IPv6 and Sensor Networks

IPv6 and Sensor Networks

Copy …Rights

IPv6 Deployment and Support

- ***This slide set is the ownership of the 6DEPLOY project via its partners***
- ***The Powerpoint version of this material may be reused and modified only with written authorisation***
- ***Using part of this material must mention 6DEPLOY courtesy***
- ***PDF files are available from www.6deploy.org***
- ***Looking for a contact ?***
  - ***Mail to : martin.potts@martel-consulting.ch***
  - ***Or bernard.tuy@renater.fr***

Agenda

IPv6 Deployment and Support

- **<u>Introduction</u>**
- **The Generic Components**
- **Standards and Technologies**
- **Conclusion**

Background

IPv6 Deployment and Support

- **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**

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

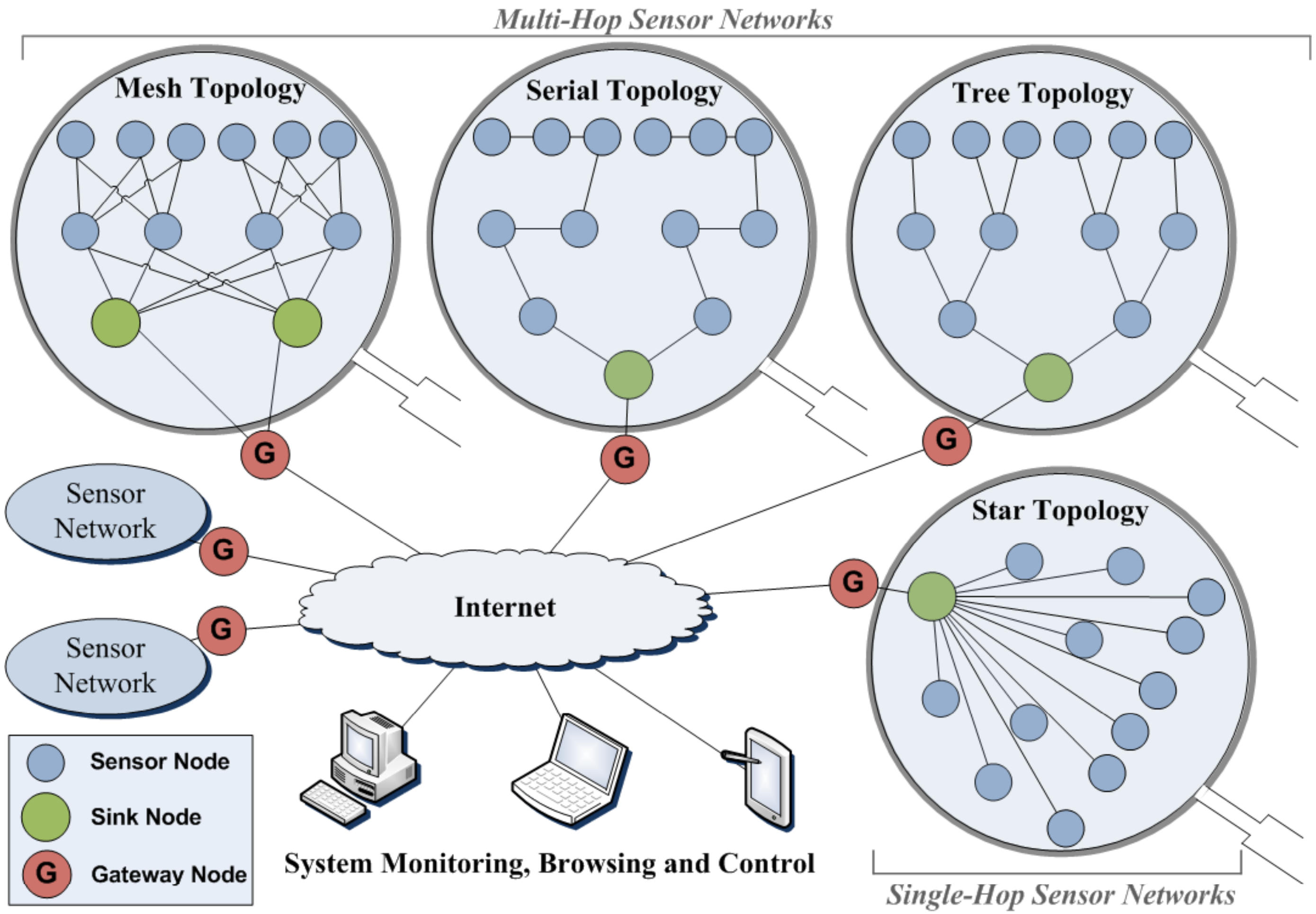
Sensor Network Technology

IPv6 Deployment and Support

- 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

Sensor Network Topology

IPv6 Deployment and Support

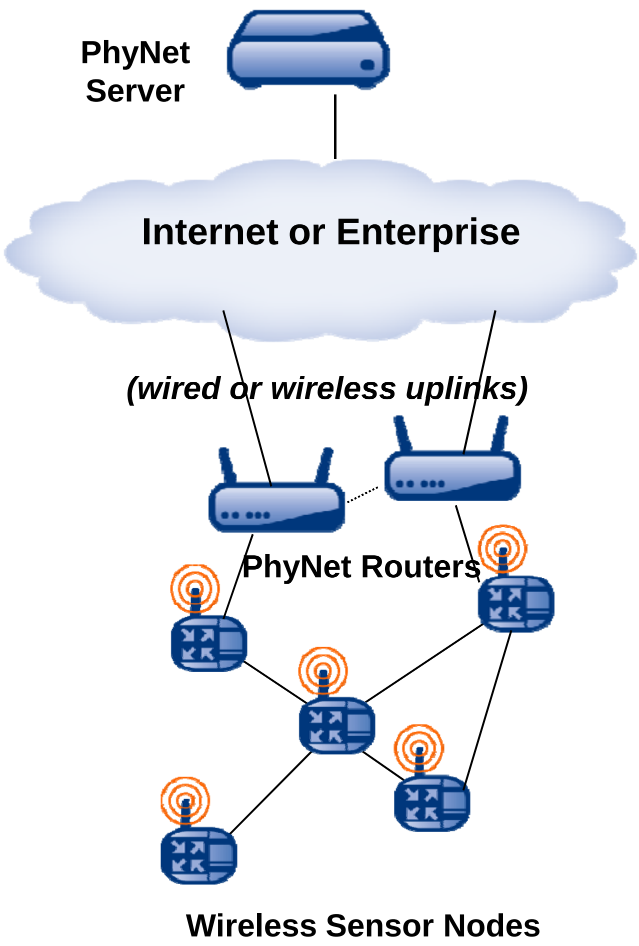


Wireless Sensor Network

IPv6 Deployment and Support

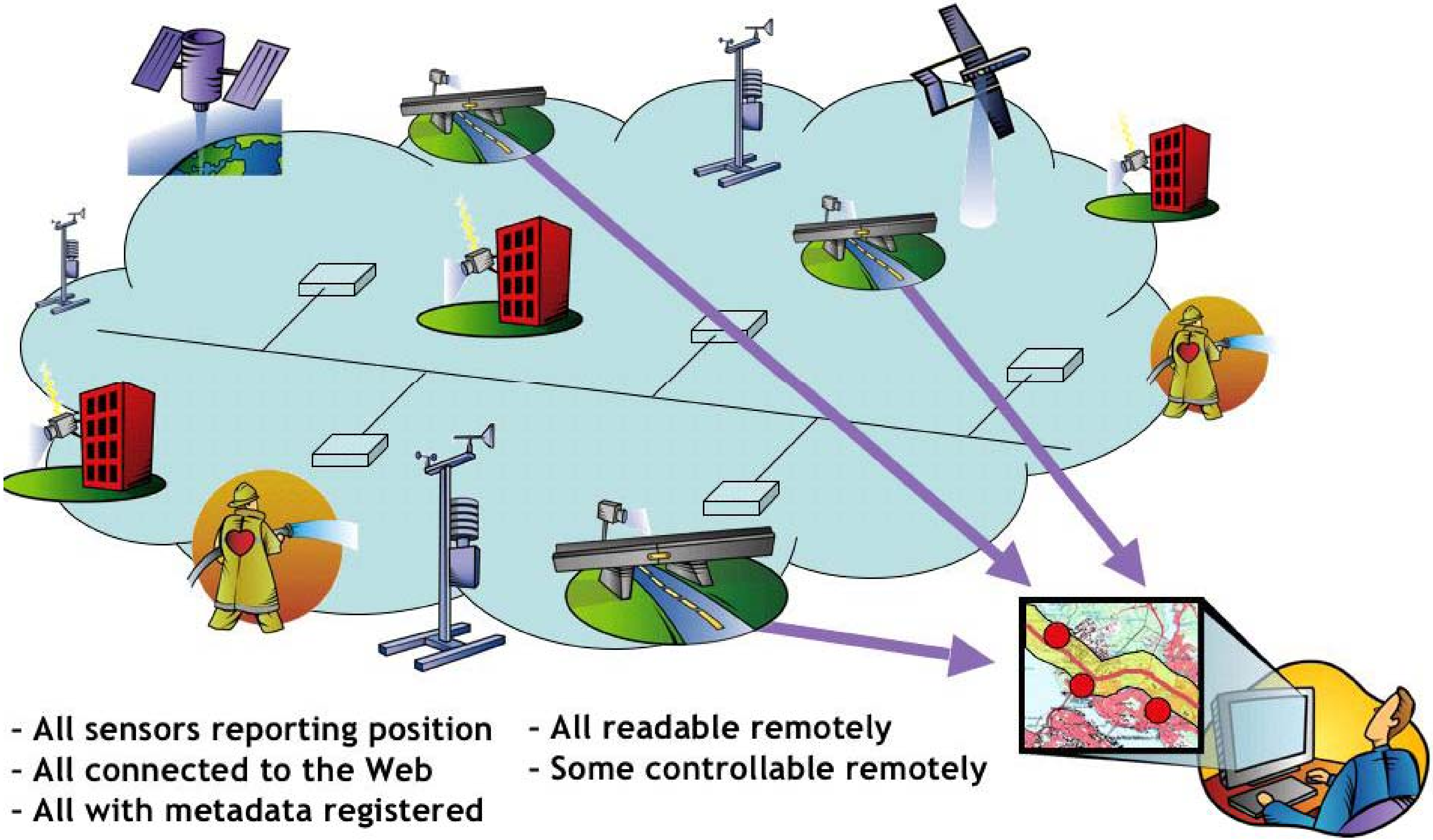
- **Network of small-footprint computers**
- **Optimised for long-life on low power**
- **Equipped to sense physical data**
- **Networked using low-power radio**

