

IEEE Std. 802.15.4

Enabling Pervasive Wireless Sensor Networks

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Embedded Systems & Communications Group

Content

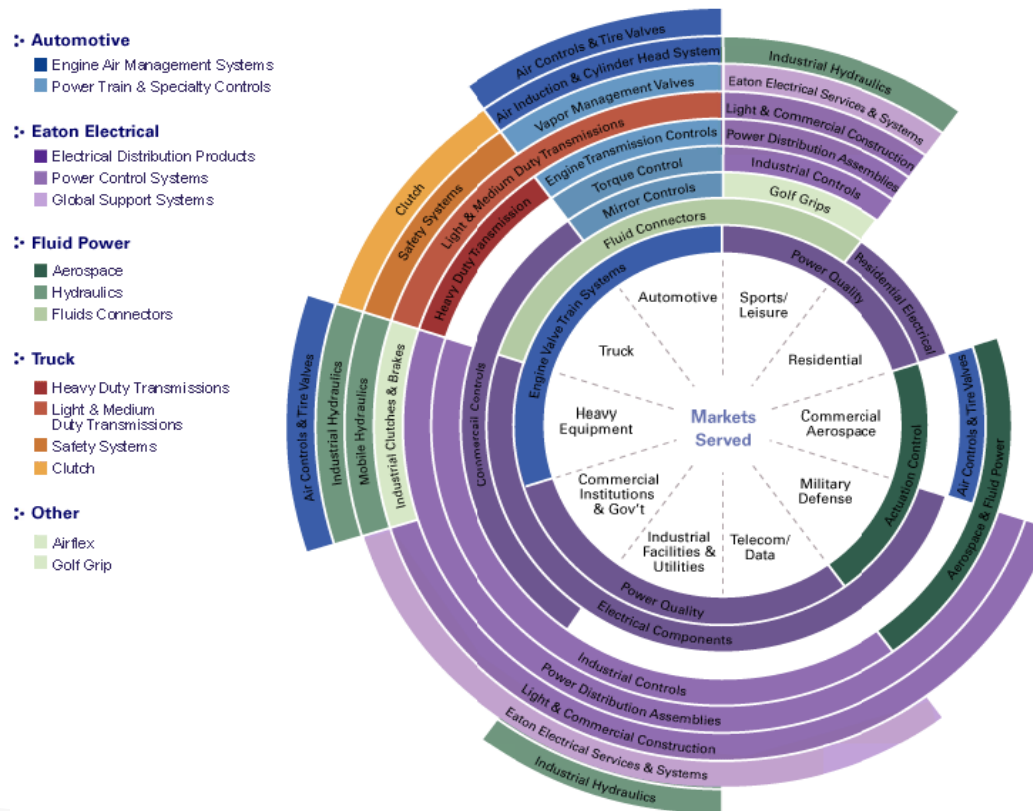
- Introduction: The Wireless Vision
- Existing Applications
- Technology Comparison
- A Brief Description of IEEE 802.15.4
- Current Challenges
- What's Beyond (and Above) IEEE 802.15.4?



Introduction

Overview

Premier Globally Diversified Industrial Manufacturer of Highly Engineered Products and Systems



Vision

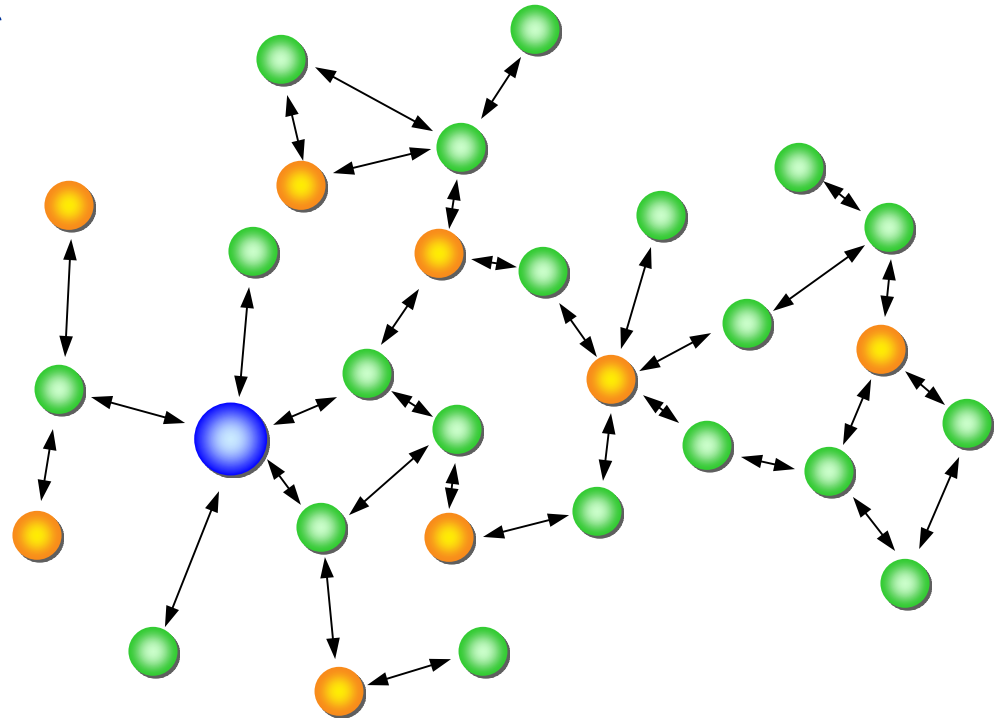
- Add value to current and future product offerings using wireless technologies to enable:
 - Increase Productivity
 - Improve Safety
 - Convenience
 - Enhance Reliability
 - Lower System Cost

Vision

Thousands of sensors in a small space → **Wireless**

But wireless implies **Low Power**

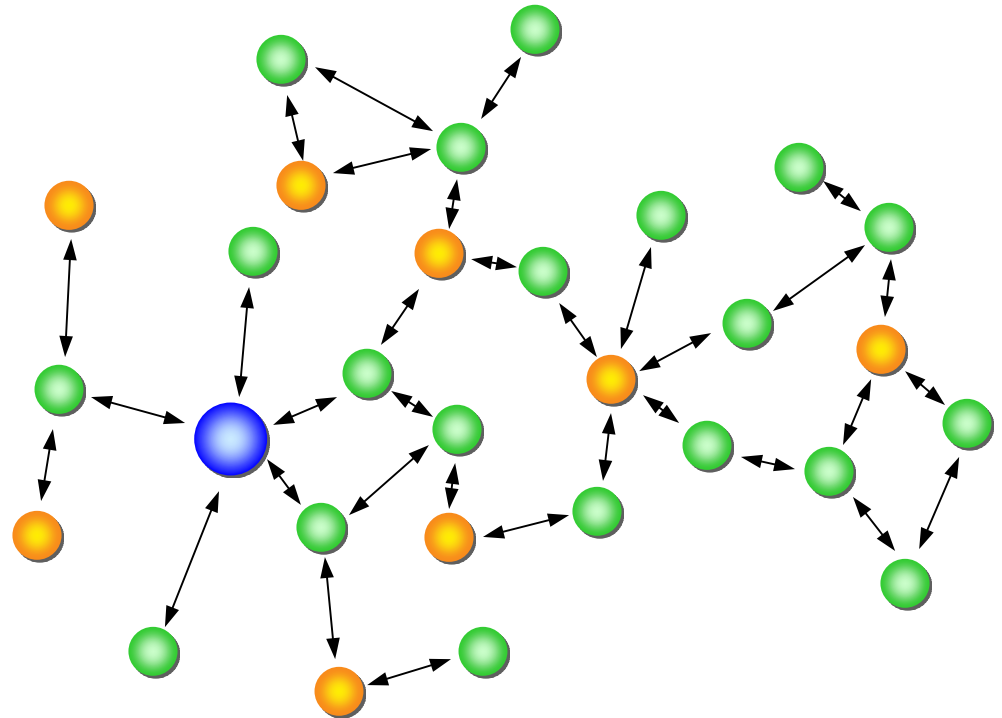
And low power implies **Limited Range**



Vision

Furthermore, it has to be
Self-Organizing

Of course all of this is
viable if a ***Low Cost***
technology can be used



Wireless

Wireless provides:

- No connectors
- Safe/flexible connectivity
- Improves resources sharing
- Ease of installation
- Mobility

Limit Switch Component



Limit Switch Installed



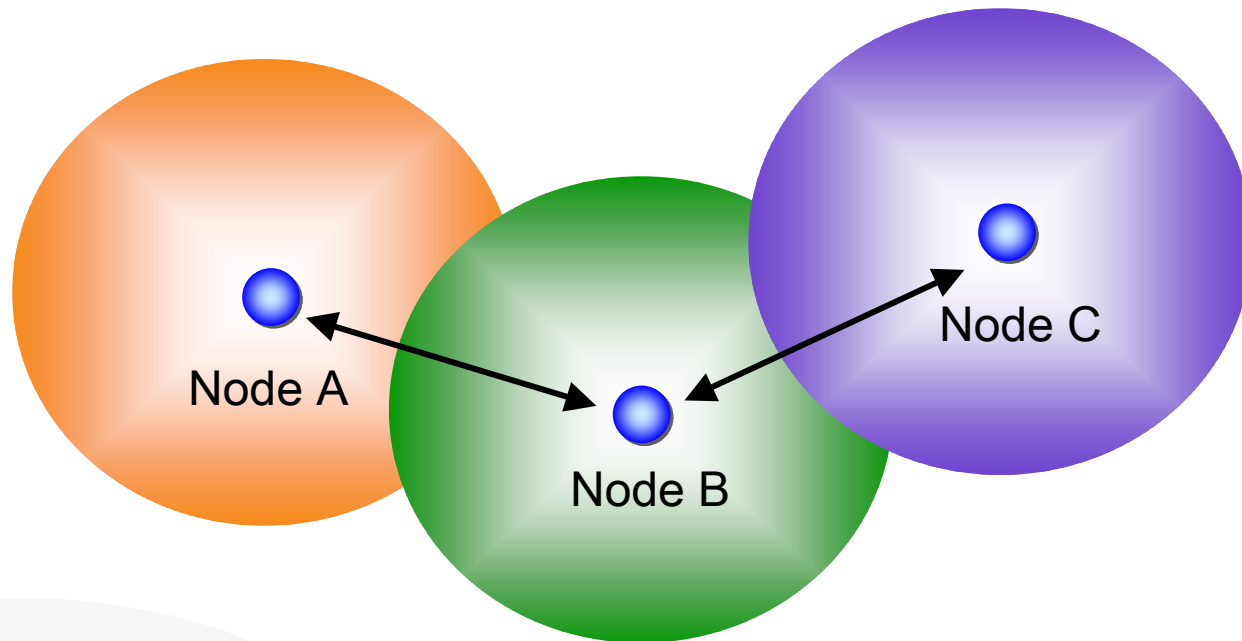
Low Power

- Fully untethered transponders does not have access to external power
 - Batteries or scavenging of surplus power!
- But if batteries are used, they should last a long time:
 - Automotive applications: 3 to 5 years (in USA)
 - Industrial applications: 5 to 10 years or more!

Limited Range

Since a node has limited transmit range, the transmission of a message beyond this range, requires that the node calls upon one or more of its neighbors in order to relay the message to its final destination.

This technique is commonly called *multi-hop* communication.



