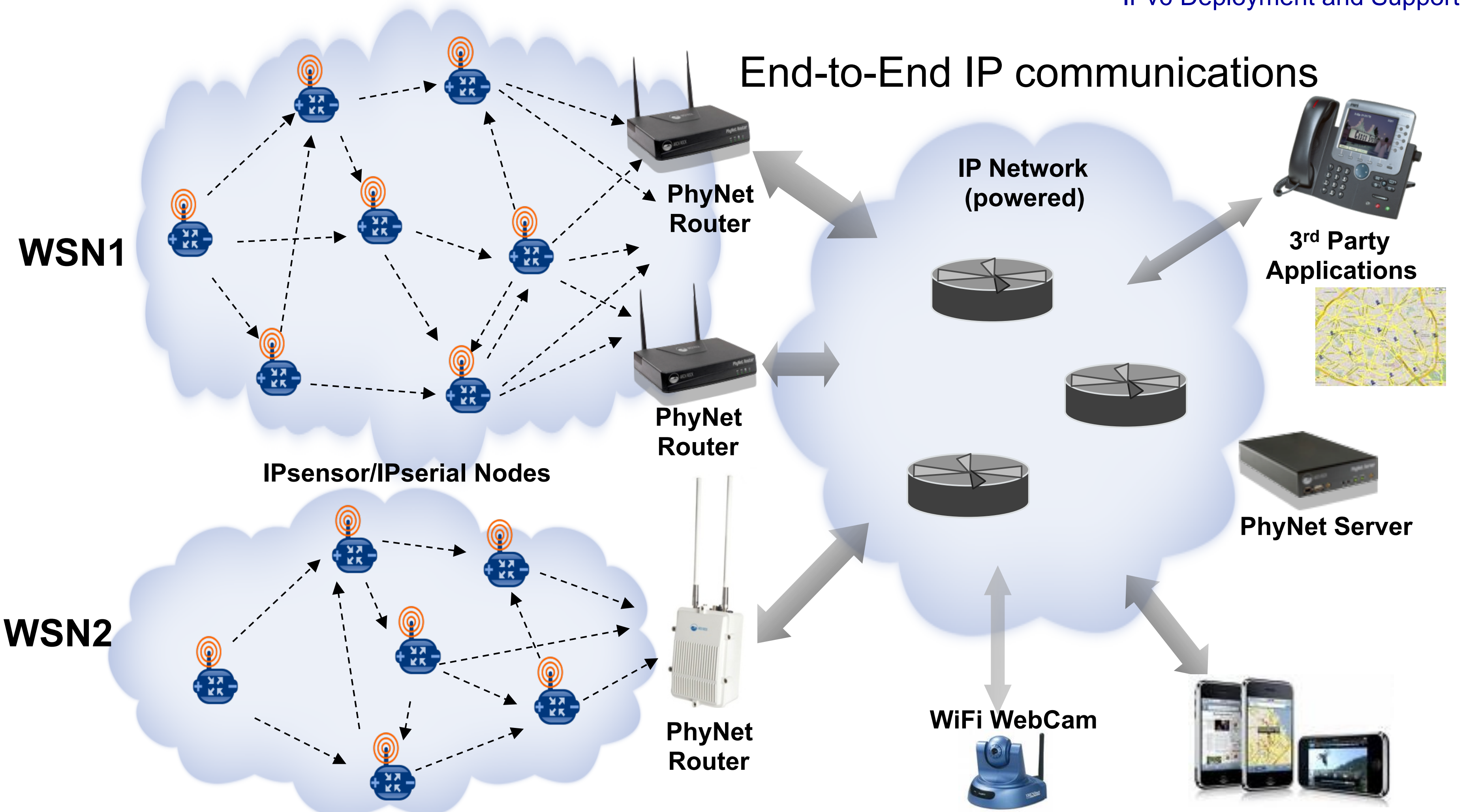


	ROM	RAM
CC2420 Driver	3149	272
802.15.4 Encryption	1194	101
Media Access Control	330	9
Media Management Control	1348	20
6LoWPAN + IPv6	2550	0
Checksums	134	0
SLAAC	216	32
DHCPv6 Client	212	3
DHCPv6 Proxy	104	2
ICMPv6	522	0
Unicast Forwarder	1158	451
Multicast Forwarder	352	4
Message Buffers	0	2048
Router	2050	106
UDP	450	6
TCP	1674	50

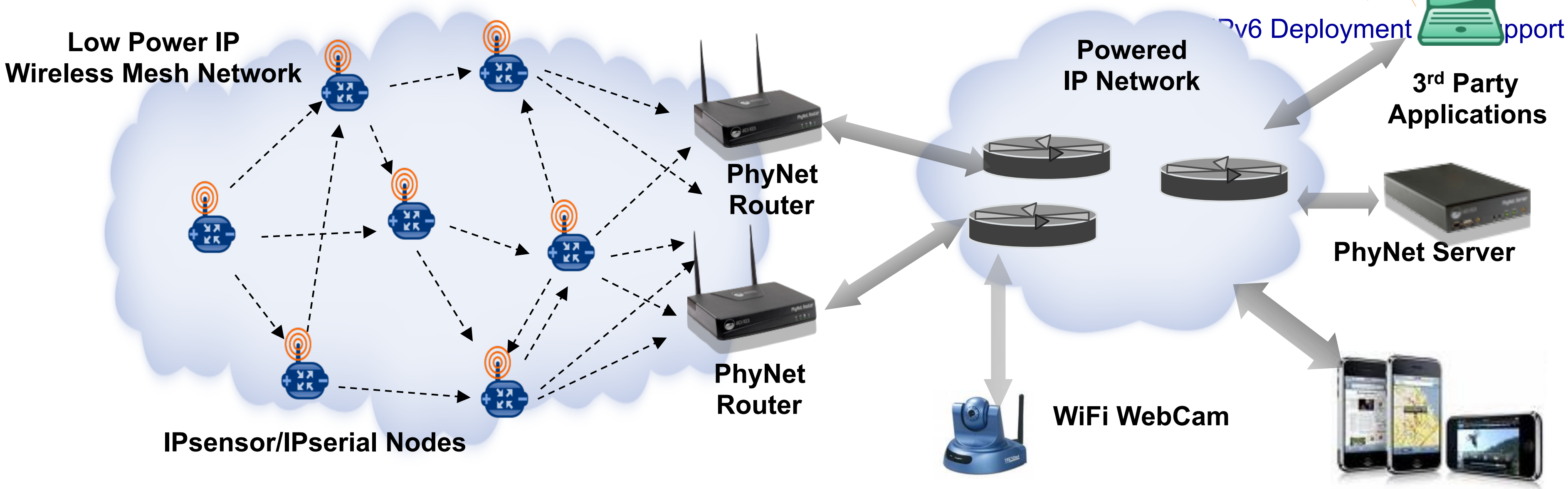
* Production implementation on TI msp430/cc2420