- Function:
  - Sense any measurable physical parameter
    - Light, motion, chemicals, proximity, biometrics
  - 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 Web

- The term Sensor Web is used by the Open Geospatial Consortium (OGC) and has the following characteristics:
  - a system that is comprised of diverse, location aware sensing devices that report data through the Web.
  - entire networks can be seen as single interconnected nodes that communicate via the Internet and can be controlled and accessed through a web interface.
  - focuses on the sharing of information among nodes, their proper interpretation and their cooperation as a whole, in order to sense and respond to changes of their environment and extract knowledge.



- All sensors reporting position
- All connected to the Web
- All with metadata registered
- All readable remotely
- Some controllable remotely

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

Advantages

- Implementing IP requires tackling the general case, not just a specific operational slice
  - Interoperability with all other potential IP network links
  - Potential to name and route to any IP-enabled device within security domain
  - Robust operation despite external factors
    - Coexistence, interference, errant devices, ...
- While meeting the critical embedded wireless requirements
  - High reliability and adaptability
  - Long lifetime on limited energy
  - Manageability of many devices
  - Within highly constrained resources

Sensor Network Constraints

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
- Interoperability among different sensor networks and seamless integration with existing IP networks is difficult
- So far many are not even IP-enabled, but are changing
- Several recent protocols and systems have been developed for them

Sensor Network Constraints

- Contrary, the Internet Protocol (IP) has been designed for networks without these constraints in mind and, hence, traditionally other layer 3 mechanisms have been developed and adapted to wireless sensor networks
  - Big packet size – power consumption

- More Sensor Implementations are based on 802.15.4

- An IP-enabled sensor network requires
  - the implementation of an IP stack in the sensor nodes and
  - appropriate interworking between IP layer and link layer.

Moving to IPv6

- **The adoption of IP as the Layer-3 protocol to connect wireless sensors has been slow down by the common belief that IP is too large to fit on a memory constrained device.**
  - There have been recent attempts to integrate Internet services with the WSN through studies concerning the integration of the IEEE 802.15.4 protocol and the Internet protocol (IP).
  - Yet, a real Internet of Things requires the large address space of IPv6.
  - This extended address space together with its auto-configuration capabilities makes IPv6 a suitable protocol for large scale sensor network deployments.

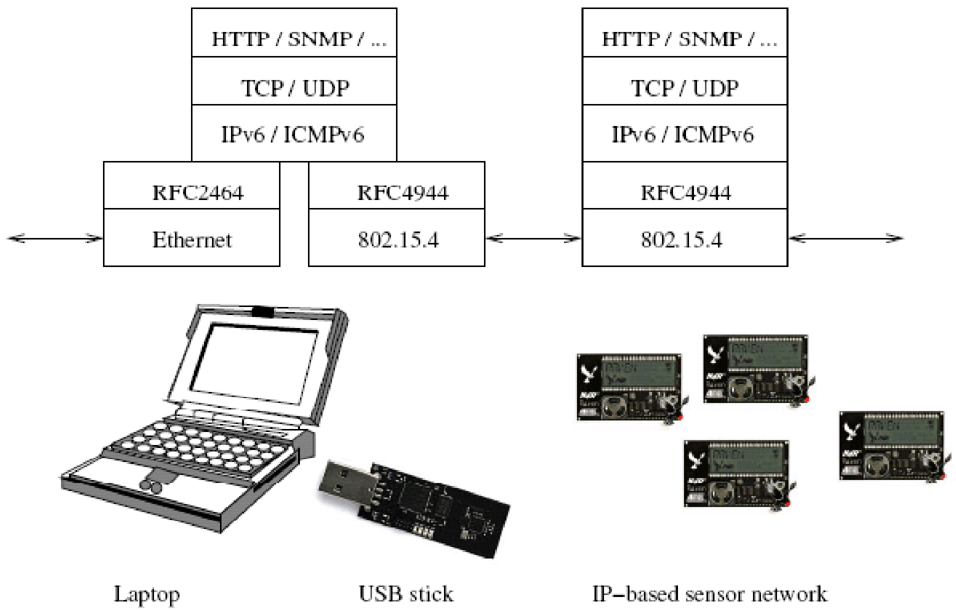
Moving to IPv6

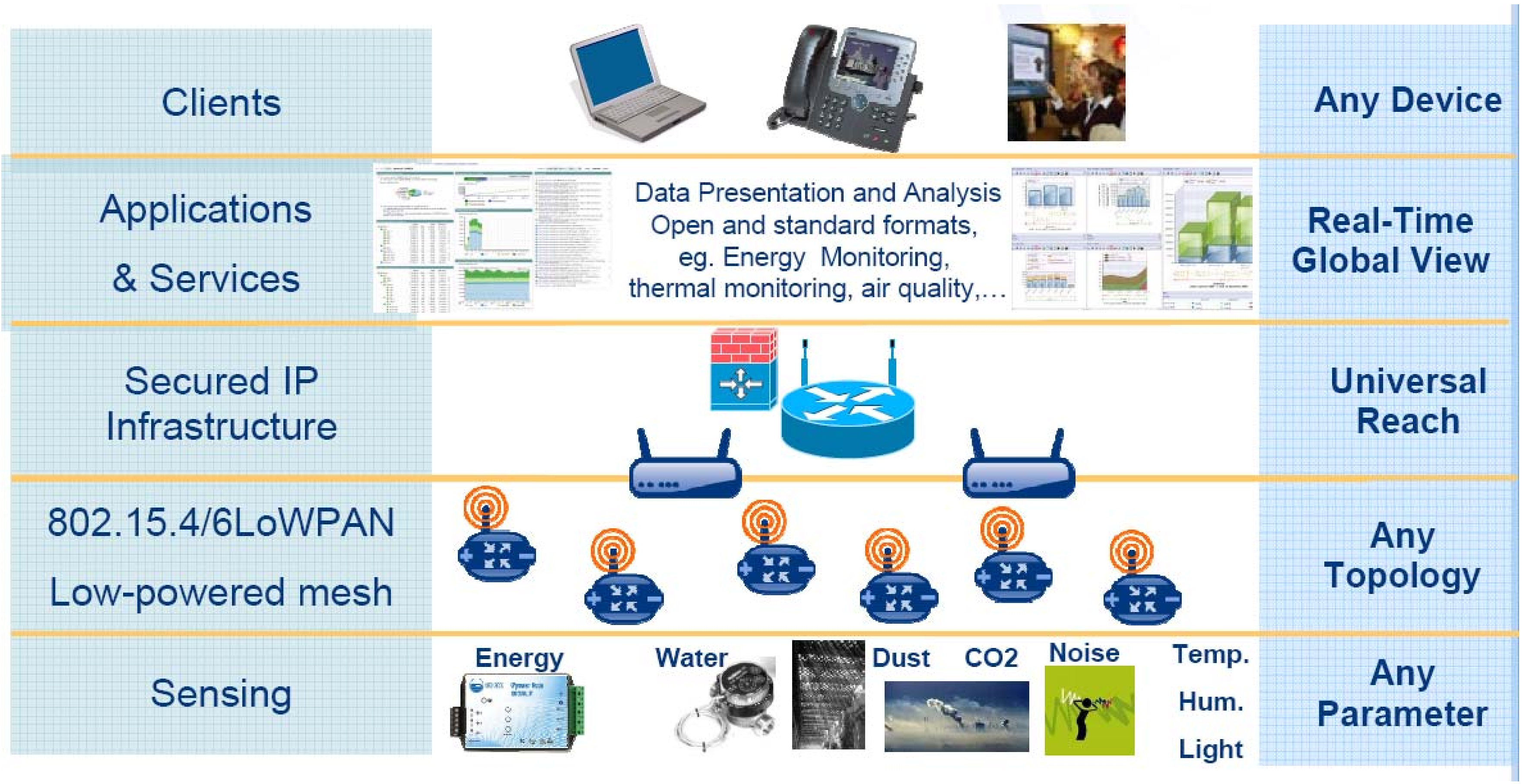
- IP-based protocols such as TCP/IP usually require heavy resources to be allocated to a sensor node.
- There have been studies conducted to resolve the problems that occur when operating IP-based stacks in sensor nodes with limited system resources, and the 6LoWPAN working group (WG) has worked on IPv6 over IEEE 802.15.4.
  - It has reduced the header overhead of IPv6, thereby reducing its power consumption.
  - involves placing an adaptation layer between the MAC and network layers to handle interoperation between these layers and to reduce resources.