Self-Organization (Ad-Hoc)

- Fully automatic routing
 - Each node connects with its immediate neighbors
- Automatic topology adaptation
 - The network automatically adapts as its topology changes, i.e., as nodes arrive at or depart from the network environment

Entry-Level Challenges

- Frequency of operation
- Coexistence and jamming
- Interoperability
- Cost and availability
- Antenna design

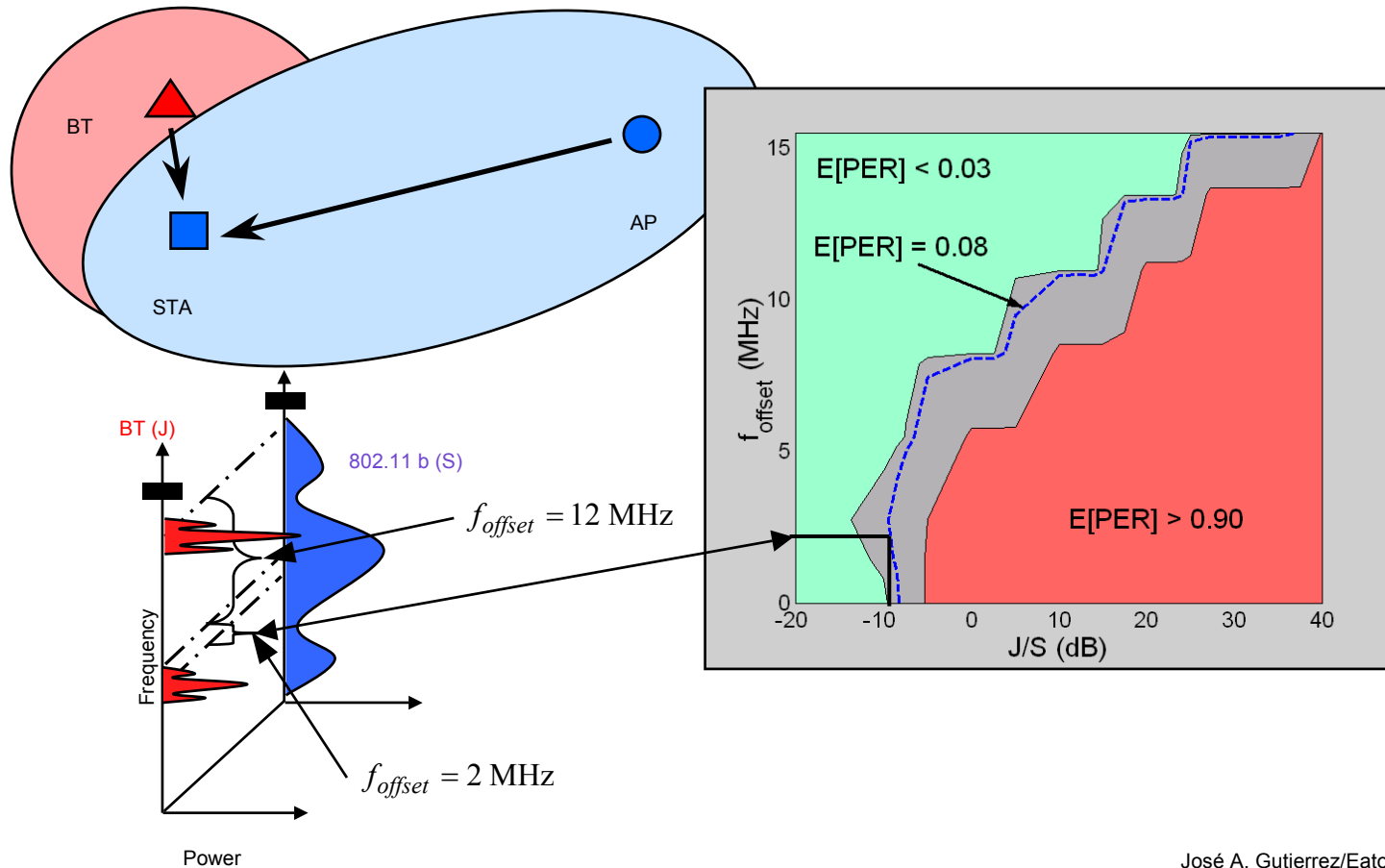


Coexistence and Jamming

- ISM bands can be used and are used by standard and non-standard technologies
- Microwaves ovens operate at 2.4GHz
- 802.11b and Bluetooth networks have major issues when colocated
- Spread Spectrum technologies help mitigate coexistence issues

How can I guarantee that my network will operate in every environment?

Coexistence and Jamming

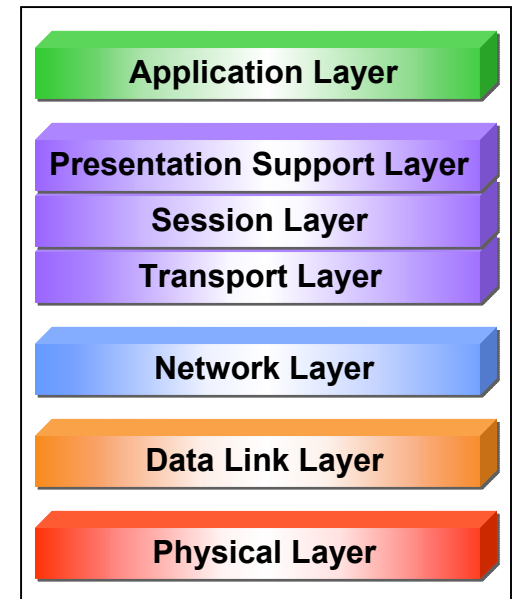


José A. Gutierrez/Eaton Corp.

Interoperability

- Standard technologies are designed to interoperate....
... but *different implementations may have slight differences*
- Non-standard technologies may behave as standards
- There are different levels of standardizations

Seven Layer ISO-OSI Protocol Layer



Cost and Availability

- Remember the \$5 Bluetooth module?
- What cost are we talking?
 - Transceiver
 - Chipset
 - Module
 - What about the external components needed?
 - and the antenna?
 - Is the stack included?

The technology will be available on Q4 200x

Antenna

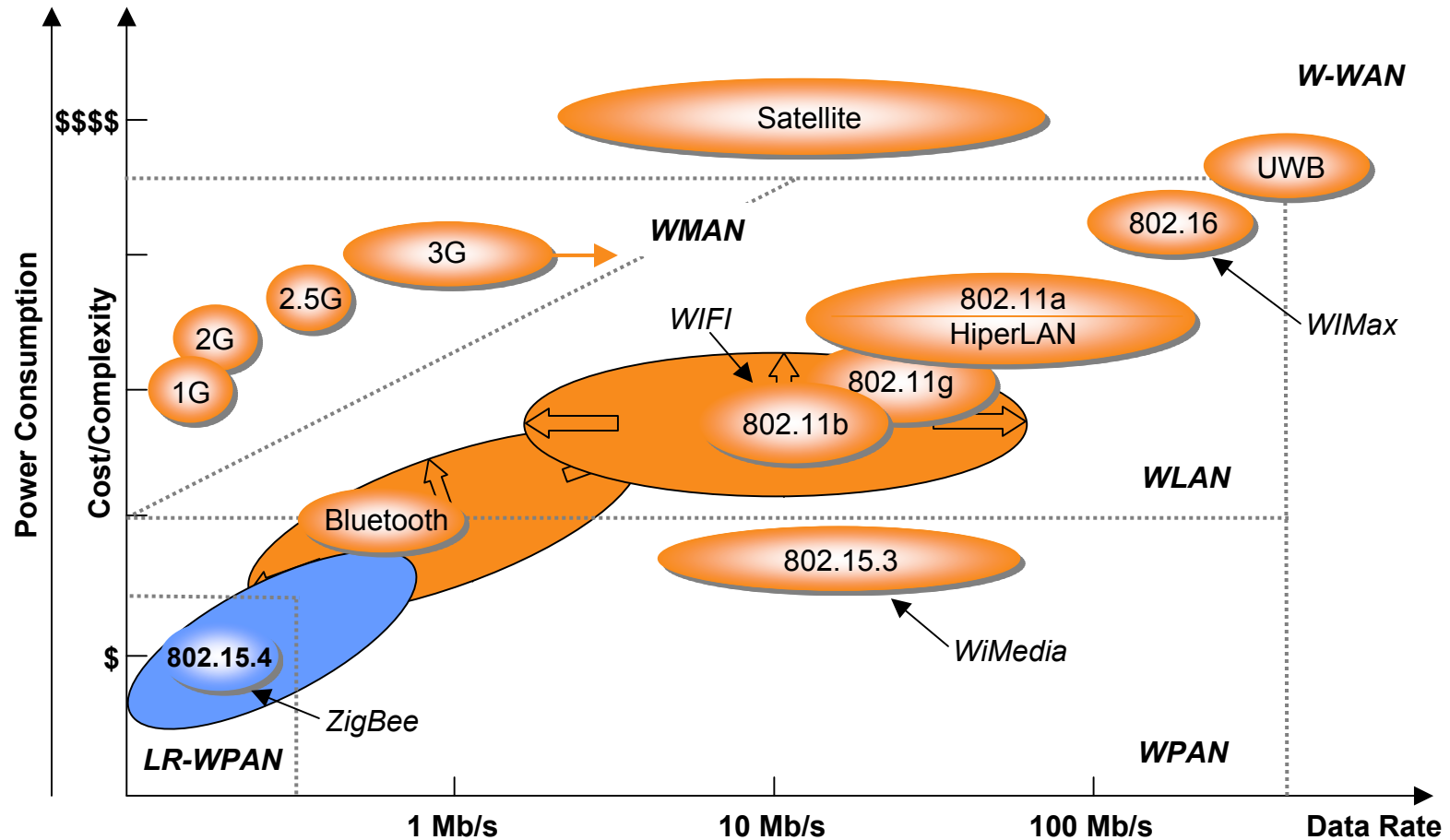
- The higher the frequency the smaller the antenna ...
... and the propagation range is worst!
- Antenna connectors are expensive
- Antenna design is considered “black magic”
- Antennas needs to be designed with the entire sensor package in mind
 - Is the antenna integrated to the sensor?
 - PCB antennas acts as attenuators
- Metal, metal, metal....



Which Technology is Good for our Needs?