- **Footprint, power, packet size, & bandwidth**

ArchRock PhyNet Architecture



PhyNet Architecture Benefits



- **Embedded Mesh Network: IPv6-based, sensing and routing with low power**
  - *Open standard, auto-configuration, power autonomy, fast recovery, fast response, security*
- **Routed End-to-End IP: Router-based edge layer extends Internet model**
  - *Ease of deployment and management, enablement of mixed network device applications*
- **Multi-Tier Architecture: Central services and distributed routing**
  - *Enterprise scale, distributed deployment, centralized management and presentation*
- **Embedded Web Services: XML/SOAP/REST-based presentation**
  - *Openness to customer application development over standard enterprise API interfaces*

ArchRock PhyNet Portfolio

Server

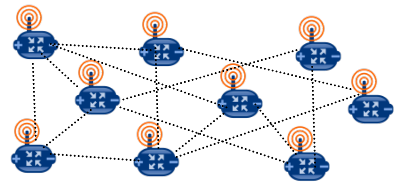
- System Management Router Management
- Data Management, Visualization and Warehouse

Router

- Indoor/Outdoor
- Network Management PAN/WAN/LAN
- Node Association
- Protocol Translation

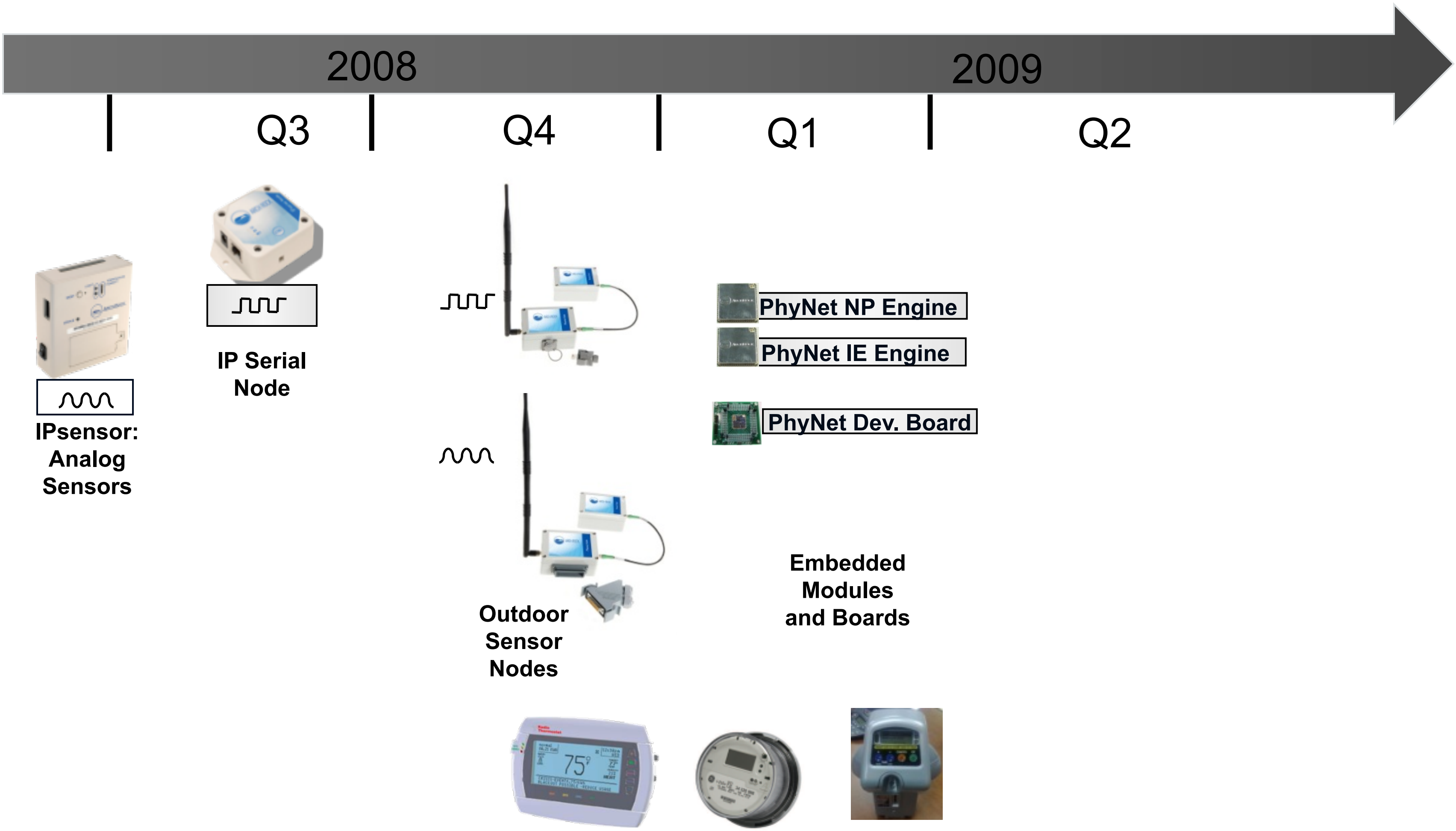
IP Nodes

- Mesh Routing
- Sensors and Actuators
- Embedded Web Services



PhyNet Wireless Nodes

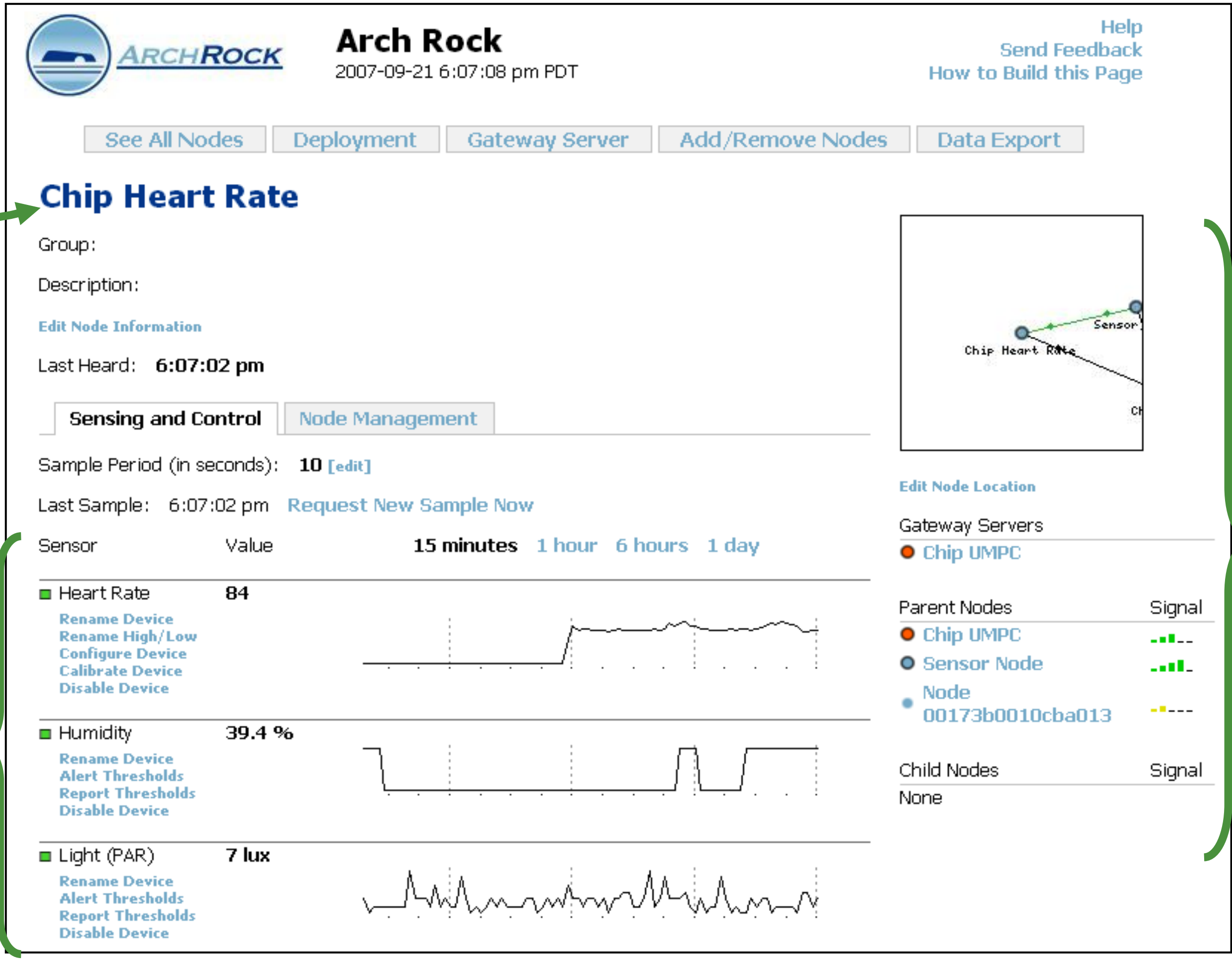
IPv6 Deployment and Support



Sensor Node Web Page Example

IPv6 Deployment and Support

Wireless sensor node name



Wireless network information

Sensor data: Current value and history

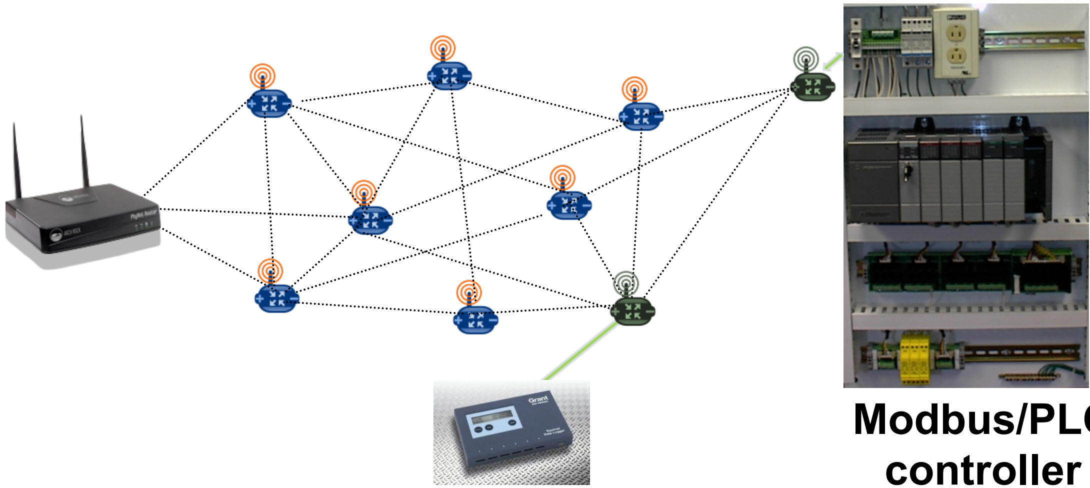
PhyNet Wireless Sensor Node

- **Indoor and Outdoor Sensors**
  - **Built-in temperature, humidity, light**
  - **External sensor inputs – analog, digital**
- **Networking**
  - **IEEE 802.15.4 Radio**
  - **Power-efficient Mesh networking**
  - **Security**
    - **AES-128 link encryption**
    - **Node authentication**
  - **IETF 6LoWPAN**
    - **Ping/Traceroute/TCP/UDP**