IPv6 over IEEE 802.15.4

IPv6 Deployment and Support

- Each sensor
  - uses IPv6 over IEEE 802.15.4
  - has IP reachability, can be managed, can send/receive data from a far remote network.




Clients
Any Device
Applications
& Services
Data Presentation and Analysis
Open and standard formats,
eg. Energy Monitoring,
thermal monitoring, air quality,…
Real-Time
Global View
Secured IP
Infrastructure
Universal
Reach
802.15.4/6LoWPAN
Low-powered mesh
Any
Topology
Sensing
Energy
Water
Dust
CO2
Noise
Temp.
Hum.
Light
Any
Parameter

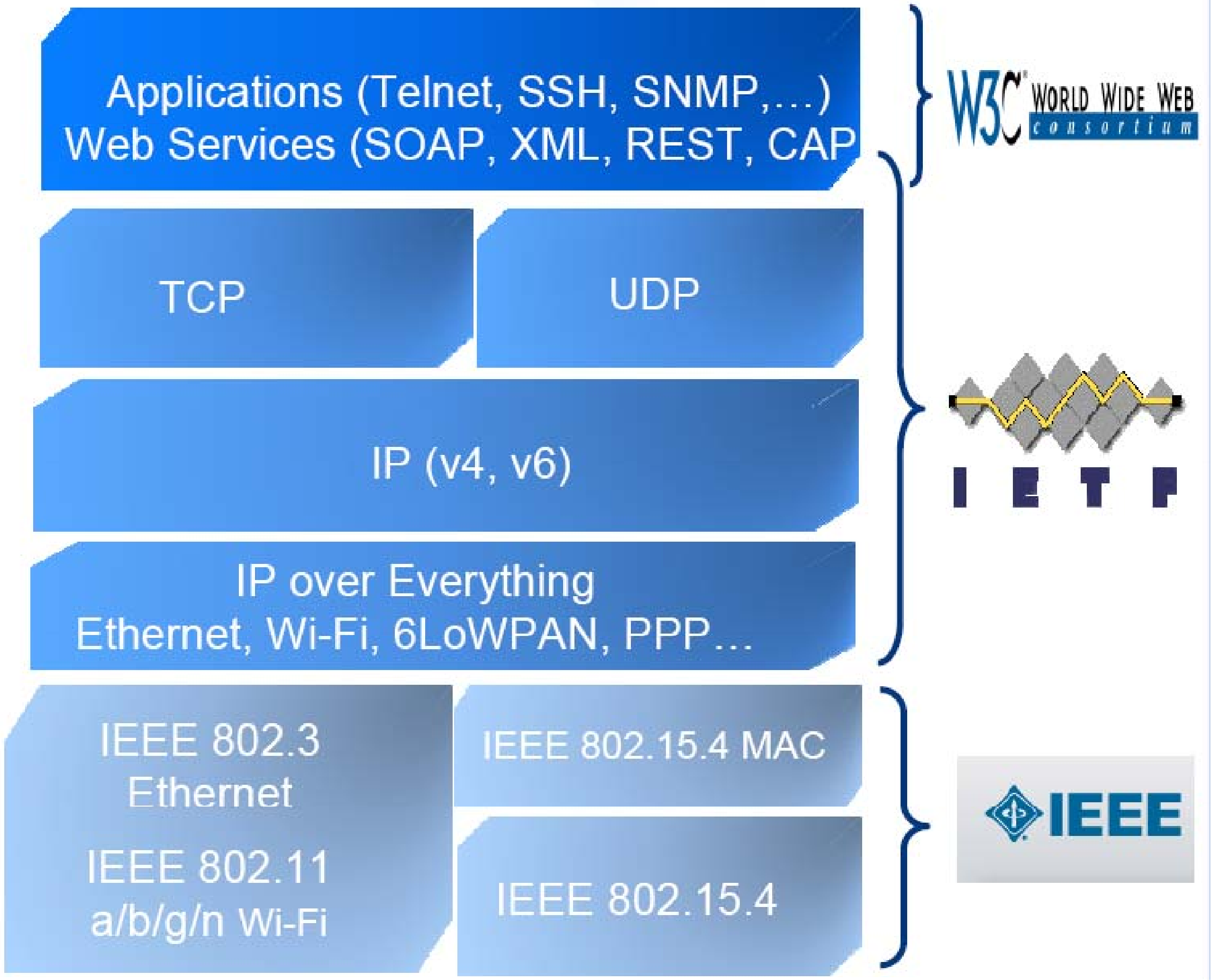
Agenda

IPv6 Deployment and Support

- Introduction
- The Generic Components
- <u>Standards and Technologies</u>
- Conclusion

Open Architecture

IPv6 Deployment and Support



IEEE 802.15.4

IPv6 Deployment and Support

- IEEE 802.15.4-2006 is a standard which specifies the physical layer and media access control for low-rate wireless personal area networks (LR-WPANs). It is maintained by the IEEE 802.15 working group.
- It is the basis for the ZigBee, WirelessHART, and MiWi specification, each of which further attempts to offer a complete networking solution by developing the upper layers which are not covered by the standard.
- Alternatively, it can be used with 6LoWPAN and standard Internet protocols to build a Wireless Embedded Internet.

IEEE 802.15.4

IPv6 Deployment and Support

- IEEE standard 802.15.4 intends to offer the fundamental lower network layers of a type of wireless personal area network (WPAN) which focuses on
  - low-cost,
  - low-speed ubiquitous communication between devices (in contrast with other, more end user-oriented approaches, such as Wi-Fi).
  - lower power consumption
  - large scale
- Important features include
  - real-time suitability by reservation of guaranteed time slots,
  - collision avoidance through CSMA/CA
  - integrated support for secure communications.
  - Devices also include power management functions such as link quality and energy detection.

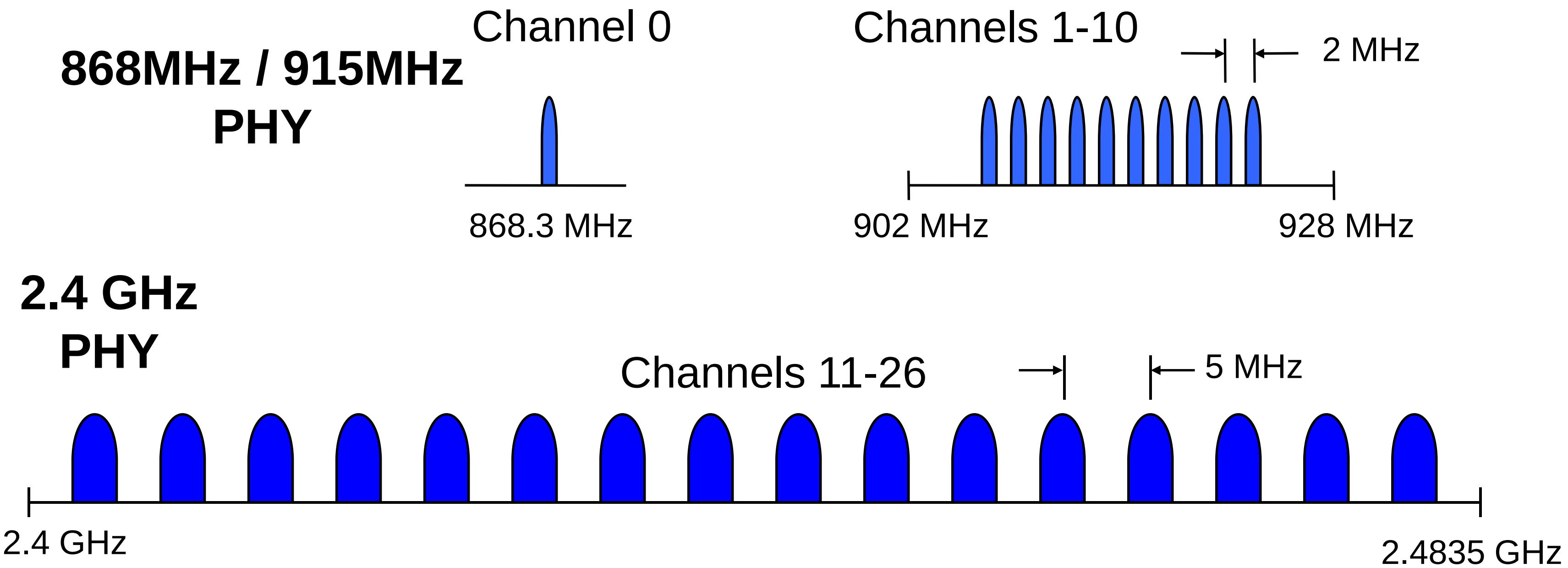
A Low-Power Standard Link

	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 Transmit power, Low 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