Leading Wireless Technologies Comparison

Standards Technology Map 2005



Technology Applications

WLAN 802.11

Centralized Wireless Networking (WLAN) in the office environment

Embedded Sensors



Bluetooth/WPAN 802.15.1

Cable replacement for consumer devices in the personal operating space

*Video
WLAN*



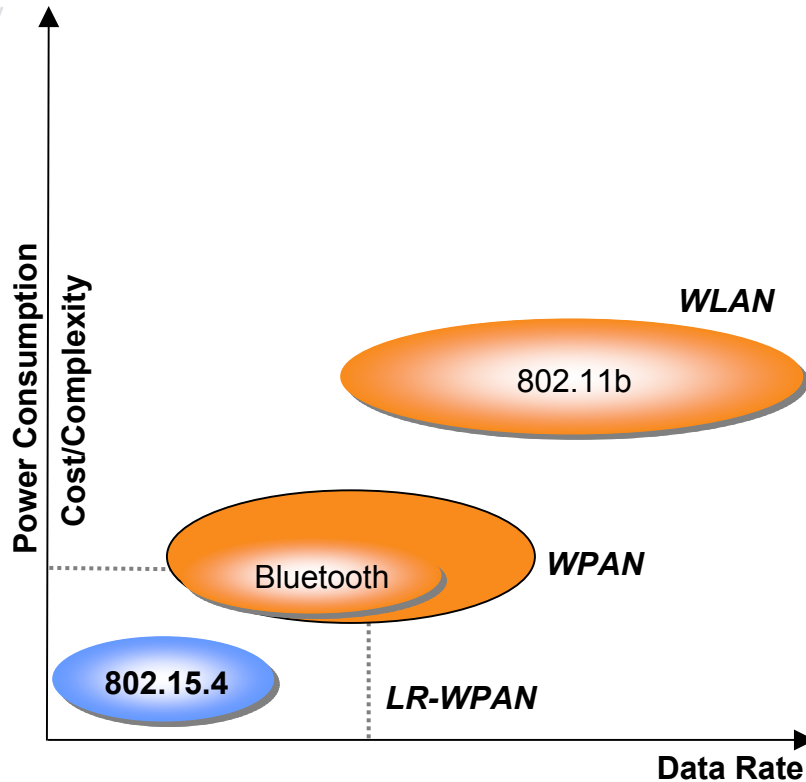
LR-WPAN 802.15.4

Low-cost wireless link for industrial/commercial sensor and actuator devices

*Voice/Video
Real-Time*



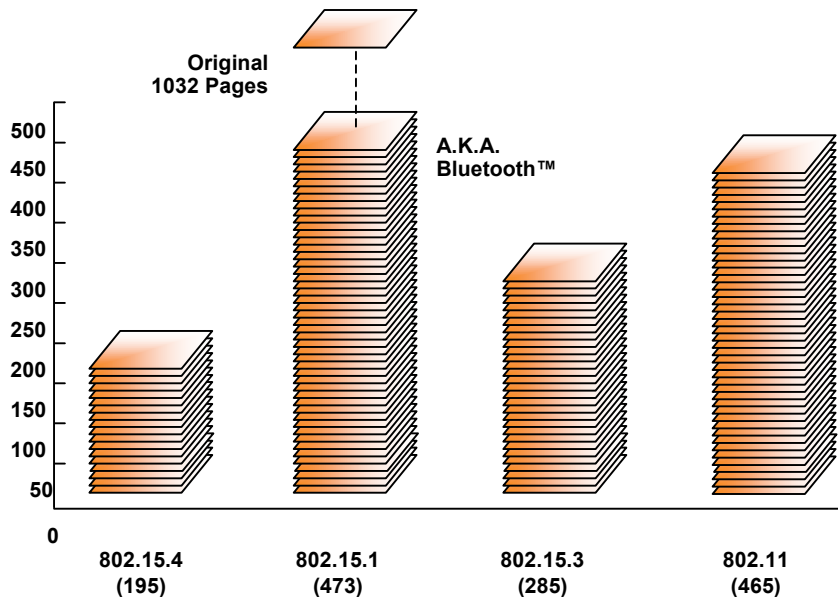
Standard Technology Options



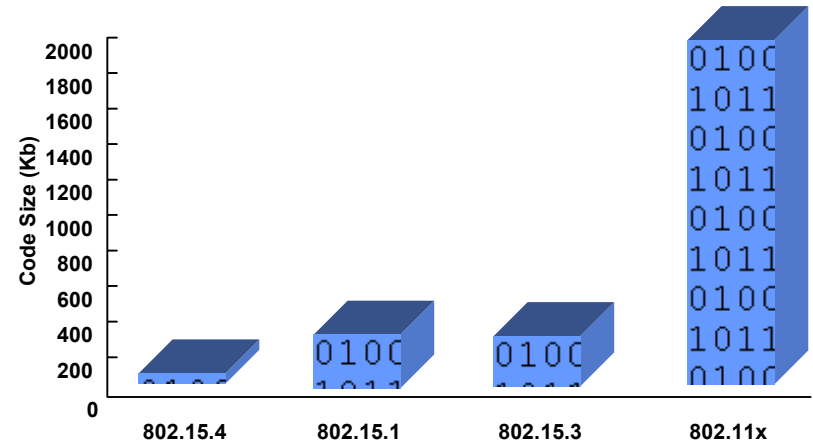
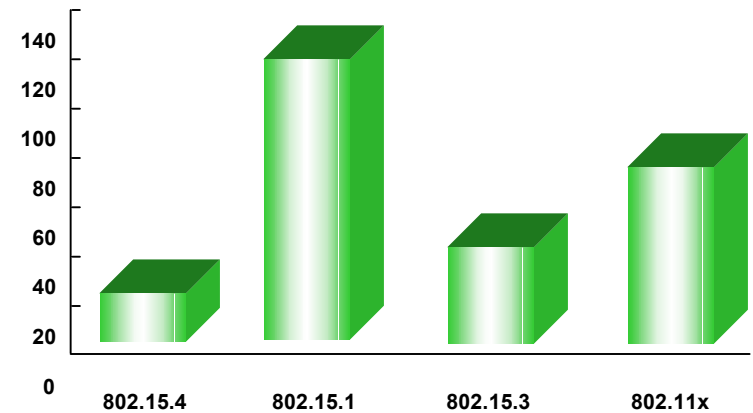
	LR-WPAN	Bluetooth™	WLAN
Range	10–30 m	~10–100 m	~100 m
Data Throughput	<0.25 MBPS	1 MBPS	~2–11 MBPS
Power Consumption	<BT/10	BT	>BT
Size	Smallest	Smaller	Larger
Nodes/Net	<<BT	BT	>BT
Cost	~\$1	~\$10–\$15	~\$40

Most industrial applications require lower cost and device power than mainstream wireless technology can achieve

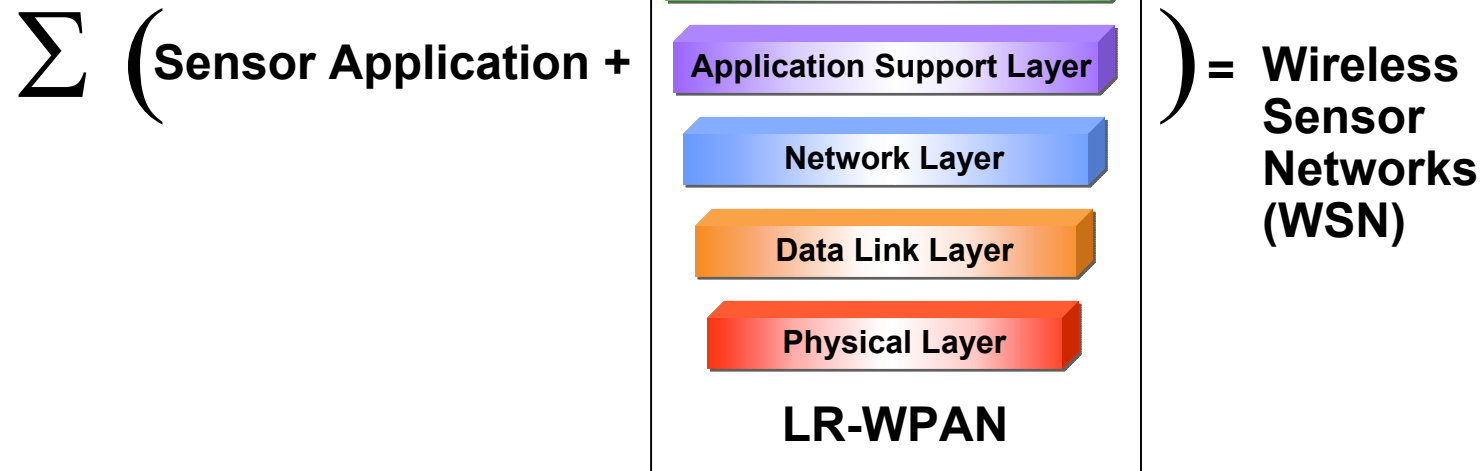
Measuring Standards Complexity



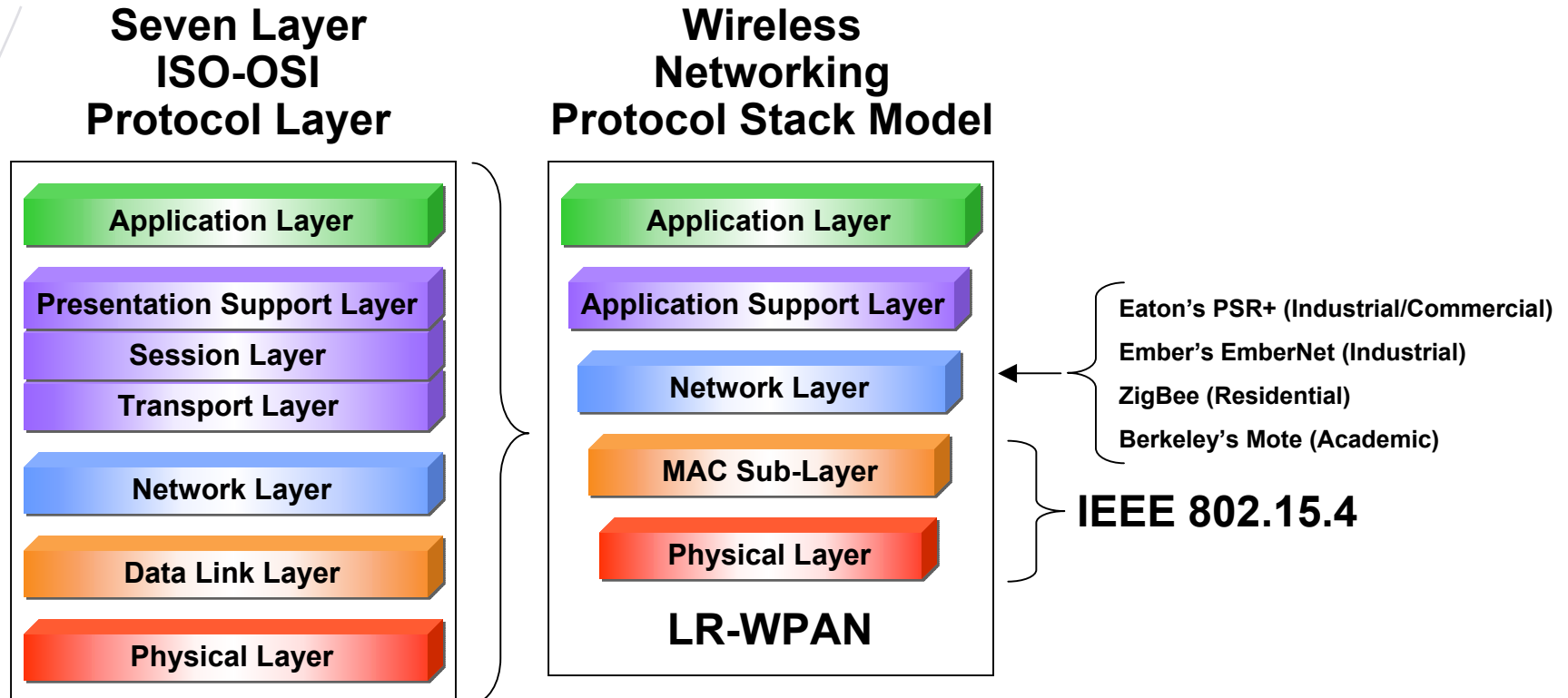
Number of Primitives



WSN Architecture



WSN Architecture



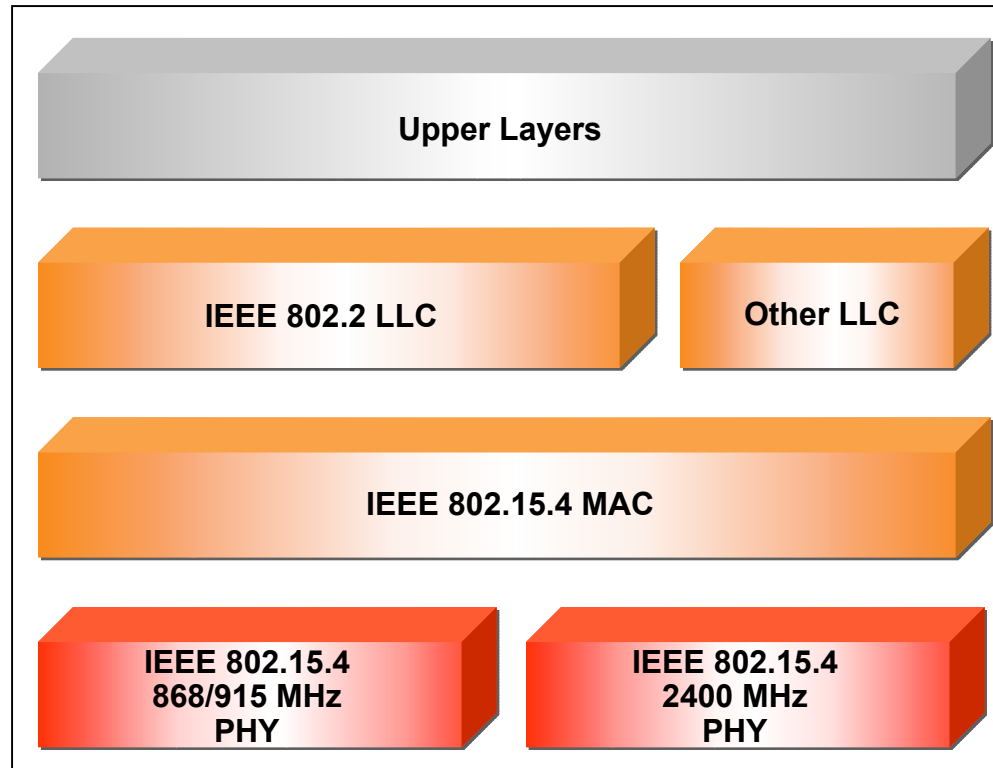
802.15.4 Main Characteristics

- Data rates of 250 kb/s, 40 kb/s and 20 kb/s
- Star or peer-to-peer operation
- Support for low latency devices
- CSMA-CA channel access
- Dynamic device addressing

802.15.4 Main Characteristics

- Fully handshake protocol for transfer reliability
- Low power consumption
- 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