PhyNet IPserial Node

Easily connect to data loggers, smart digital sensors & legacy wired buses

RS232 / RS485 interfaces



datalogger

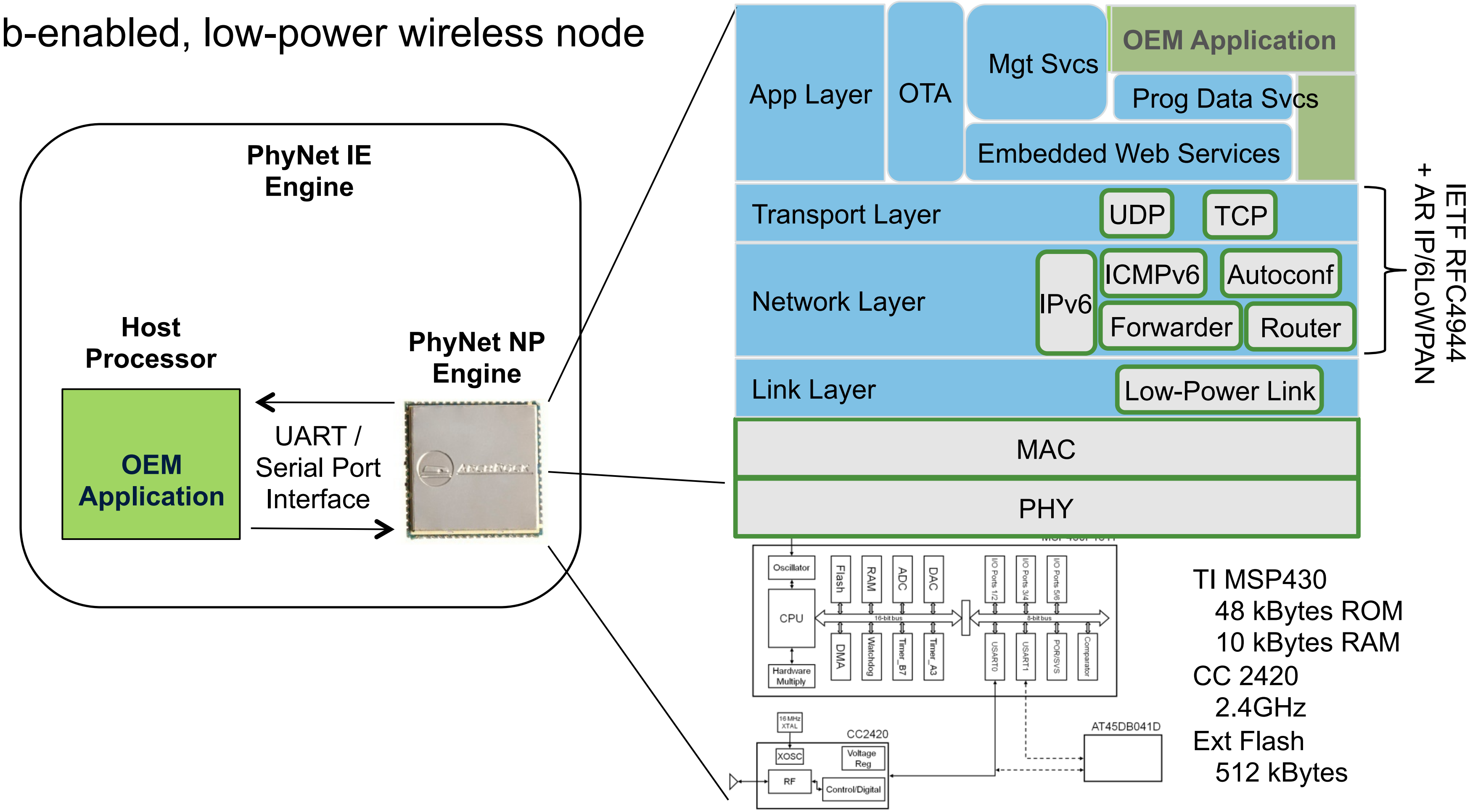
Modbus/PLC controller

- **Address a broad set of instruments and data loggers**
- **Bring sensing and control systems using legacy wired buses (e.g., ModBus) equipped with serial interfaces into the mesh**
- **Communicate with a many types of precise, small-footprint digital sensors**
- **All IPseries Nodes route and provide IP services (telnet, UDP, TCP, etc.)**

PhyNet Engine – OEM Offering

IPv6 Deployment and Support

Turns customer device into an IP- and web-enabled, low-power wireless node



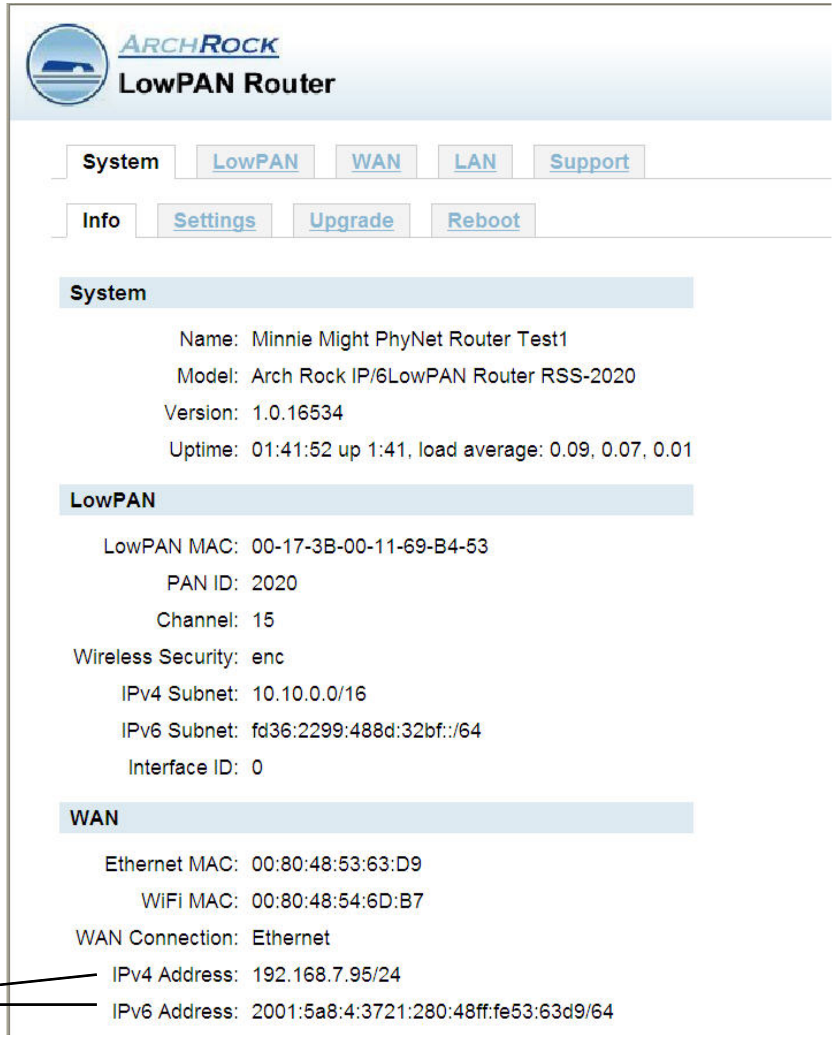
PhyNet Router

Features

- 802.15.4 WSN
- Ethernet/WiFi, GPRS uplinks

- Dynamic routing across multiple PNRs at edge of PAN offering nodes multiple egress points