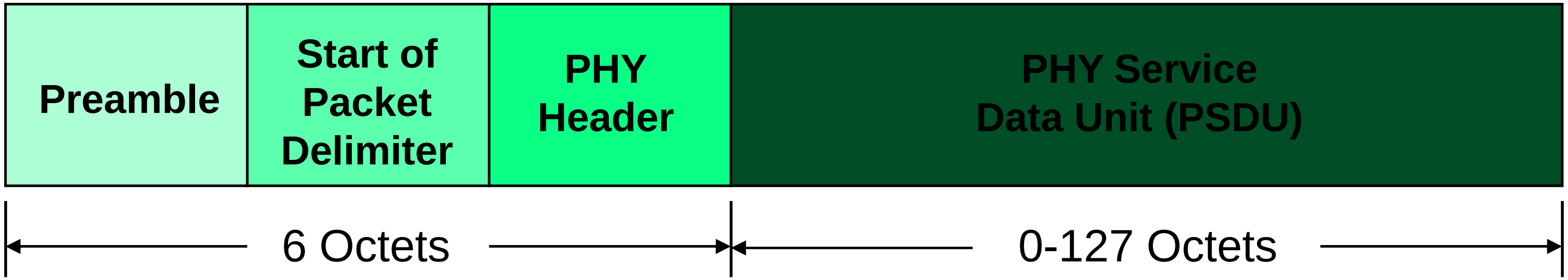
Transmit Power

- Capable of at least 1 mW

Receiver Sensitivity (Packet Error Rate <1%)

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

IEEE 802.15.4 Physical Layer



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

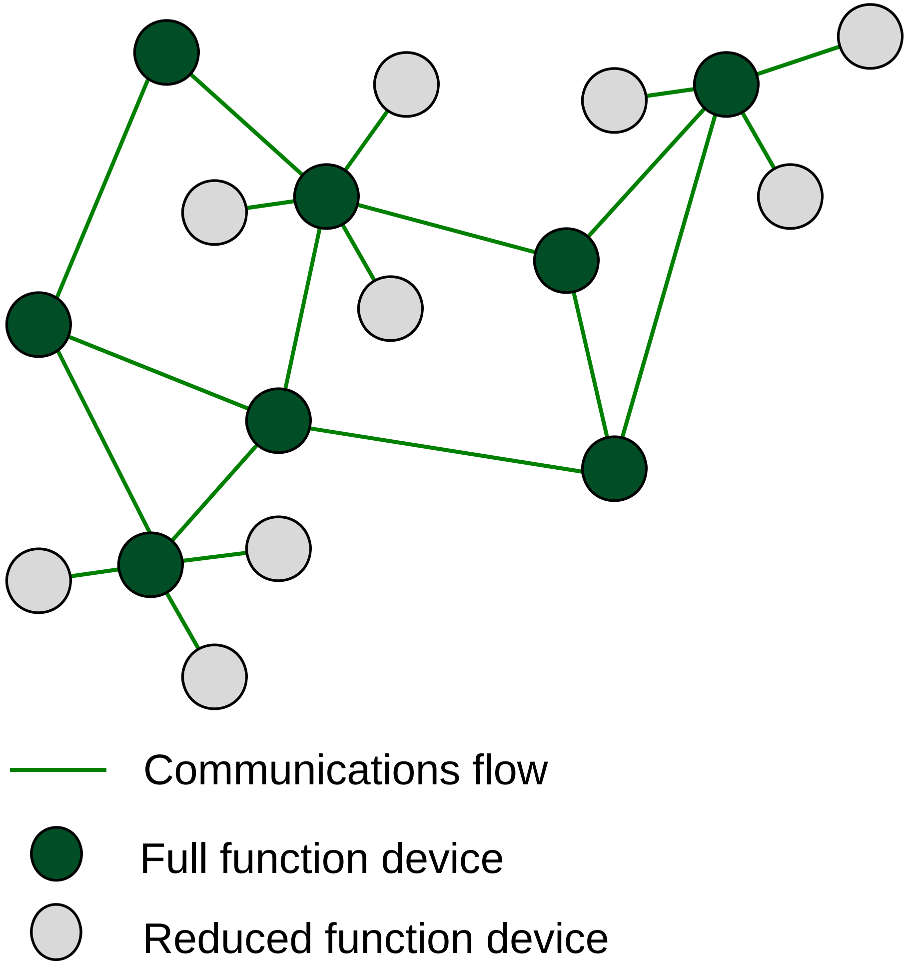
Frequency Bands

- 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 Overview

IPv6 Deployment and Support

- **Network Topologies**
  - Star, Peer-to-Peer, meshed
- **Full function device (FFD)**
  - Any topology
  - Network coordinator capable
  - Talks to any other device
  - ArchRock nodes are FFD
- **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 specifications are stable and well tested IETF Draft Standards**
  - **IPv6 Addressing Architecture, ICMPv6, Neighbor 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**
  - **http://www.ietf.org/html.charters/ipv6-charter.html**
- **IPv6 Transition, then now Operations focused Working Groups**
  - **NGTrans WG (closed), v6ops (active)**
- **Working Groups focusing on Wireless Sensor Networks**
  - **6LoWPAN - IPv6 over Low power Wireless Personal Area Networks http://www.ietf.org/html.charters/6lowpan-charter.html**
  - **RoLL - Routing Over Low power and Lossy networks http://www.ietf.org/html.charters/roll-charter.html**

6LoWPAN

IPv6 Deployment and Support

- 6lowpan is an acronym of IPv6 over Low power Wireless Personal Area Networks. 6lowpan is the name of the working group in the internet area of IETF.
- The 6lowpan group aimed at defining header compression mechanisms that allow IPv6 packets to be sent to and received from over IEEE 802.15-based networks.
- IPv4 and IPv6 are the work horses for data delivery for local-area networks, metropolitan area networks, and wide-area networks such as the Internet.
- Likewise, IEEE 802.15.4 devices provide sensing communication-ability in the wireless domain. The inherent natures of the two networks though, is different.

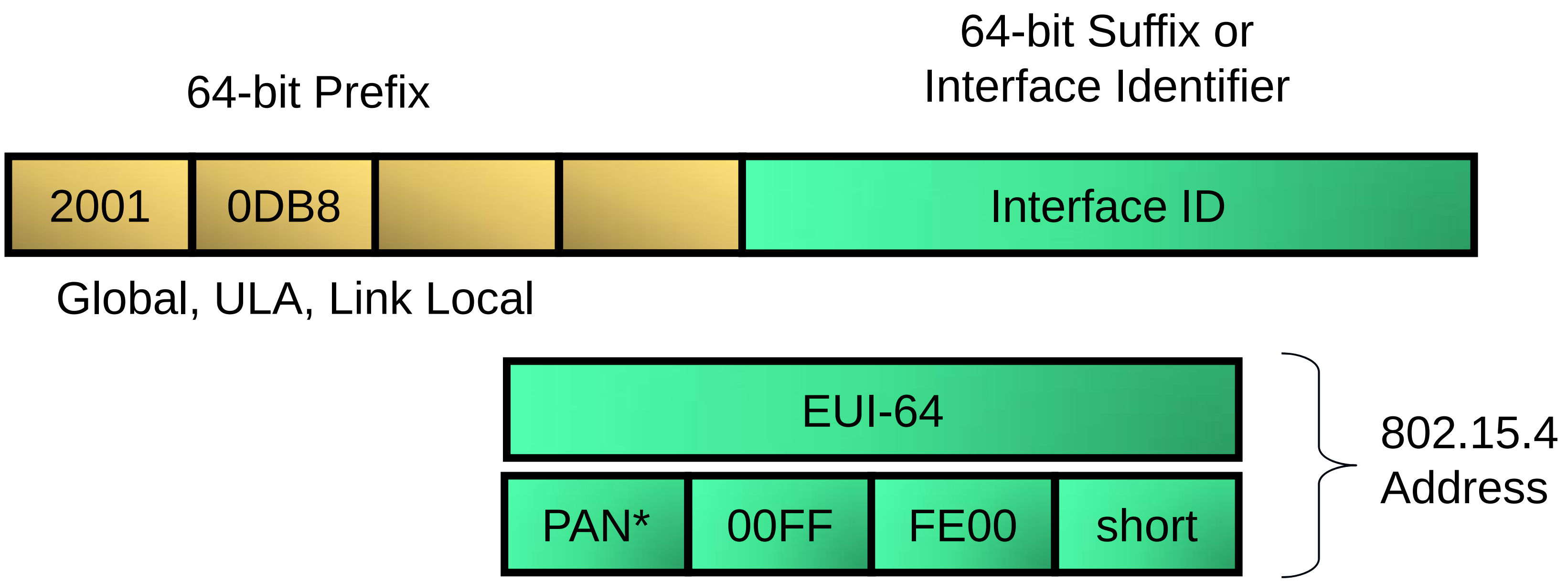
6LoWPAN – IPv6 Adaptation

IPv6 Deployment and Support

- Adapting the packet sizes of the two networks
  - IPv6 requires the maximum transmission unit (MTU) to be at least 1280 Bytes. In contrast, IEEE802.15.4's standard packet size is 127 octets.
  - An adaptation mechanism to allow interoperability between IPv6 domain and the IEEE 802.15.4 can best be viewed as a layer problem. Identifying the functionality of this layer and defining newer packet formats, if needed, is an enticing research area.
  - **RFC 4944** proposes an adaptation layer to allow the transmission of IPv6 datagrams over IEEE 802.15.4 networks.
- IPv6 nodes are assigned 128 bit IP addresses in a hierarchical manner, through an arbitrary length network prefix.
- IEEE 802.15.4 devices may use either of IEEE 64 bit extended addresses or (after an association event), or 16 bit addresses that are unique within a PAN.
- Small Packets to keep packet error rate low and permit media sharing