802.15.4 Protocol Architecture

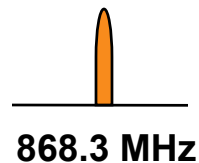


802.15.4 Physical Layer

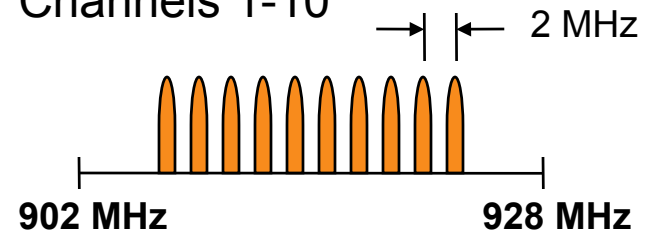
Operating Frequency Bands

**868MHz/915MHz
PHY**

Channel 0

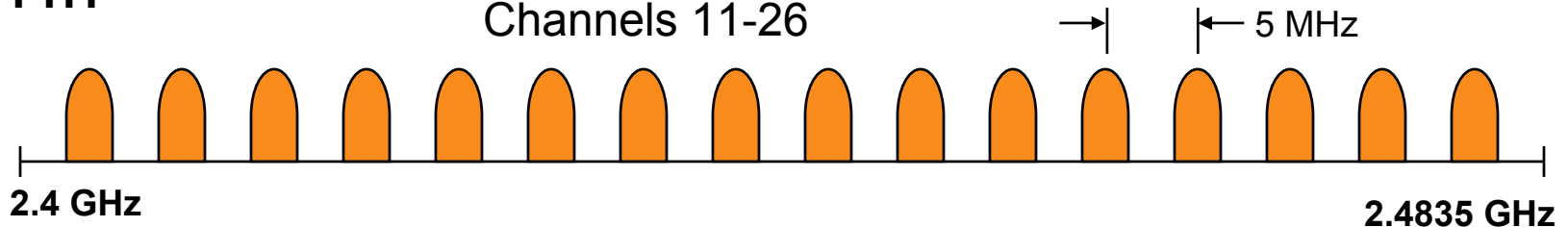


Channels 1-10






**2.4 GHz
PHY**

Channels 11-26



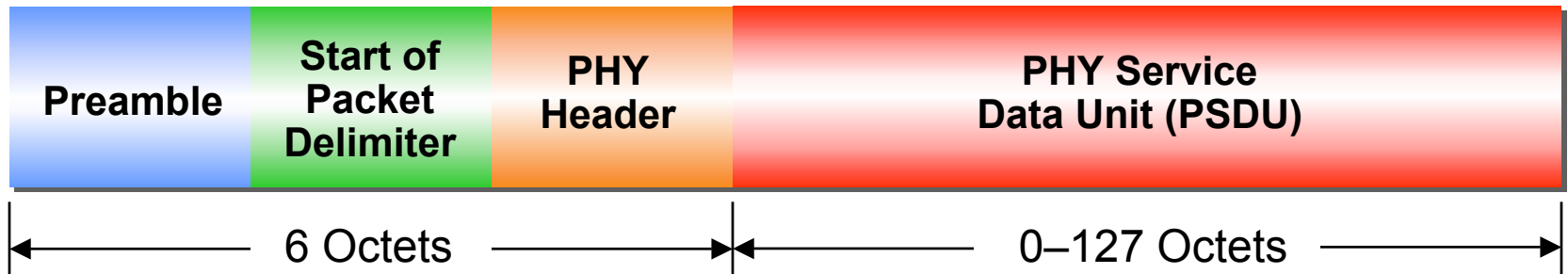
802.15.4 Channel Assignment

	Channel	Center Frequency (MHz)	Availability
868 MHz Band	0	868.3	 Europe
915 MHz Band	1	906	 Americas
	2	908	
	3	910	
	4	912	
	5	914	
	6	916	
	7	918	
	8	920	
	9	922	
	10	924	
2.4 GHz Band	11	2405	 World Wide
	12	2410	
	13	2415	
	14	2420	
	15	2425	
	16	2430	
	17	2435	
	18	2440	
	19	2445	
	20	2450	
	21	2455	
	22	2460	
	23	2465	
	24	2470	
	25	2475	
	26	2480	

802.15.4 Packet Structure

PHY Packet Fields

- Preamble (32 bits) – synchronization
- Start of Packet Delimiter (8 bits)
- PHY Header (8 bits) – PSDU length
- PSDU (0 to 1016 bits) – Data field



802.15.4 Modulation Scheme

2.4 GHz PHY

- 250 kb/s (4 bits/symbol, 62.5 kBaud)
- Data modulation is 16-ary orthogonal modulation
- 16 symbols are ~orthogonal set of 32-chip PN codes
- Chip modulation is MSK at 2.0 Mchips/s

868MHz/915MHz PHY

- Symbol rate
 - 868 MHz Band: 20 kb/s (1 bit/symbol, 20 kBaud)
 - 915 MHz Band: 40 kb/s (1 bit/symbol, 40 kBaud)
- Data modulation is BPSK with differential encoding
- Spreading code is a 15-chip m-sequence
- Chip modulation is BPSK at
 - 868 MHz Band: 300 kchips/s
 - 915 MHz Band: 600 kchips/s

802.15.4 Common Parameters

Transmit Power

- Capable of at least 1 mW

Transmit Center Frequency Tolerance

- ± 40 ppm

Receiver Sensitivity (packet error rate $<1\%$)

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

RSSI Measurements

- Packet strength indication
- Clear channel assessment

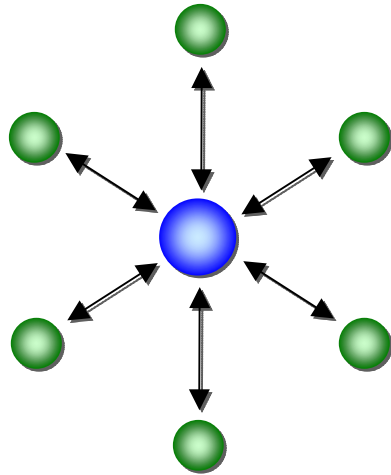
802.15.4 MAC Design Drivers

- Extremely low cost
- Ease of implementation
- Reliable data transfer
- Short range operation
- Very low power consumption

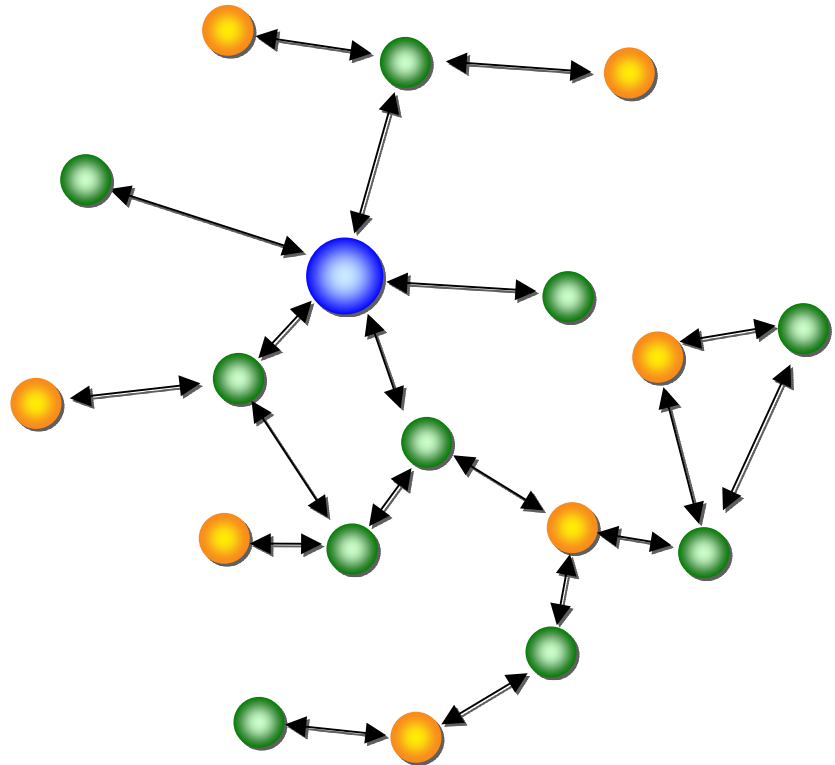
Simple but flexible protocol!

802.15.4 Network Topologies

Star



Mesh



802.15.4 Device Classes

- Full function device (FFD)
 - Any topology
 - PAN 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
 - Very simple implementation

802.15.4 Definitions

Coordinator

- An FFD with network device functionality that provides coordination and other services to the network.

PAN Coordinator

- A coordinator that is the principal controller of the PAN. A network has exactly one PAN coordinator.

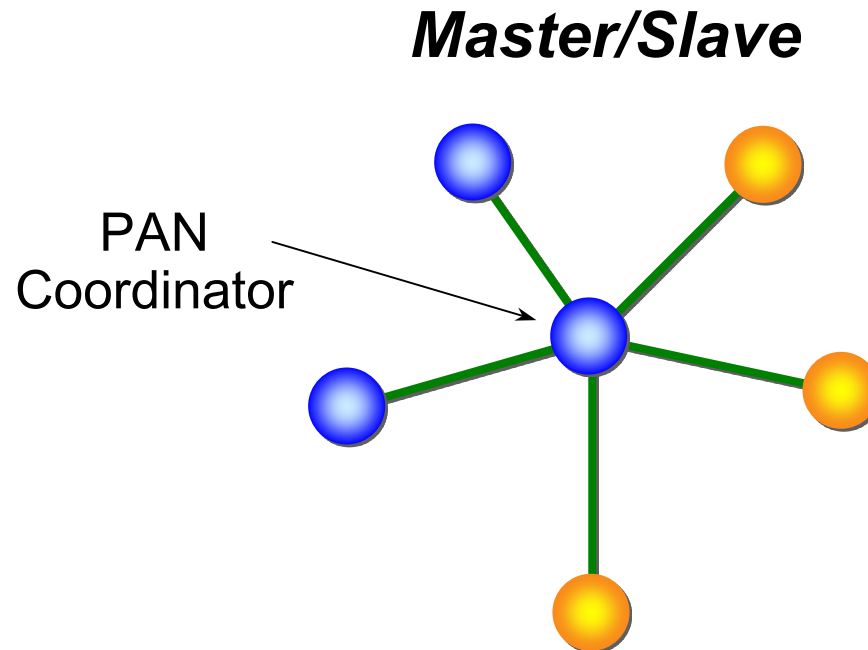
Network Device




- An RFD or FFD implementation containing an IEEE 802.15.4 medium access control and physical interface to the wireless medium.