- IPv4 to IPv6 routing and protocol translation



Benefits

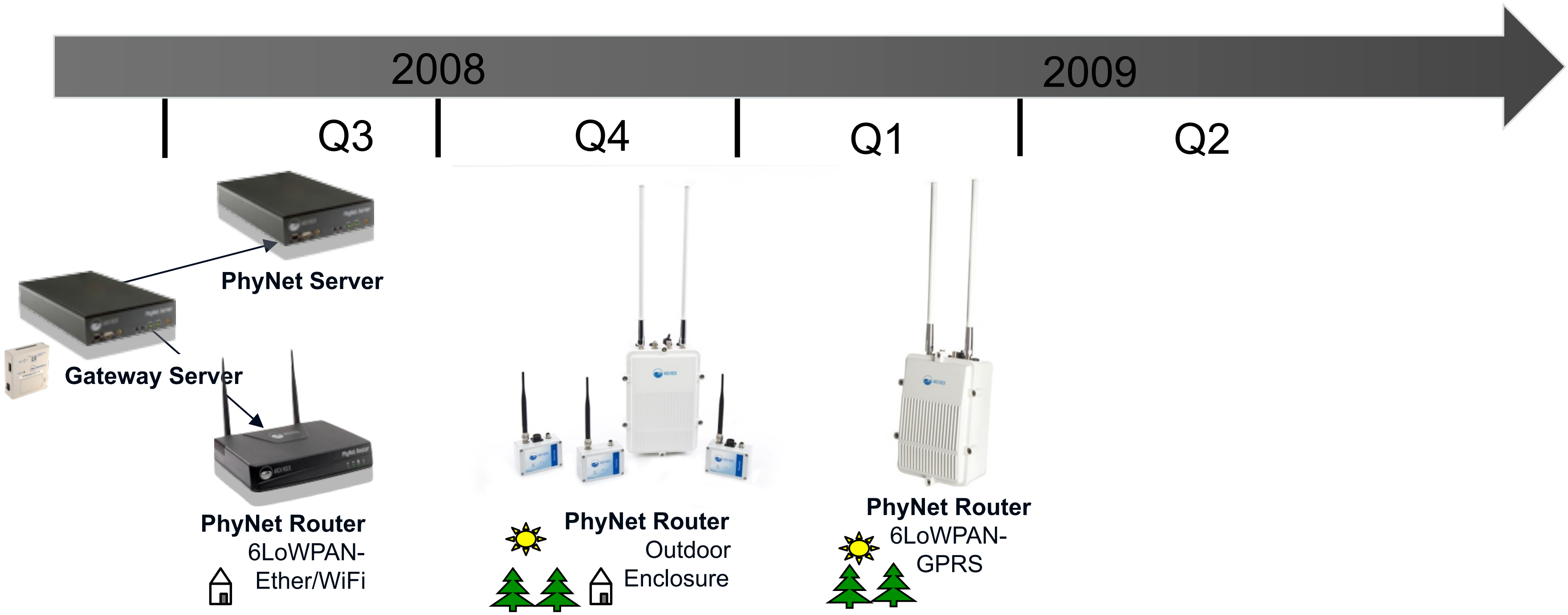
- Eliminates need to co-locate server on-site with WSN

- Robustness
- Resiliency
- Higher throughput
- Lower latency
- Longer node battery life

- Supports IPv4 backhaul and enterprise networks

PhyNet Routers

IPv6 Deployment and Support



- **IPv4 and IPv6**
- **6LoWPAN**
- **Power over Ethernet**

PhyNet Server

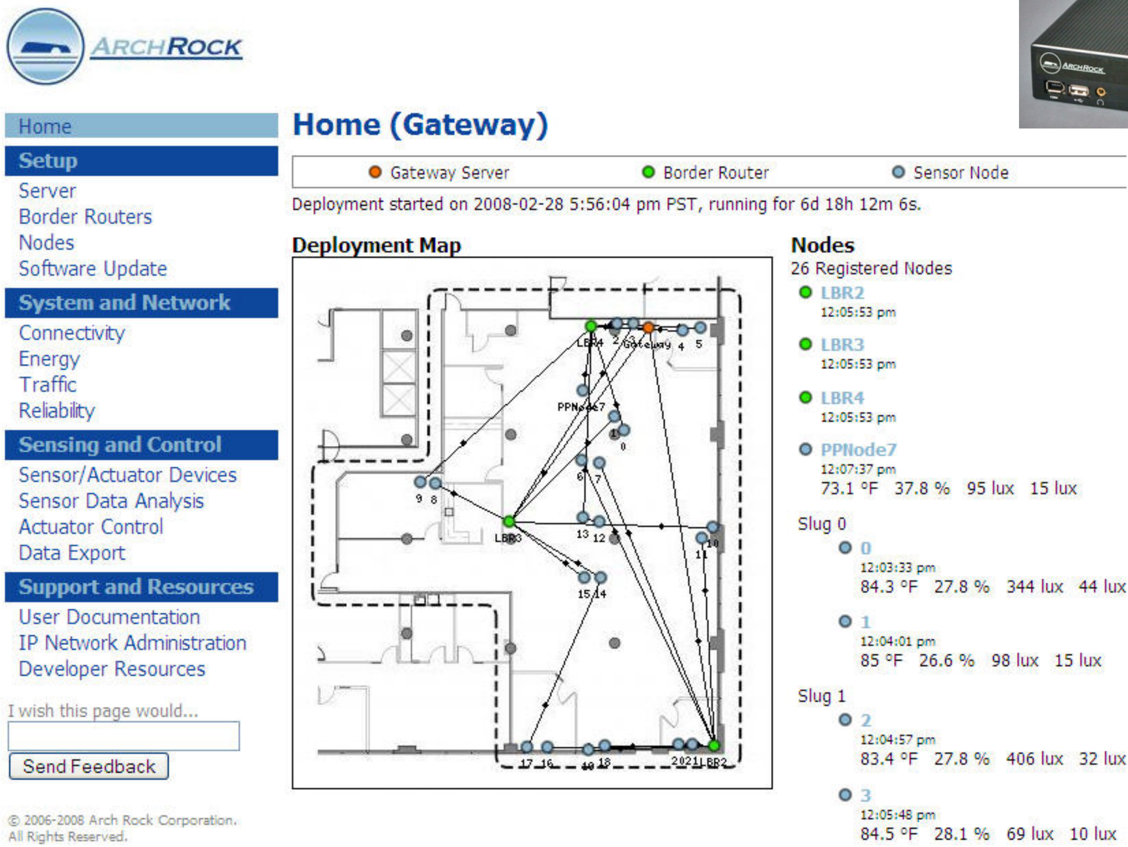
IPv6 Deployment and Support

End-to-end IP architecture and embedded web services provides a extensible out-of-the box management interface

Discover, register, move and configure nodes; enable and disable sensors

Display performance stats; set reporting intervals, thresholds and alerts.

Visualization and analysis of multiple sensor data streams



Redundant Access Routers

Summary sensor data

Agenda

IPv6 Deployment and Support

- Introduction
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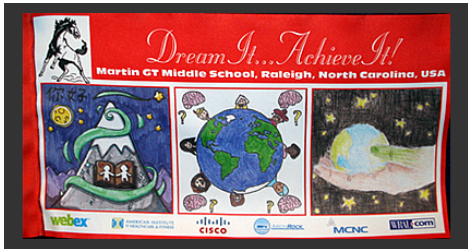
Collaborative WSN Communities

- Web 2.0 – Collaboration – Cloud Computing
  - Education
  - Research
  - Interest Groups
  - Public Information

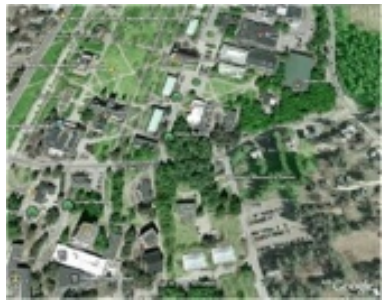


- End to End IP architecture to get data directly from sensor nodes

PhyNet in Wireless Cities

IPv6 Deployment and Support

- **City environment, biology, air quality**
  - Alarms, surveillance, treaty verification
- **Disaster situational tracking and sensing**
  - Infrastructure health monitoring
- **Metering**
  - Parking meters
  - Street lights
- **Solutions**
  - Outdoor PhyNet router(s) connected to Public WLAN or GPRS Infrastructure
  - Outdoor PhyNet or embedded nodes