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

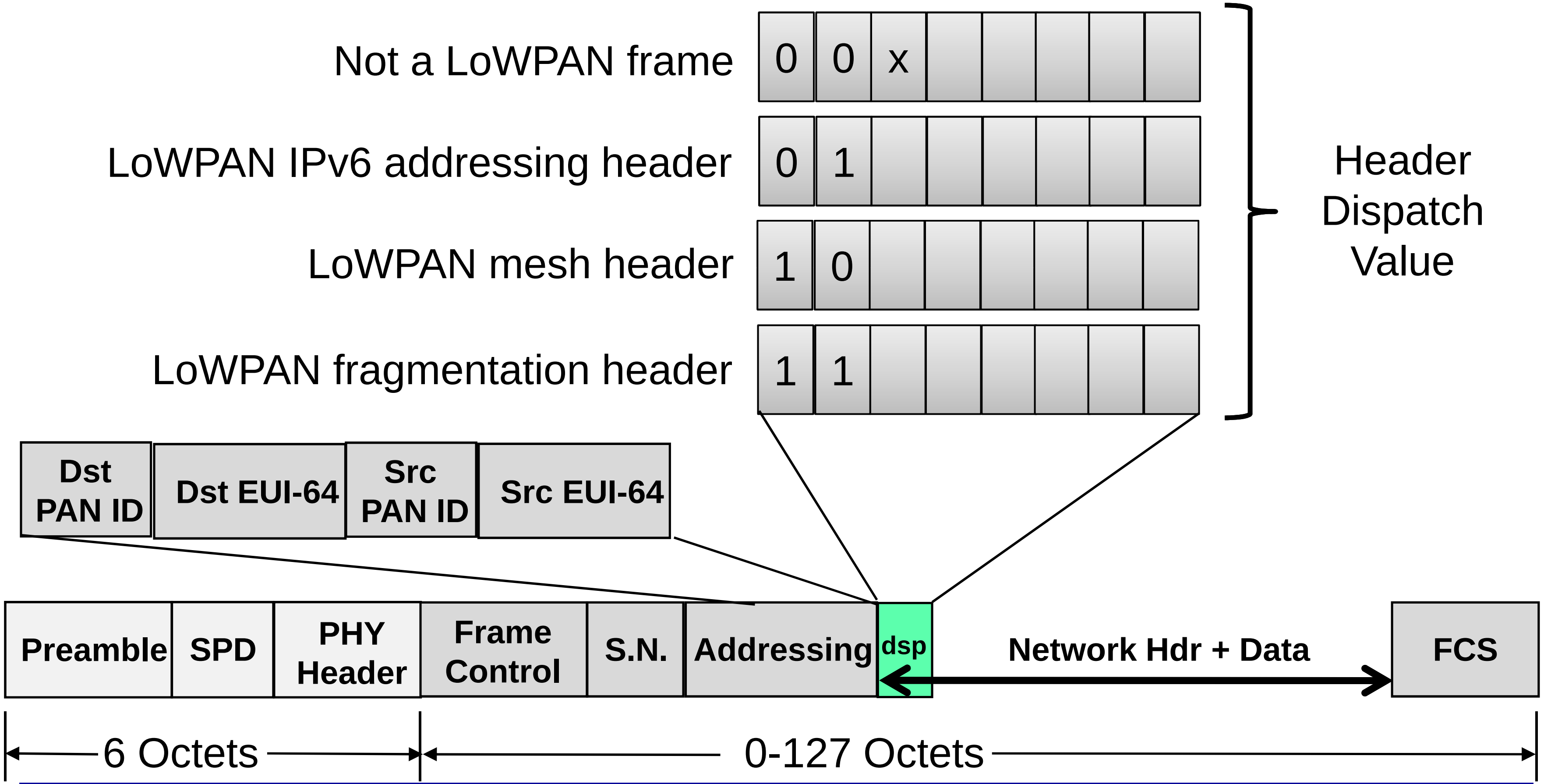
Allow IP routing over a mesh of 802.15.4 nodes

Localized internet of overlapping subnets

6LoWPAN – The First Byte

IPv6 Deployment and Support

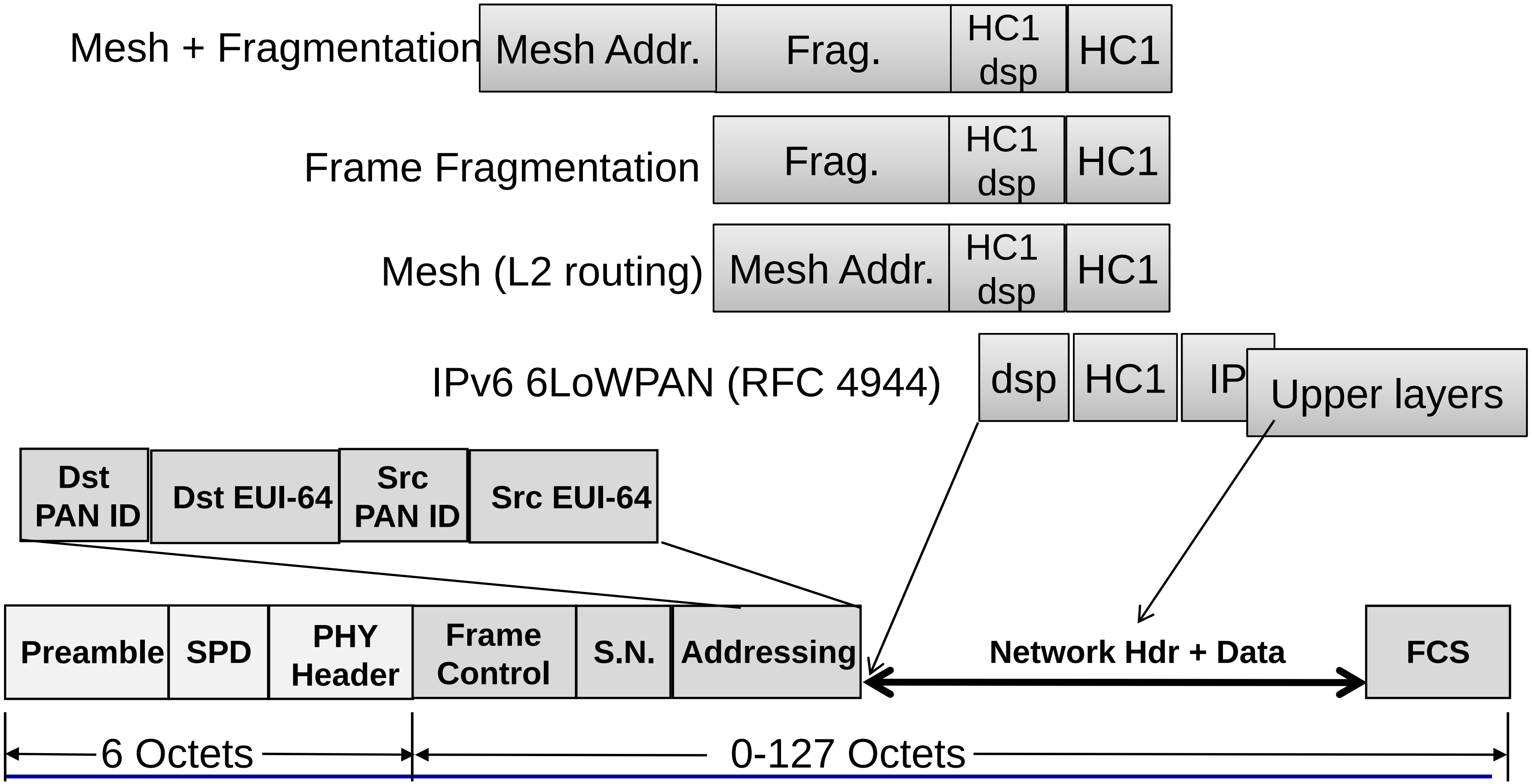
- **Coexistence with other network protocols over same link**
- **Header dispatch (dsp) - understand what's coming**