802.15.4 Low-Power Operation

- Duty-cycle control using superframe structure
- Indirect data transmission
- Devices may sleep for extended period over multiple beacons
- Allows control of receiver state by higher layers

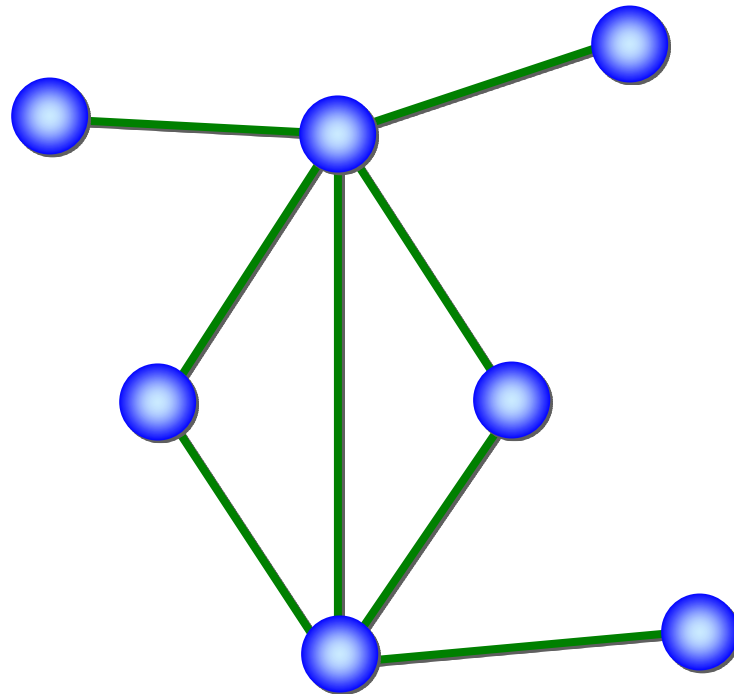
802.15.4 MAC Star Topology



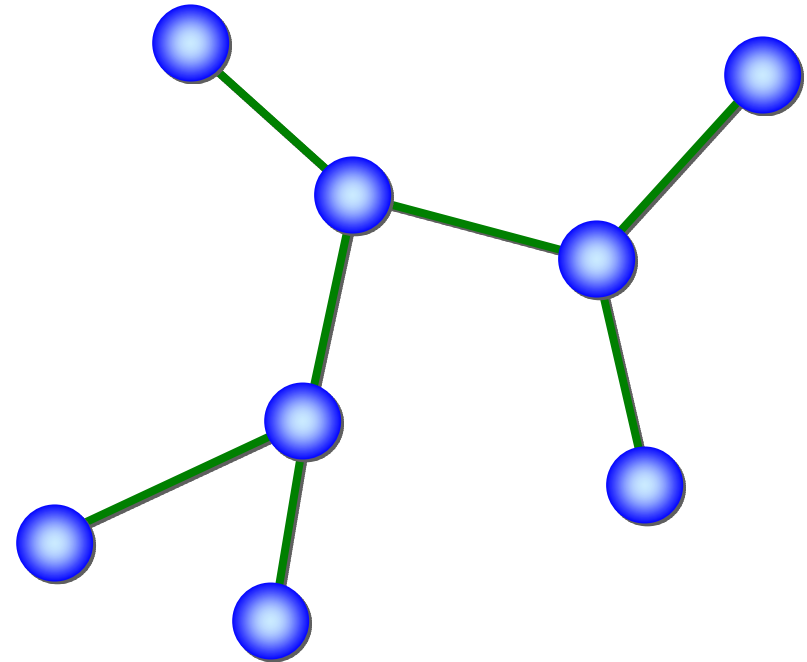
-  *Full function device*
-  *Reduced function device*
-  *Communications flow*

802.15.4 MAC Peer-to-Peer

Point To Point

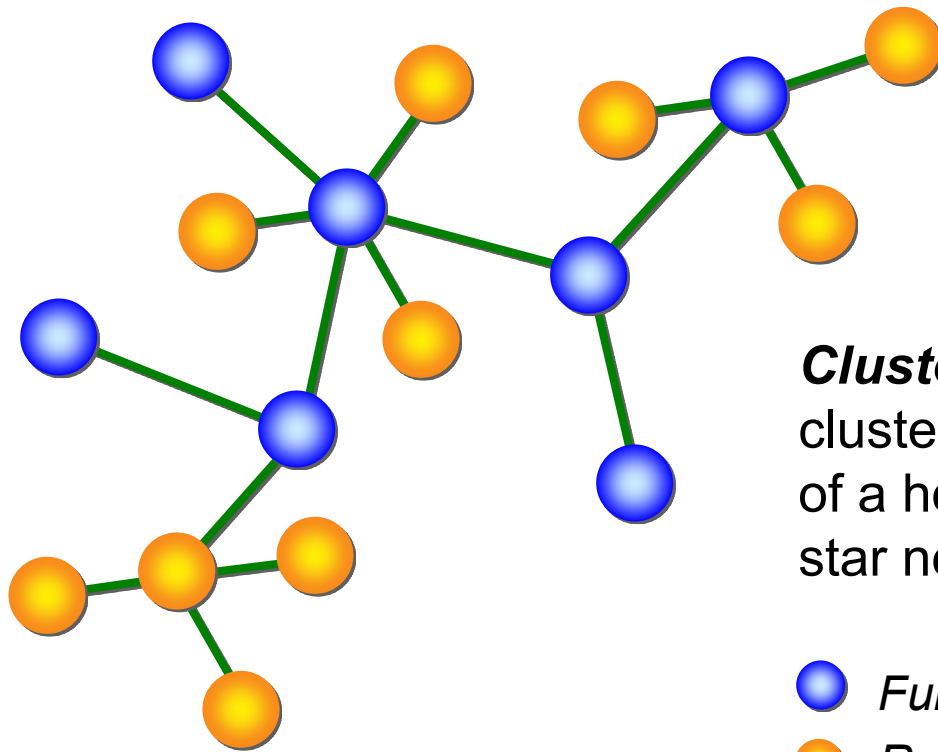


Cluster Tree






● Full function device
— Communications flow

802.15.4 MAC Combined Topology



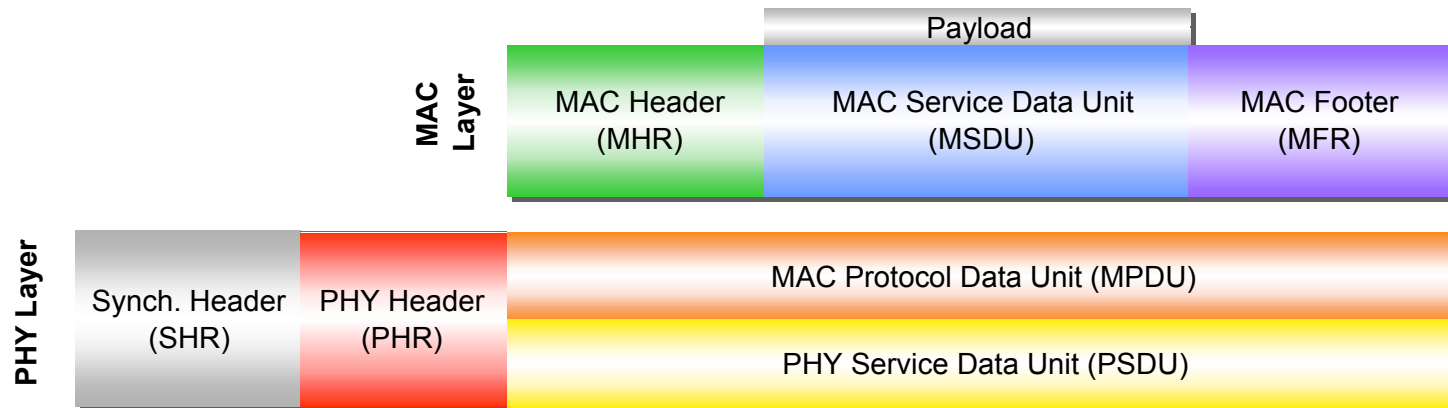
Clustered Stars—for example, cluster nodes exist between rooms of a hotel and each room has a star network for control.

-  *Full function device*
-  *Reduced function device*
-  *Communications flow*

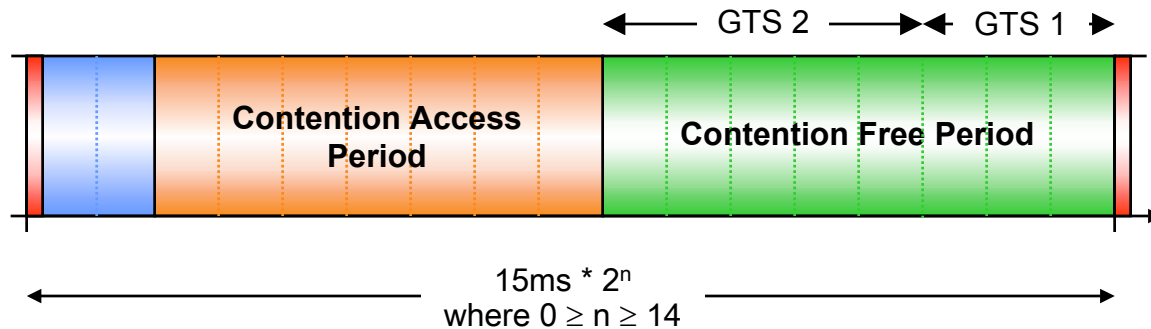
802.15.4 MAC Frame Structure





4 Types of MAC Frames:

- Data frame
- Beacon frame
- Acknowledgment frame
- MAC command frame



802.15.4 MAC Superframe Structure

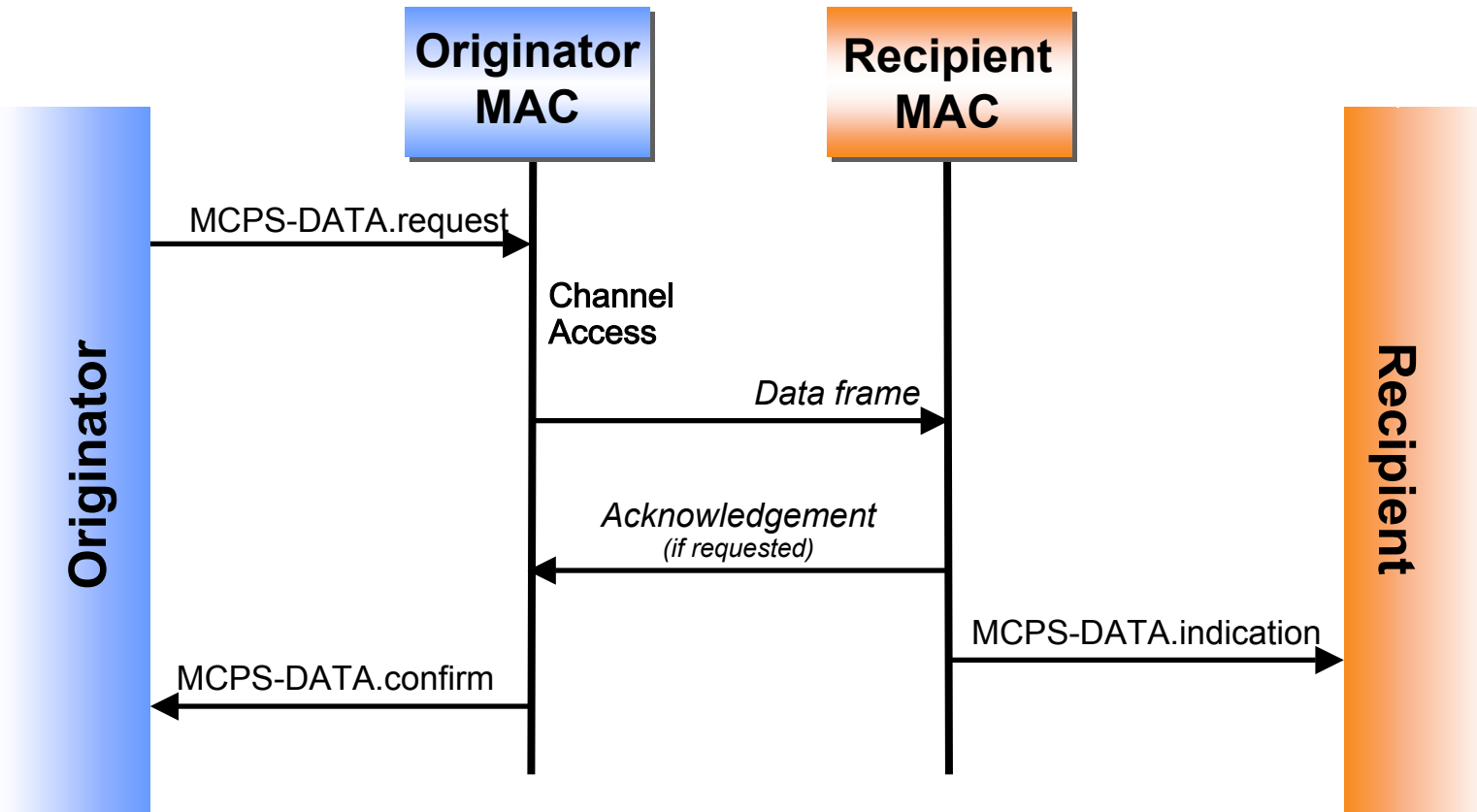


-  **Network Beacon**—Transmitted by network coordinator. Contains network information, frame structure and notification of pending node messages.
-  **Beacon Extension Period**—Space reserved for beacon growth due to pending node messages
-  **Contention Period**—Access by any node using CSMA-CA
-  **Guaranteed Time Slot**—Reserved for nodes requiring guaranteed bandwidth [$n = 0$]

802.15.4 MAC Traffic Types

- Periodic data
 - Application defined rate (e.g., *sensors*)
- Intermittent data
 - Application/external stimulus defined rate (e.g., *light switch*)
- Repetitive low latency data
 - Allocation of time slots (e.g., *mouse*)

802.15.4 MAC Data Service



802.15.4 MAC Management Service

- Access to the PAN Information Base
- Association / disassociation
- Guaranteed Time Slot allocation
- Message pending
- Node notification
- Network scanning/start
- Network synchronization/search



Eaton Applications!