PhyNet in Green Buildings

- Commercial Building Infrastructure health monitoring
- Indoors or outdoors environmental data
- Energy savings
- Air quality
- Building comfort, energy efficiency
- Monitoring Condition-based machine maintenance
- Advanced metering, resource usage
  - Sub-metering (up to desk level)
  - Lighting control

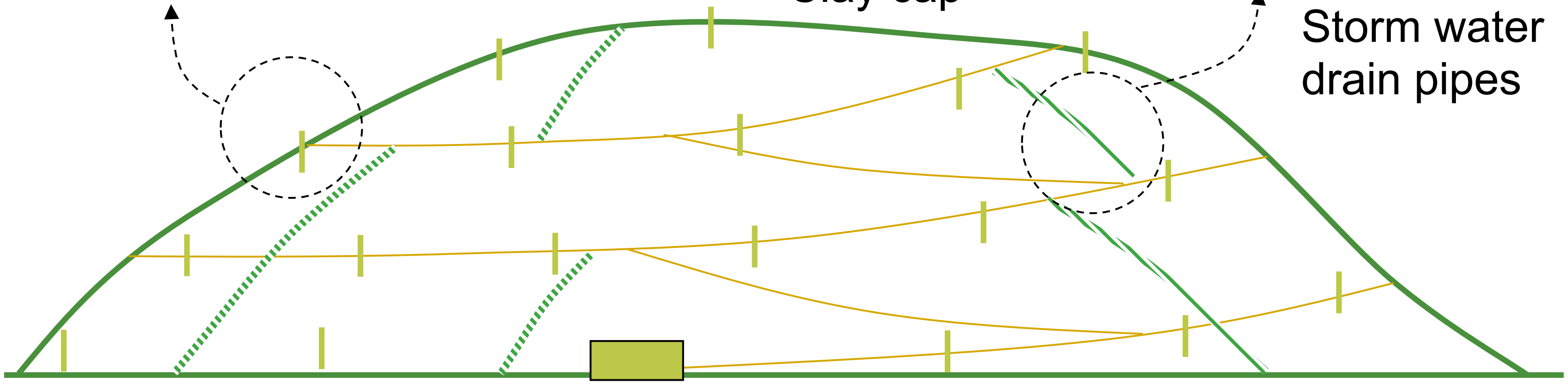
Anatomy of a Landfill

Methane well and
gas collection pipes

Leachate fluid
collection pipes

Clay cap

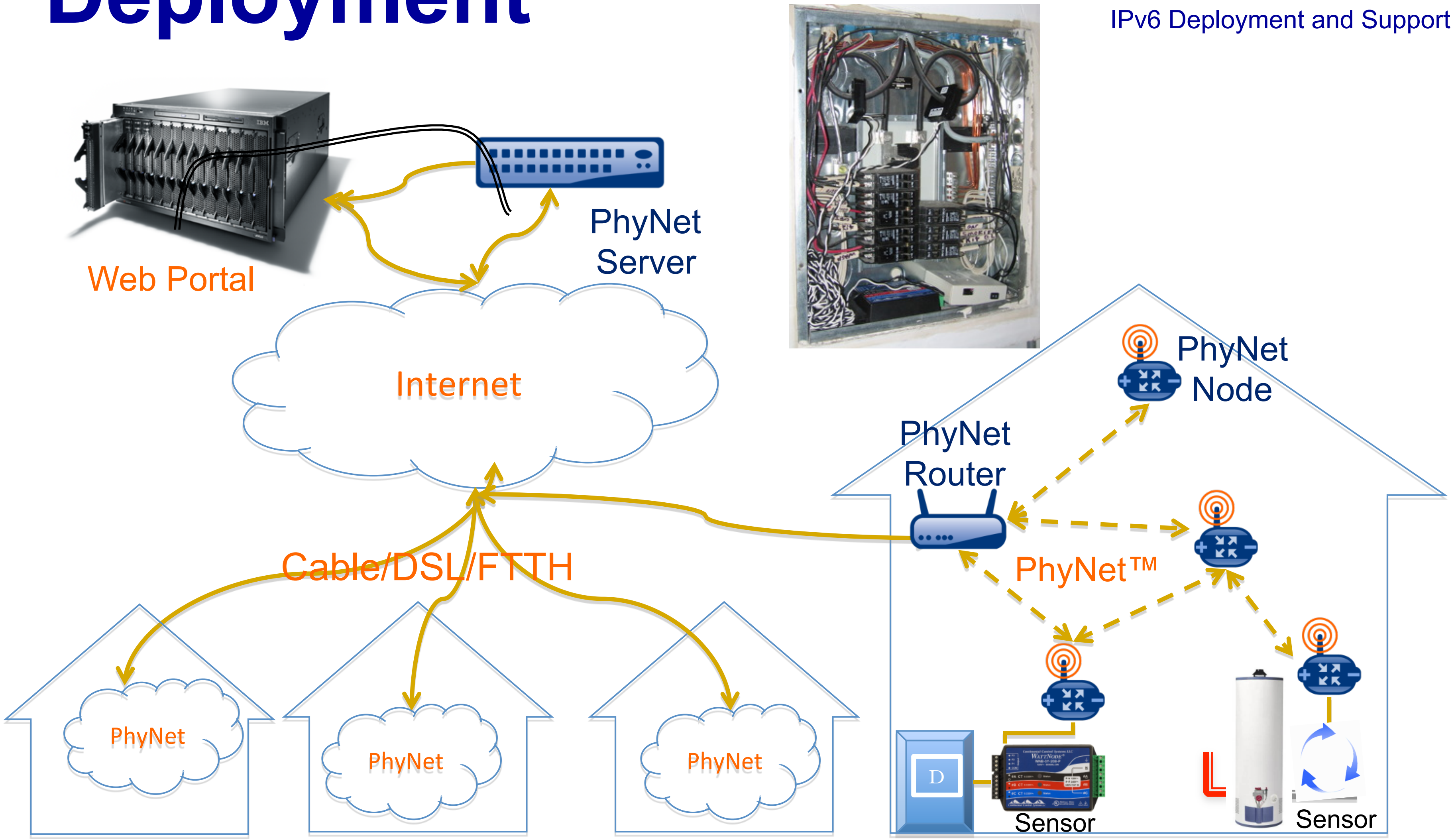
Storm water
drain pipes



Collection, processing and monitoring facility

PhyNet Green Building Deployment

IPv6 Deployment and Support



PhyNet in the Data Center

IPv6 Deployment and Support

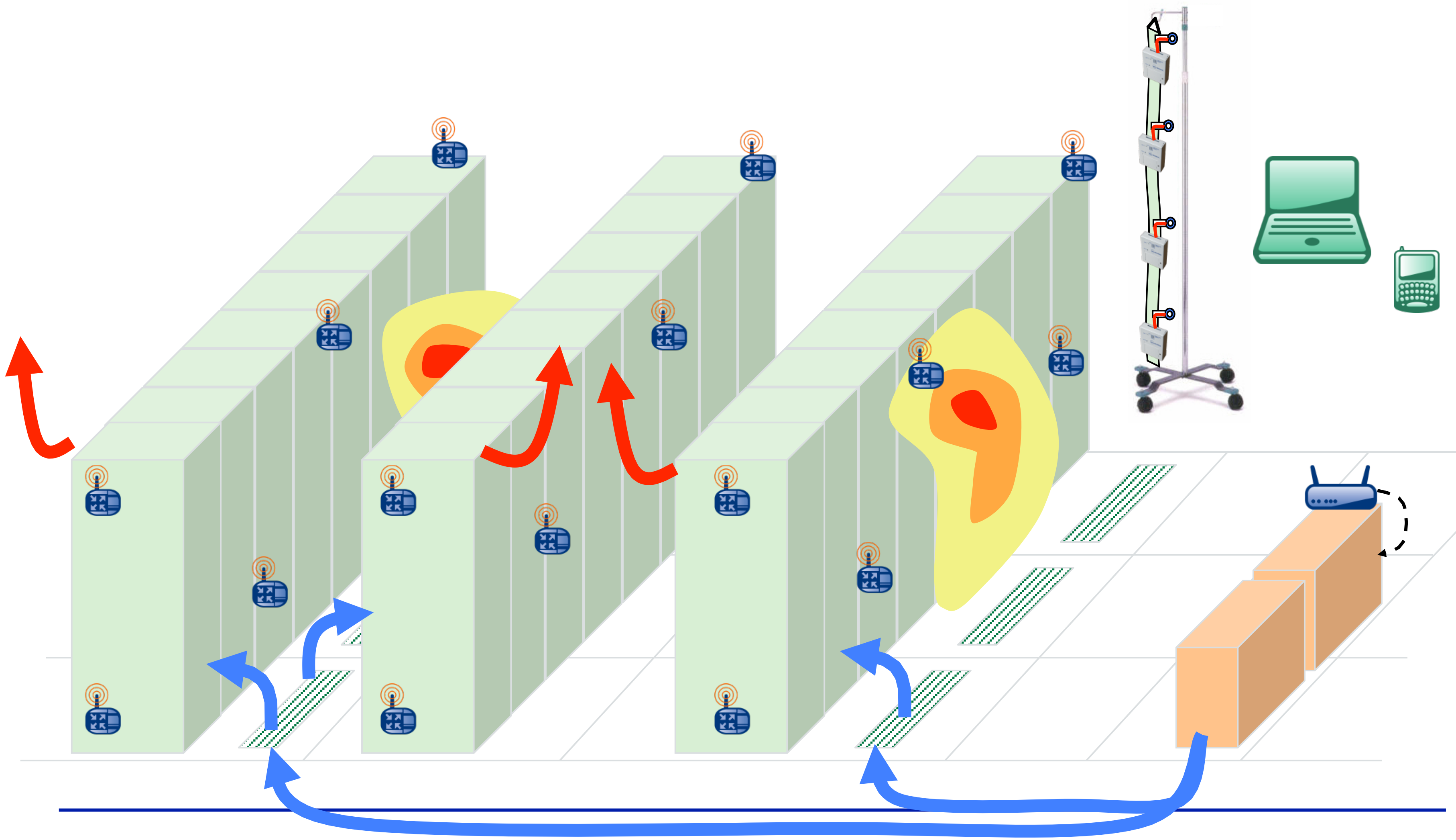
- **Continuous Visibility**
  - Temperature, humidity and Air flow profiles
  - Power -- Which device/rack is using exactly how much
- **Analysis/Data export**
  - Alerts and notifications based on thresholds
  - Complete fine-grain data for detailed historical analysis
- **Action**
  - Manual tuning of HVAC system
  - Closed loop automatic control as warranted
  - Virtualization and load migration
    - Concentrate compute loads and cooling for better efficiency
    - Spread compute load to optimize cooling resources