6LoWPAN – Adaptation Layer

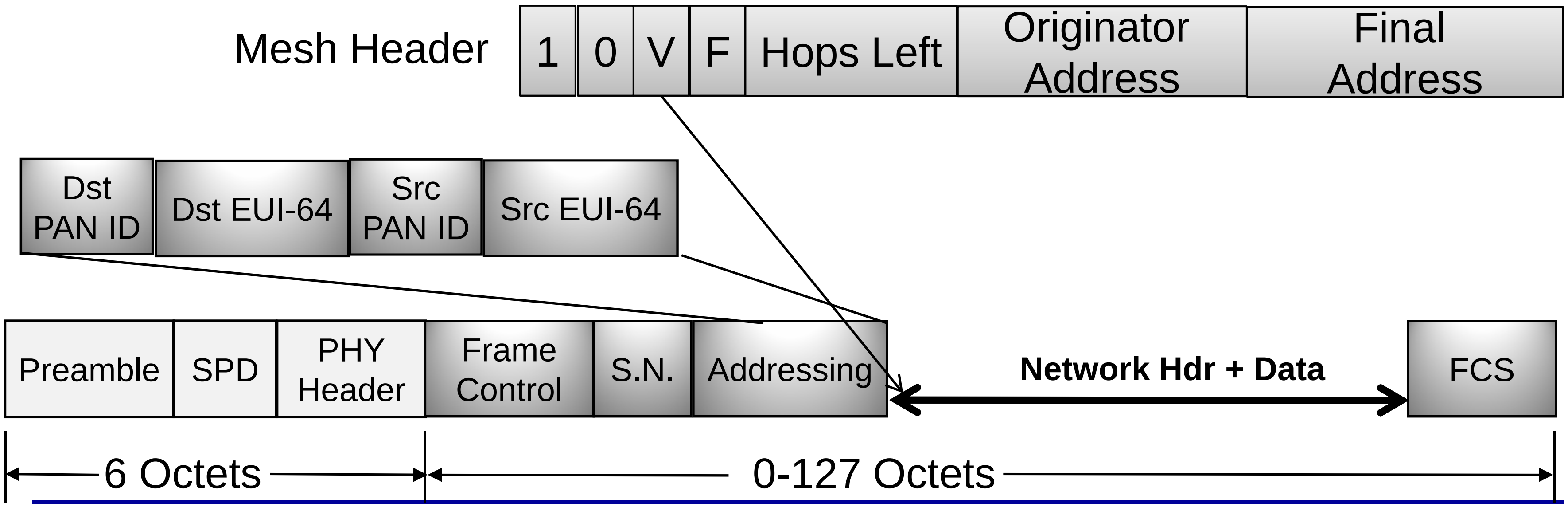
IPv6 Deployment and Support

- 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 – "Mesh Under"

- 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 vs Zigbee

IPv6 Deployment and Support

- Zigbee
  - communication between 15.4 nodes (“layer 2” in IP terms), not the rest of the network (other links, other nodes).
  - Defines new upper layers, all the way to the application, similar to IRDA, USB, and Bluetooth, rather utilizing existing standards.
  - Specification in progress (Zigbee 2006 incompatible with Zigbee 1.0, Zigbee Pro just finalized)
  - Code size for full featured stack is 90KB vs. 30KB for 6LoWPAN
- 6LoWPAN
  - defines how established IP networking layers utilize the 15.4 link.
  - It enables 15.4 to15.4 and 15.4 to non-15.4 communication
  - It enables the use of a broad body of existing standards as well as higher level protocols, software, and tools.
  - It is a focused extension to the suite of IP technologies that enables the use of a new class of devices in a familiar manner.

RoLL - Routing Over Low power and Lossy networks

- Low power and Lossy networks (LLNs) are made up of many embedded devices with limited power, memory, and processing resources.
- They are interconnected by a variety of links, such as IEEE 802.15.4, Bluetooth, Low Power WiFi, wired or other low power PLC (Powerline Communication) links.
- LLNs are transitioning to an end-to-end IP-based solution to avoid the problem of non-interoperable networks interconnected by protocol translation gateways and proxies.

RoLL - Routing Over Low power and Lossy networks

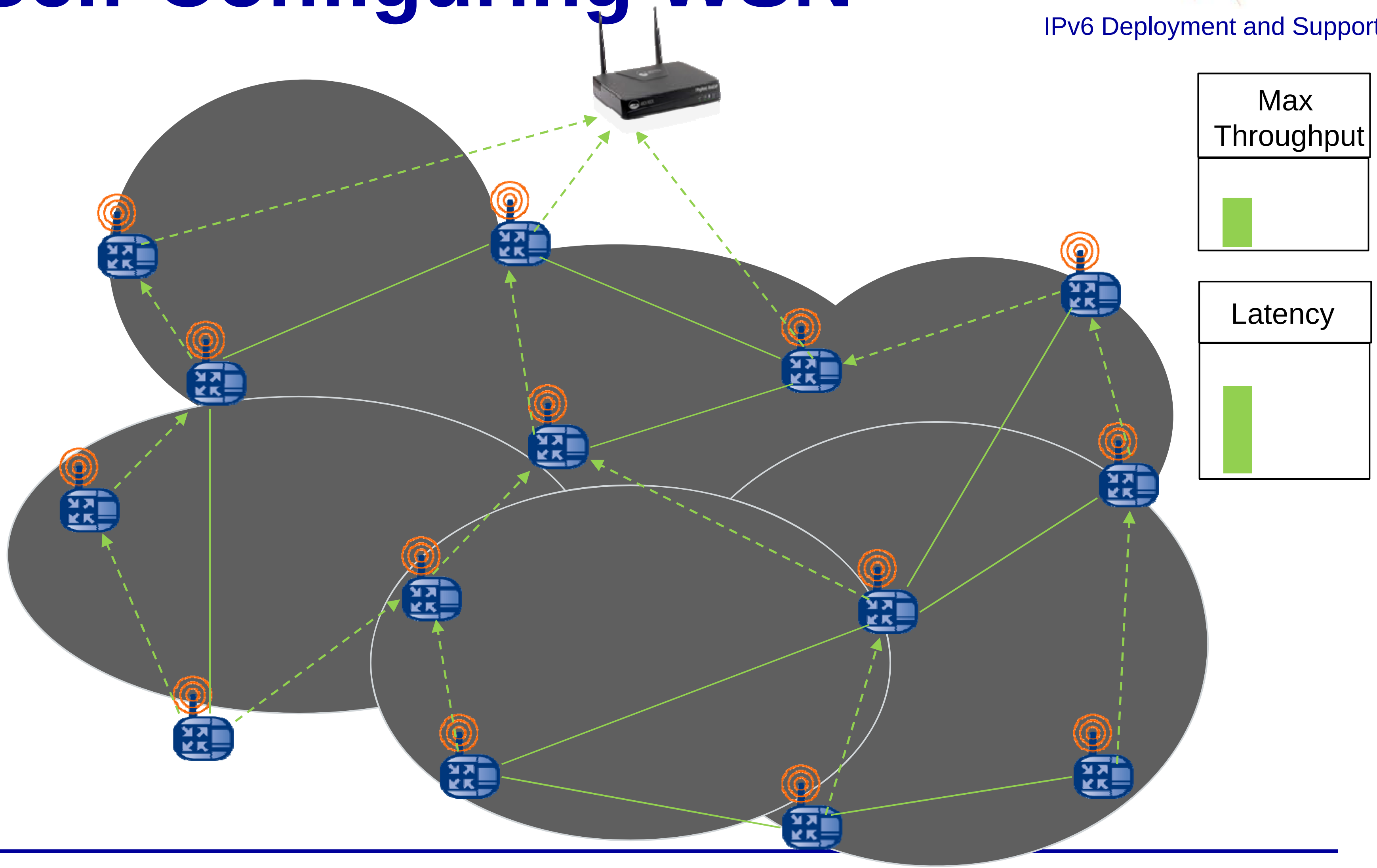
- Distinguishing characteristics:
  - LLNs operate with a hard, very small bound on state.
  - In most cases, LLN optimize for saving energy.
  - Typical traffic patterns are not simply unicast flows (e.g. in some cases most if not all traffic can be point to multipoint).
  - In most cases, LLNs will be employed over link layers with restricted frame-sizes, thus a routing protocol for LLNs should be specifically adapted for such link layers.
  - LLN routing protocols have to be very careful when trading off efficiency for generality; many LLN nodes do not have resources to waste.
- These specific properties cause LLNs to have specific routing requirements.