Based on IEEE 802.15.4 Technology

Current Applications

- Residential applications
- Industrial and commercial applications
- Awarded DOE contract to increase energy efficiency of the Industries of the Future using Wireless Sensor technology
- Awarded DOE contract to secure US national energy infrastructure

Home Heartbeat™ System

The World's First Home Awareness System



Base Station:
Logic and memory



Sensors

- Temperature
- Water
- Power
- Door/window open
- Other



**Home
Key™**

- User interface
- Commissioning tool

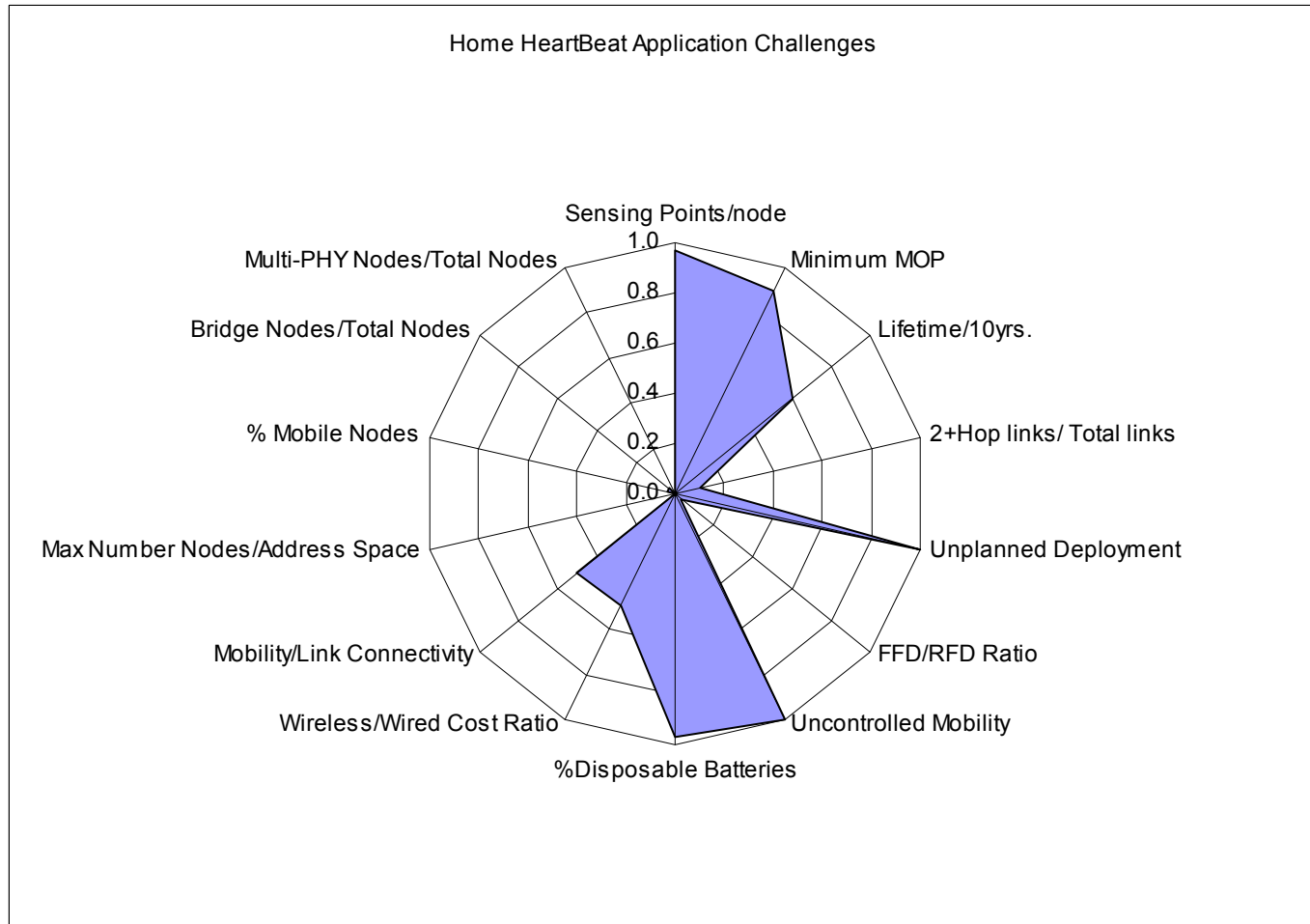


Home Heartbeat™

The World's First Home Awareness System

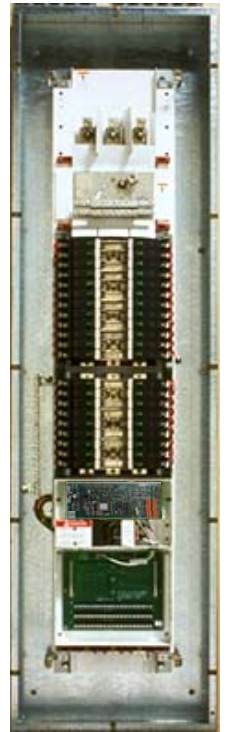


Home Heartbeat™

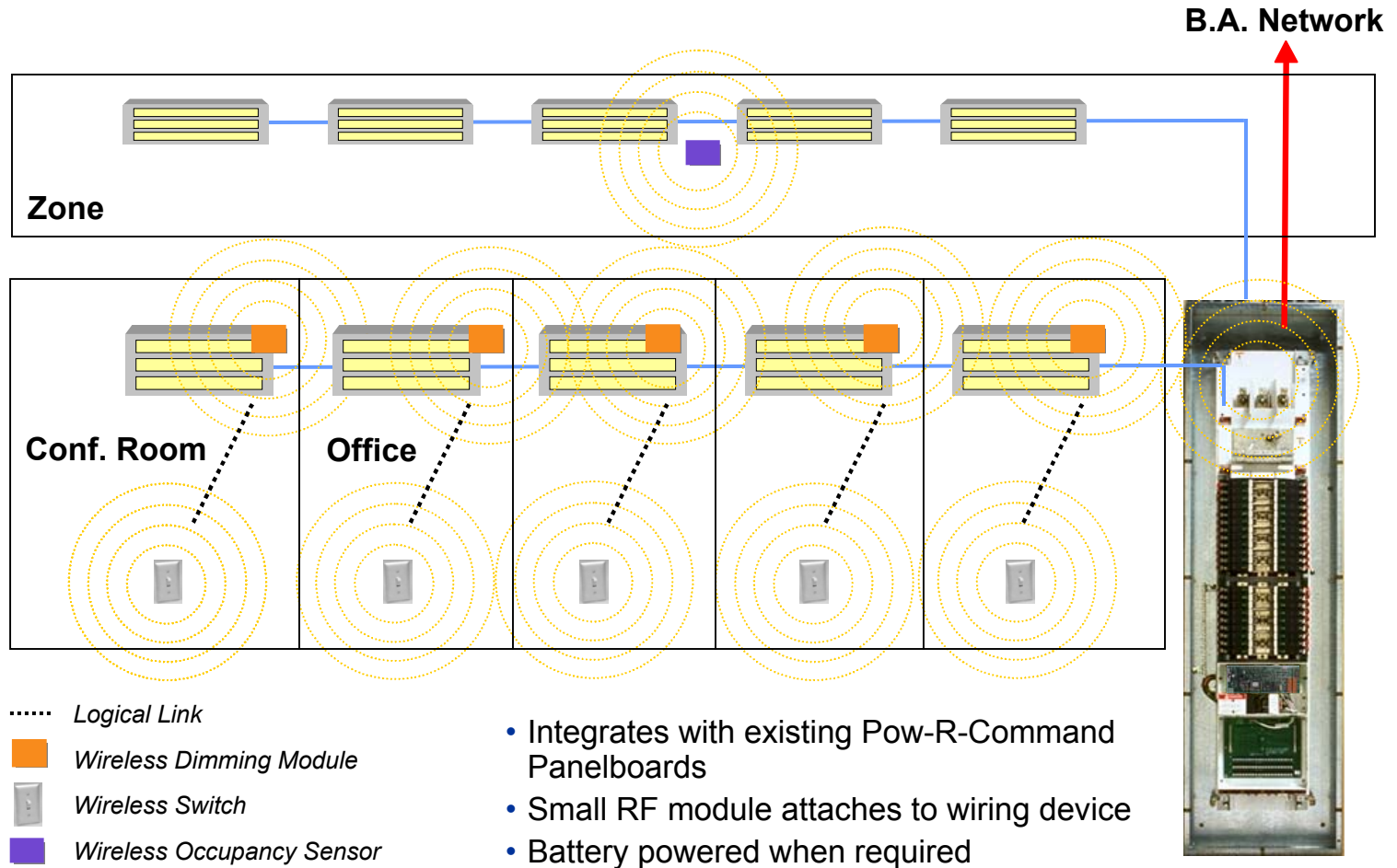


Wireless Lighting Control

- Wireless Lighting Control in Commercial buildings provides:
 - Simple installation process
 - Lower total installed cost for labor and materials
 - No need to pull/install new control wires or disturb ceilings in older buildings where asbestos exists
 - Wiring devices installed at desired locations