    - Time and demand based load migration -- end of the month, qtr, year
  - Long term planning from better data

Benefits

- **Energy savings**
  - More efficient cooling (reduced HVAC costs)
  - Reduction of power used by servers
    - by dynamic redistribution of the compute load
- **Conformance**
  - “Name-plate” vs. actual power usage
- **Lower capital expenditure**
  - Less “over-provisioning”
  - Better tuning of capacity to demand
  - For HVAC and compute servers

PhyNet for Server Room Thermal Auditing/Monitoring

IPv6 Deployment and Support



PhyNet in Refrigeration Monitoring

IPv6 Deployment and Support

Problem Open loop employee monitoring of in-store refrigeration susceptible to spoilage for high-value food items

ArchRock Solution Closed-loop M2M monitoring with sensor network which scales to multiple locations__

Store 1

AR IPsensor nodes
- Temperature
- Humidity
- Mesh Routing
- Embedded Web Services

Store 2

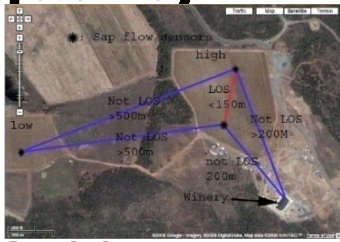
PhyNet Router
- Dynamic Routing
- Ethernet/WiFi uplinks

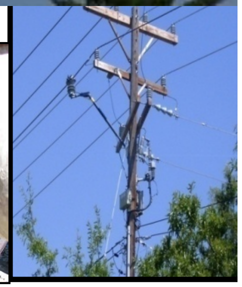
PhyNet Server
- Located offsite
- Remote Monitoring & Management for single location or entire chain
- Threshold alerts protect High Value Food Items
- Defrost cycle trend analysis