RoLL - Routing Over Low power and Lossy networks

- Existing routing protocols such as OSPF, IS-IS, AODV, and OLSR have been found to not satisfy all of these specific routing requirements.
- The Working Group focuses only on IPv6 routing
- Various aspects are taken into consideration including:
  - high reliability in the presence of time
  - varying loss characteristics and
  - connectivity while permitting low-power operation

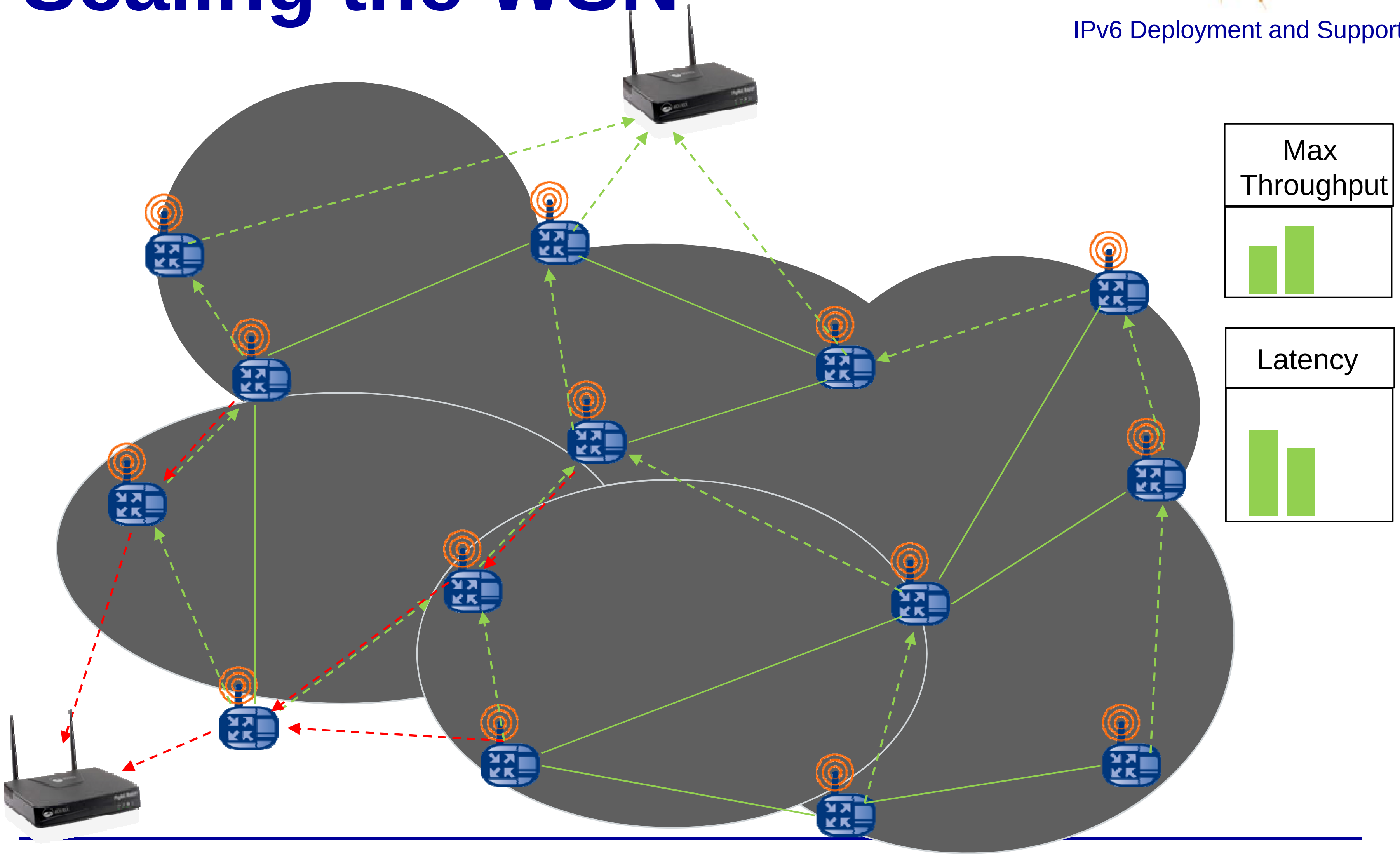
Self-Configuring WSN

IPv6 Deployment and Support



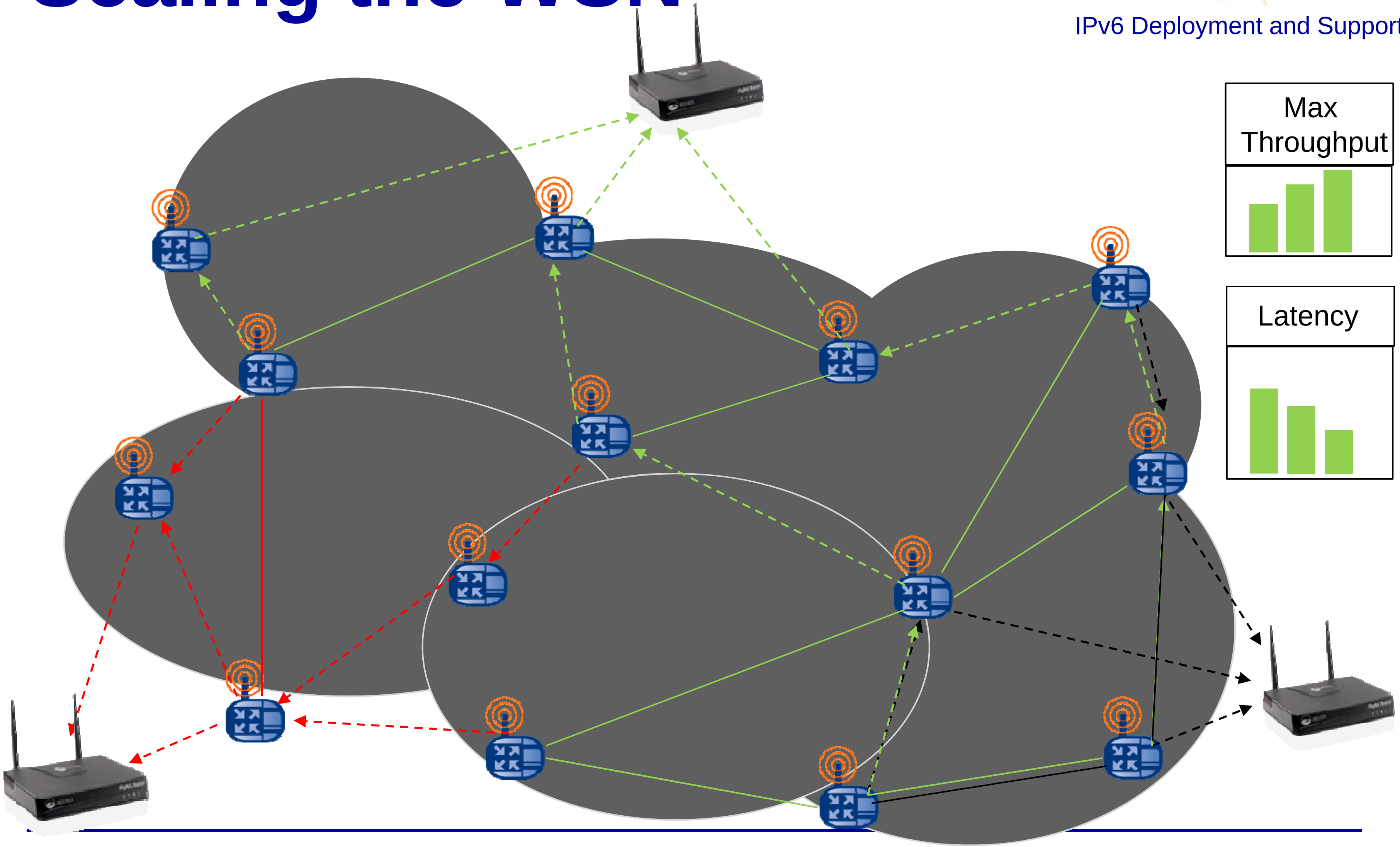
Scaling the WSN

IPv6 Deployment and Support



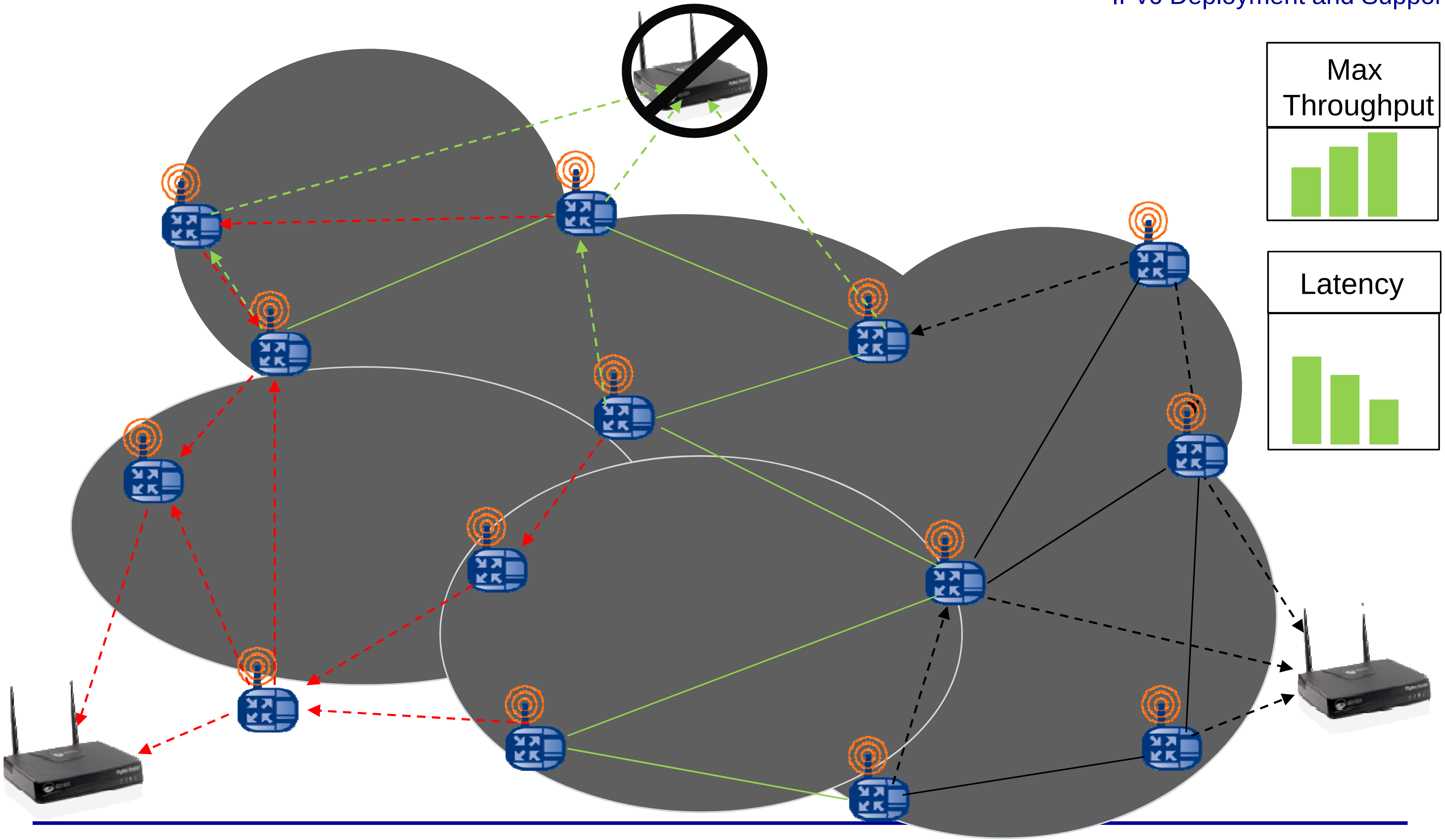
Scaling the WSN

IPv6 Deployment and Support



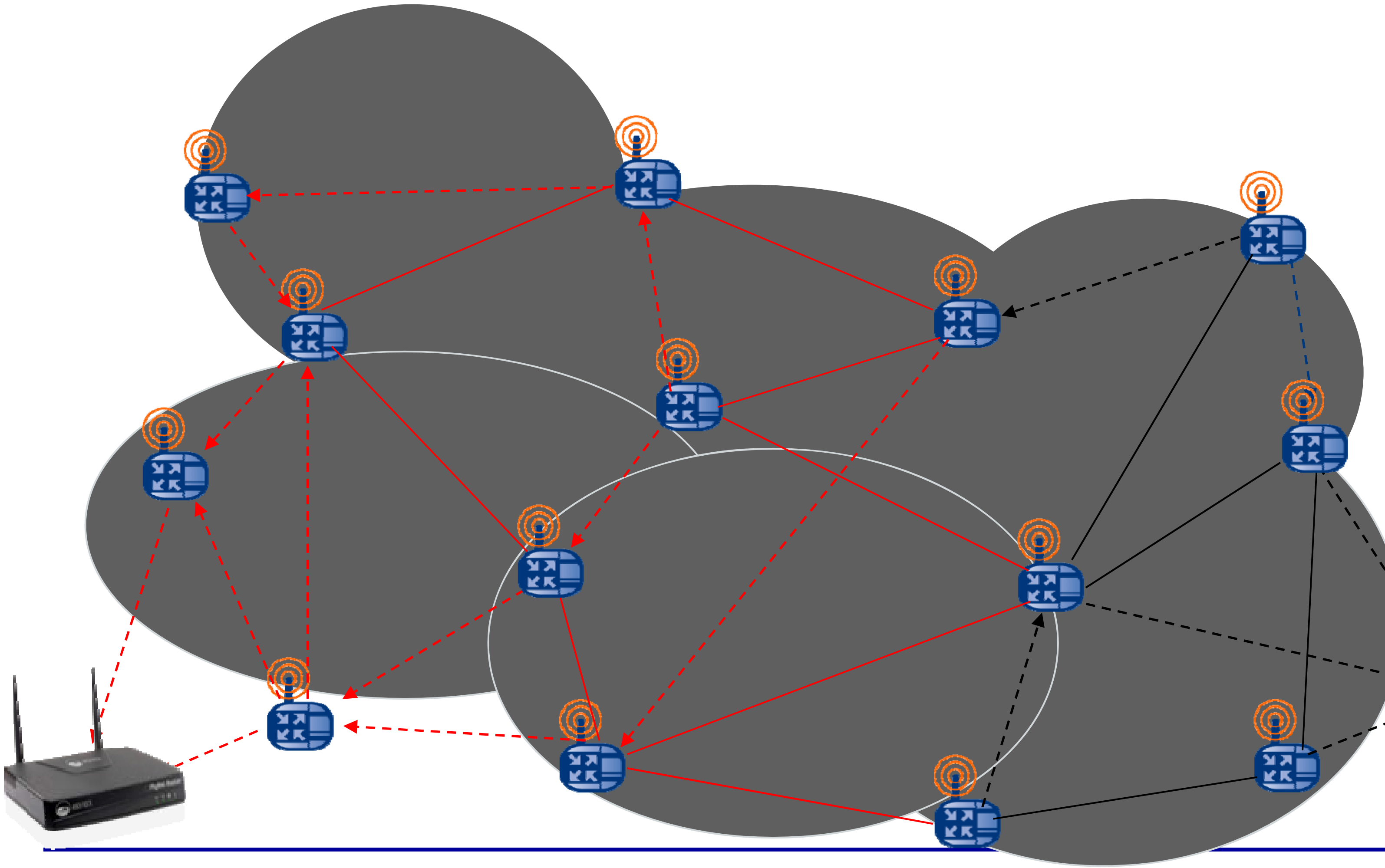
Resiliency of the WSN

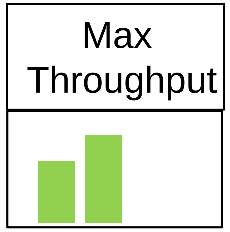
IPv6 Deployment and Support

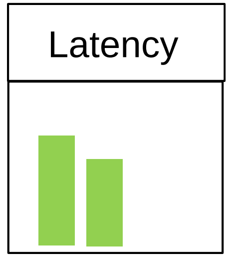


Resiliency of the WSN

IPv6 Deployment and Support







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

TinyOS

- TinyOS is an open-source operating system designed for wireless embedded sensor networks.
- It features a component-based architecture which enables rapid innovation and implementation while minimizing code size.
- TinyOS's component library includes network protocols, distributed services, sensor drivers, and data acquisition tools.
- TinyOS's event-driven execution model
  - enables fine-grained power management
  - allows the scheduling flexibility made necessary by the unpredictable nature of wireless communication and physical world interfaces.
- TinyOS has been ported to over a dozen platforms and numerous sensor boards

TinyOS

- A 6lowpan/IPv6 stack has been implemented for the TinyOS 2.0 operating system.