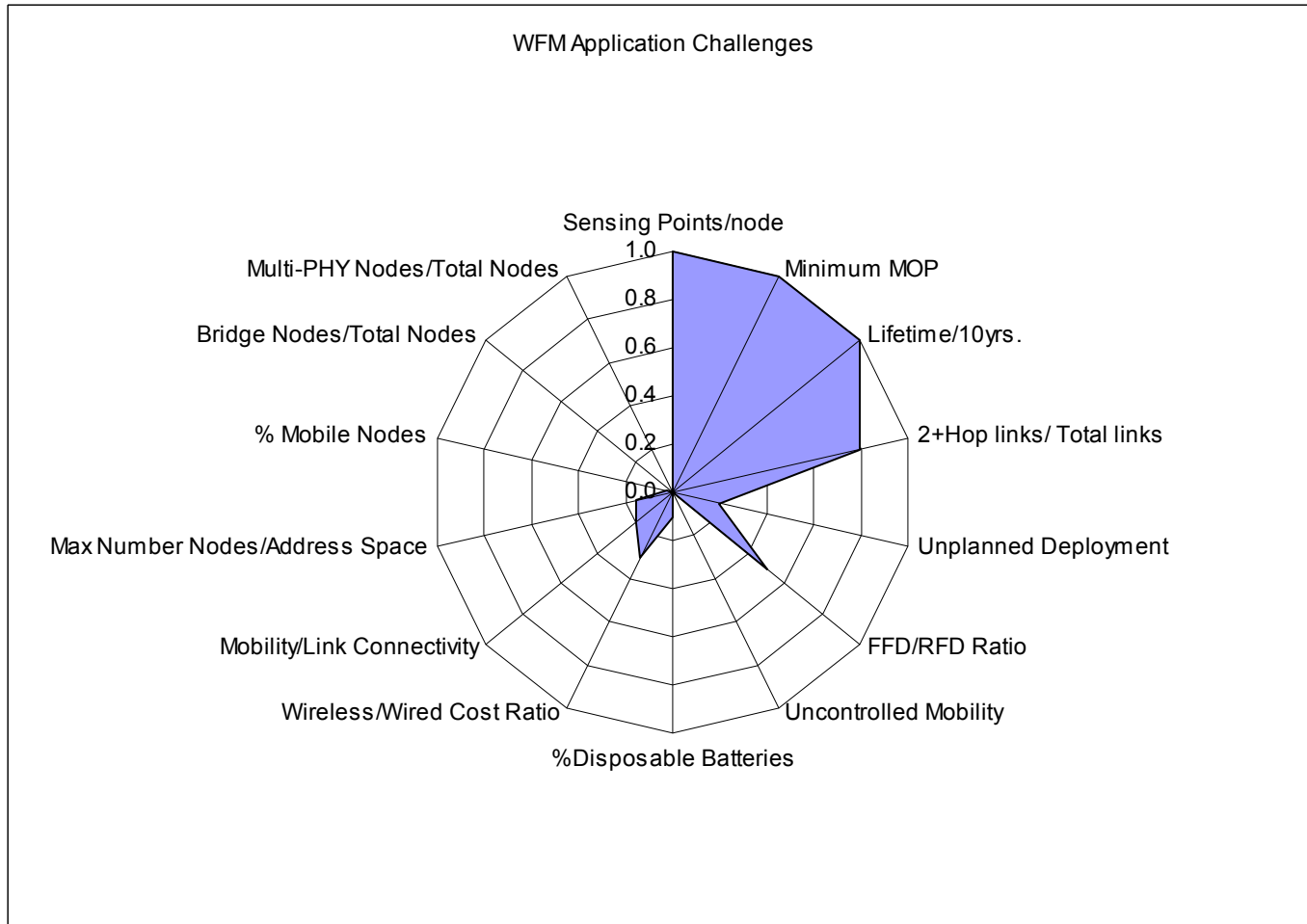
Wireless Lighting Control



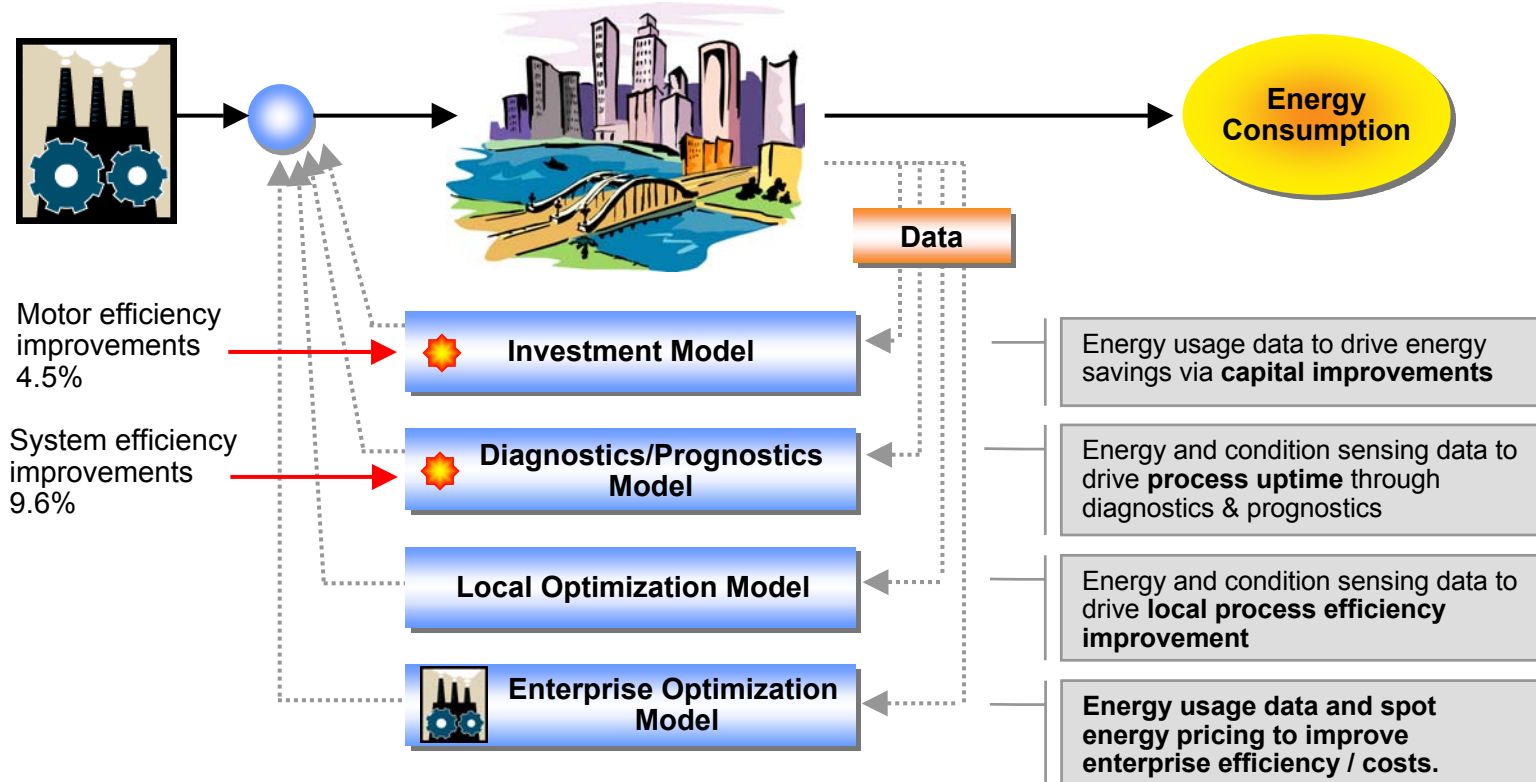
Wireless Lighting Control




Wireless Lighting Control



Energy Savings for Industrial

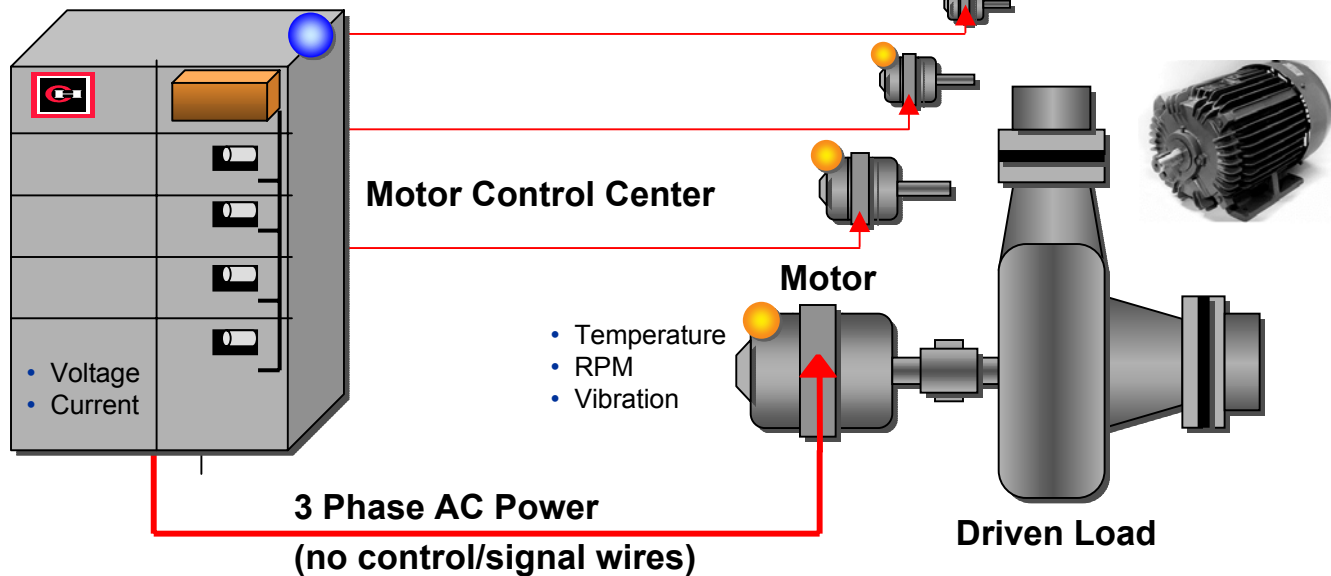
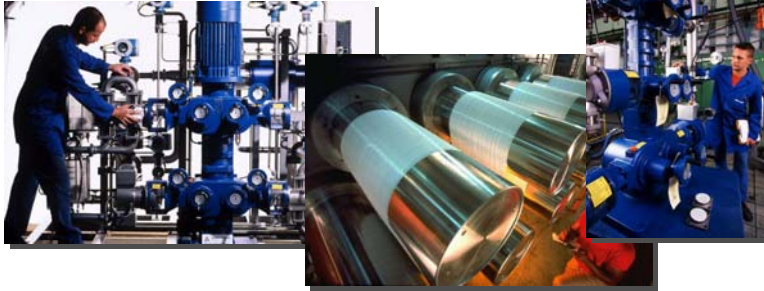


 Areas of focus

Eaton's WSN enables continuous energy savings!

Energy Sensing

Architectural Concept



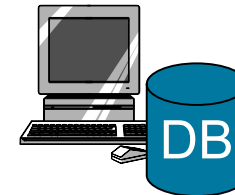
Architectural Concept



**Utility
Substation**

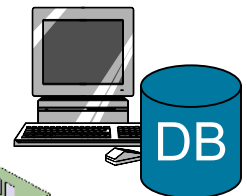


Switchboard



**Energy
Management**

**Condition Based
Diagnostics &
Prognostics**



**Motor Control
Center**

**Wireless communication also
enables a wide range of cost
effective conditions based
maintenance features and
capabilities**