Outdoor Environmental Monitoring

IPv6 Deployment and Support

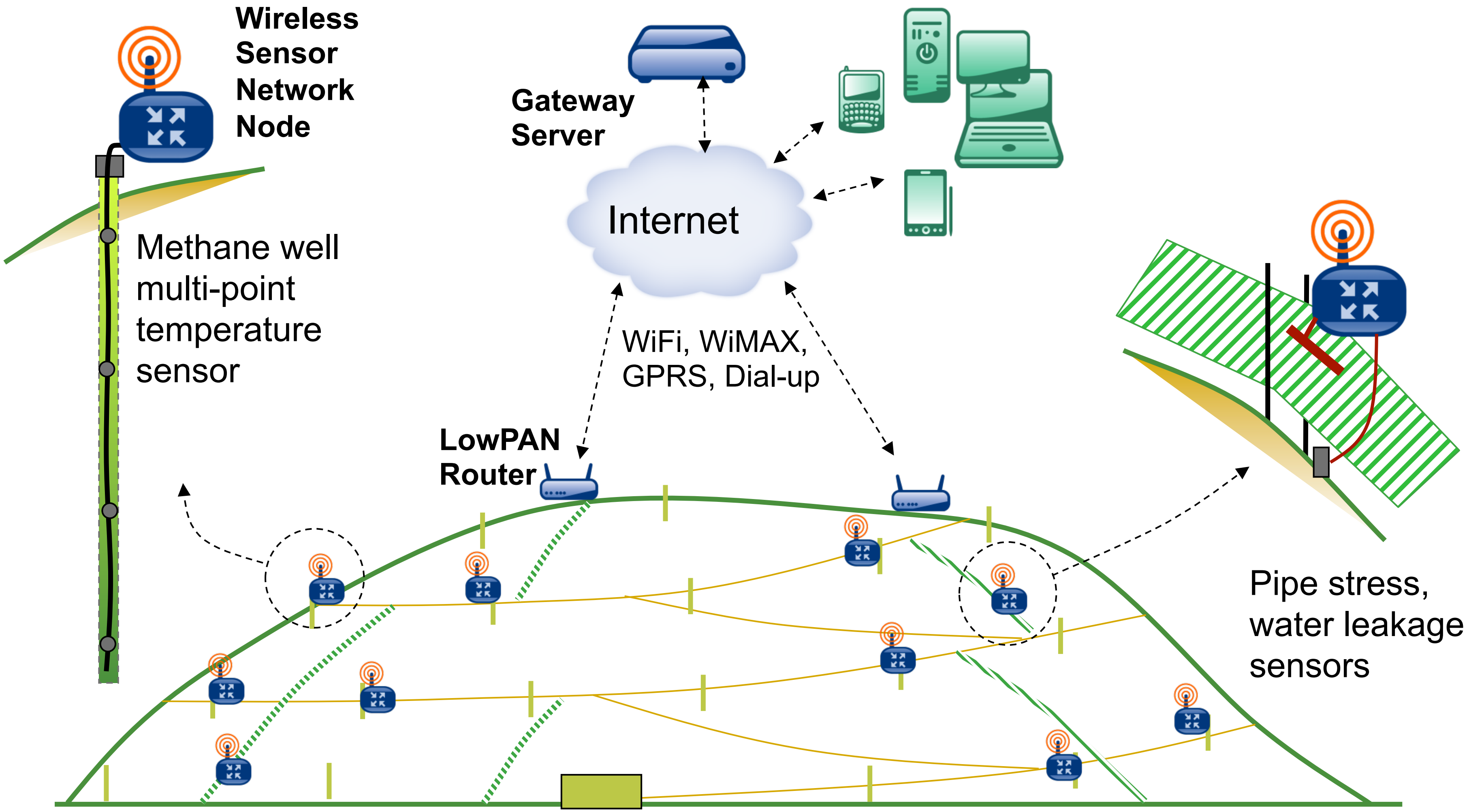
- Natural environment, biology, air quality
- Resources preservation
  - Water,…
- Disaster situational tracking and sensing
- Infrastructure health monitoring
- Advanced metering, resource usage





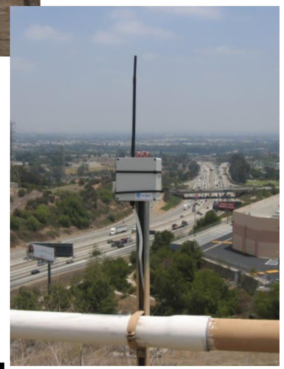
The Wireless Landfill

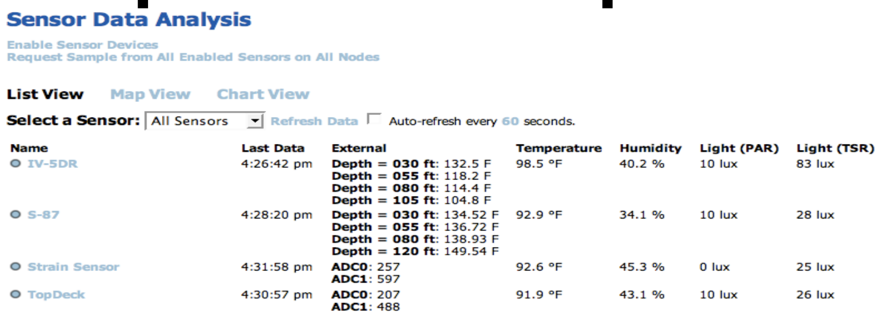
IPv6 Deployment and Support



Continuous Visibility and Alerting

- **Gas wells**
  - **Under-the-cap temperature, at various depths**
  - **Methane concentrations and flow characteristics**
- **Pipe stress, deformation and breakage**
  - **Fluid detection**
  - **Bending**
  - **Stress**
- **Leachate fluid composition and production**
  - **pH**
  - **Flow rate**





Sensor Data Analysis

Enable Sensor Devices
Request Sample from All Enabled Sensors on All Nodes

List View Map View Chart View

Select a Sensor: All Sensors Refresh Data Auto-refresh every 60 seconds.

Name	Last Data	External	Temperature	Humidity	Light (PAR)	Light (TSR)
IV-5DR	4:26:42 pm	**Depth = 030 ft**: 132.5 F **Depth = 055 ft**: 118.2 F **Depth = 080 ft**: 114.4 F **Depth = 105 ft**: 104.8 F	98.5 °F	40.2 %	10 lux	83 lux
S-87	4:28:20 pm	**Depth = 030 ft**: 134.52 F **Depth = 055 ft**: 136.72 F **Depth = 080 ft**: 138.93 F **Depth = 120 ft**: 149.54 F	92.9 °F	34.1 %	10 lux	28 lux
Strain Sensor	4:31:58 pm	**ADC0**: 257 **ADC1**: 597	92.6 °F	45.3 %	0 lux	25 lux
TopDeck	4:30:57 pm	**ADC0**: 207 **ADC1**: 488	91.9 °F	43.1 %	10 lux	26 lux

Conclusion

IPv6 Deployment and Support

- Sensor devices everywhere
  - Wireless Sensor Networks will be everywhere
- Desirable to have them run IP
  - Internet of things…
- IPv6 can help with sheer volume of addressing required
  - Open standard
  - Interoperable with existing IP infrastructure
  - Interoperability with existing non-IP WSNs
- Security important