- It is possible to exchange IPv6 packets between the motes and a PC without an 802.15.4 interface. In case IP forwarding is set up on the PC and a properly assigned and routable global IPv6 prefix is used, the motes can be connected to the global Internet.
- The main limitation to interoperability with other 6lowpan implementations is the absence of a proper 802.15.4 stack in TinyOS 2.0. Although the implementation supports the ICMP echo mechanism and the UDP protocol, many features required for IPv6 implementations are missing.
- Among others, the Neighbor Discovery has not been implemented and packets are broadcasted on the link-layer, IPv6 extensions headers are not processed, IPv6 fragmentation is not supported and ICMP error messages are not generated.

Contiki

- **Contiki** open source, highly portable, multi-tasking OS for networked memory-constrained networked embedded systems.
- A typical Contiki configuration is 2 KB of RAM and 40 KB of ROM.
- Contiki consists of an event-driven kernel on top of which application programs are dynamically loaded and unloaded at runtime.
- Contiki contains two communication stacks: uIP and Rime.
  - uIP - a small RFC-compliant TCP/IP stack that makes it possible for Contiki to communicate over the Internet.
  - Rime - a lightweight communication stack aimed at low-power radios.
- Contiki runs on a variety of platform ranging from embedded microcontrollers to old home computers. Code footprint is on the order of kilobytes and memory usage can be configured to be as low as tens of bytes.
- Contiki is written in the C programming language.

Agenda

IPv6 Deployment and Support

- **Introduction**
- **The Generic Components**
- **Standards and Technologies**
- **<u>Conclusion</u>**

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

Conclusions

IPv6 Deployment and Support

- 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