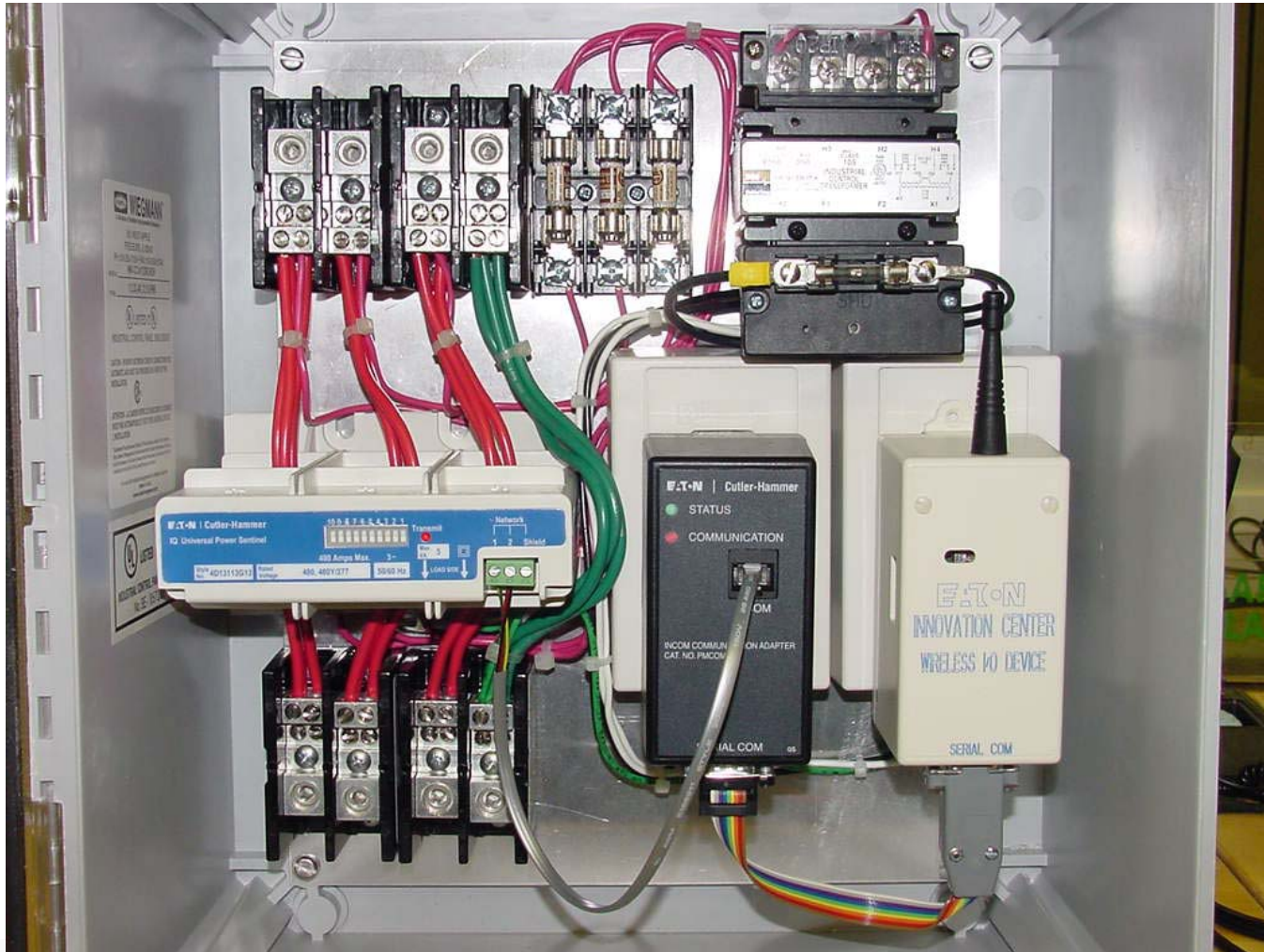


**Separately
mounted
machine control**

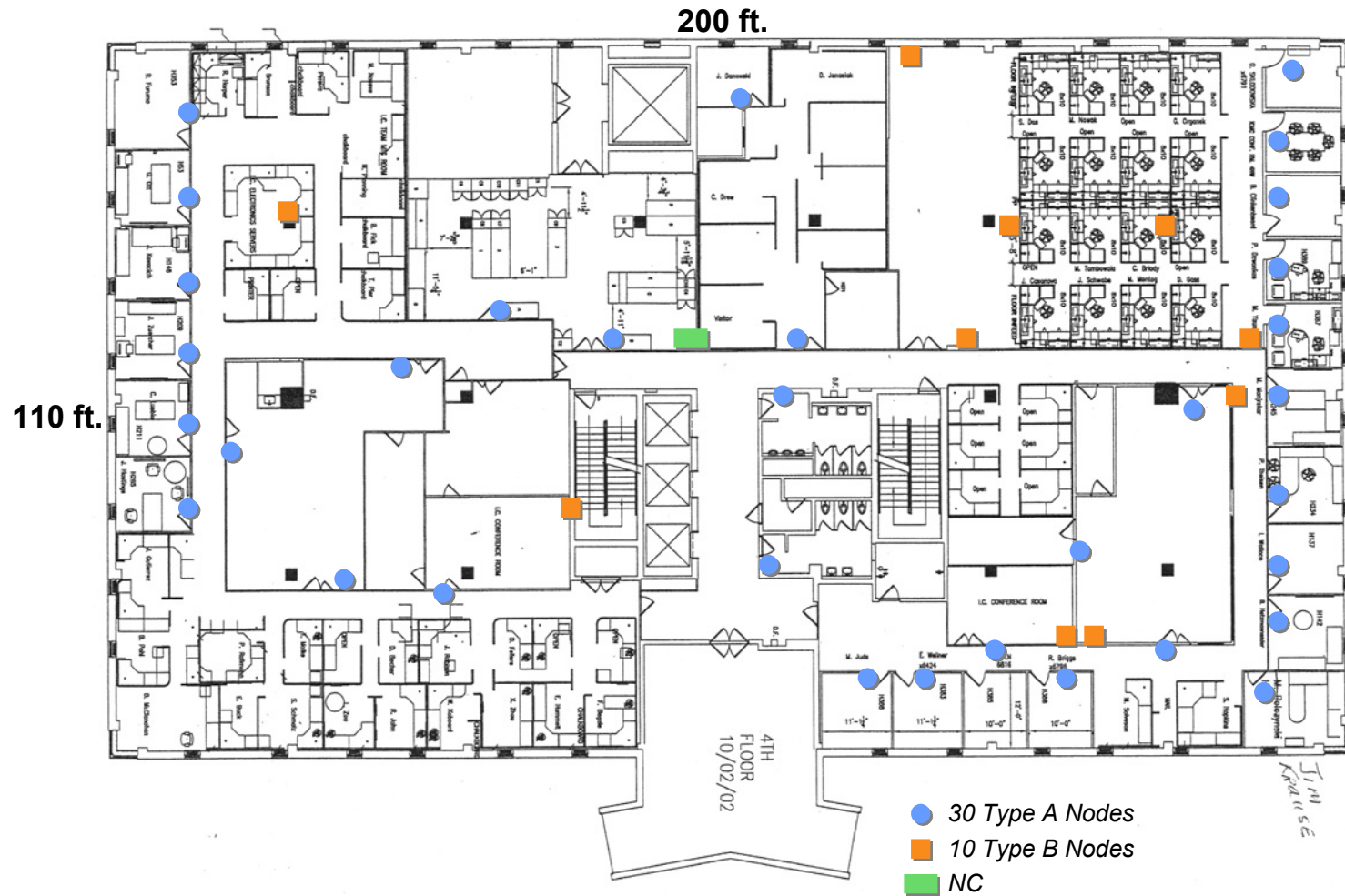


**Facility lighting
and energy**

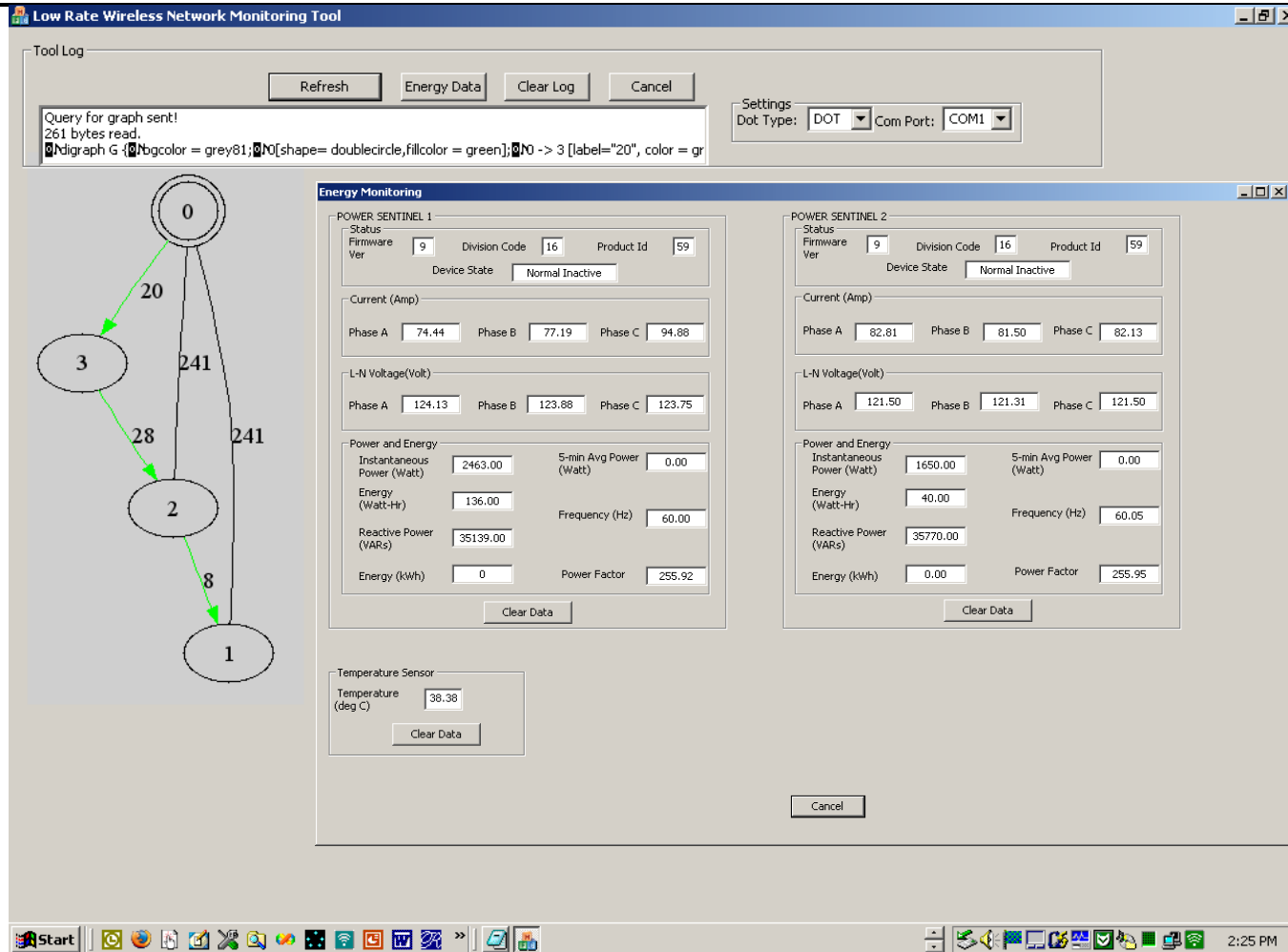
Wireless Energy Sentinel



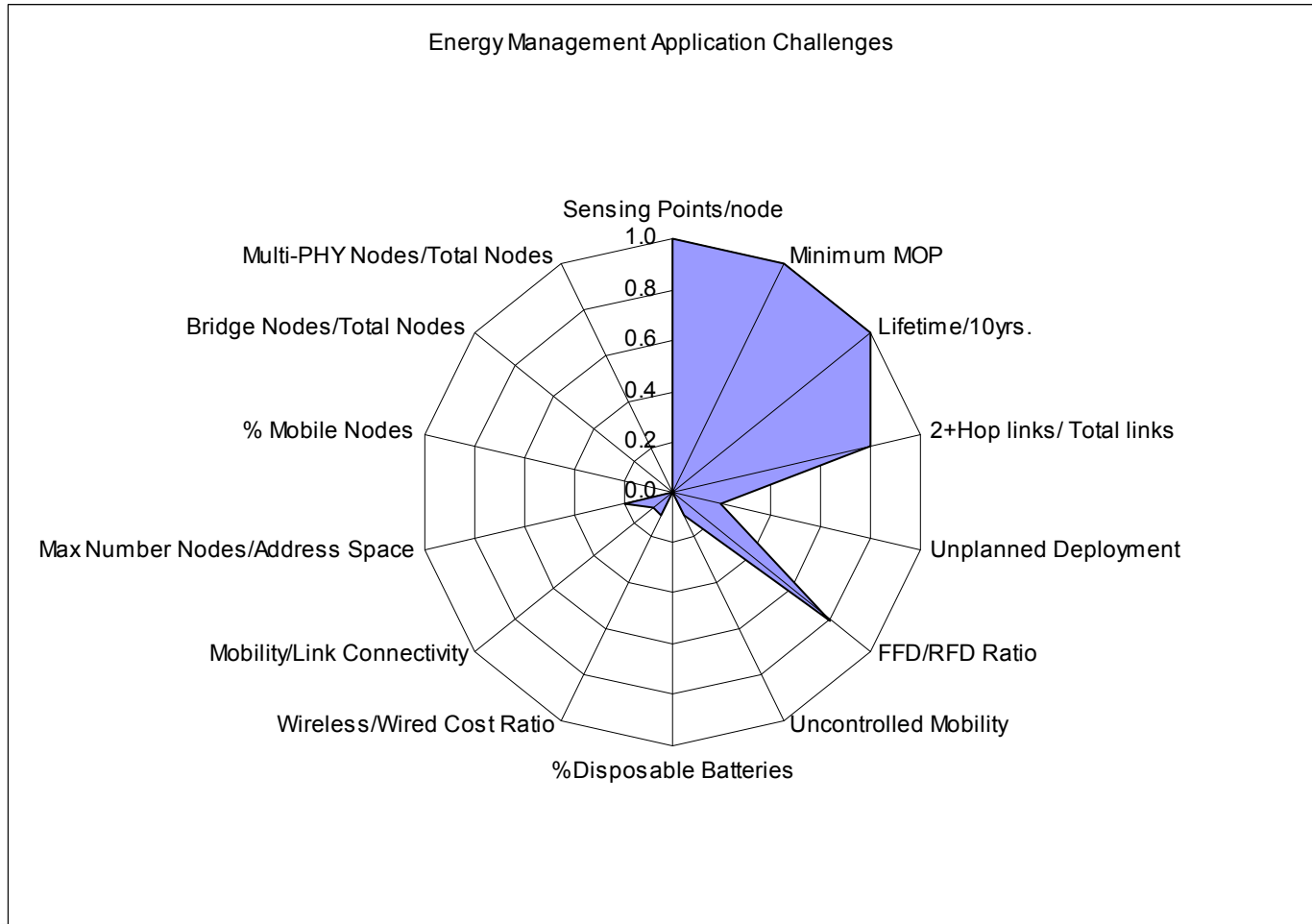
LRWPAN Field Test Site



Closing the Loop on Energy Savings



Closing the Loop on Energy Savings



Industrial Applications: Safe Sensing



Securing Energy Infrastructure



*“Eaton’s low-cost,
robust, threat aware
wireless sensor network
for assuring the
Nation’s energy
infrastructure.”*

Since the recent terrorist attacks, there have been increased concerns in the protection of the Nation’s critical infrastructure from willful or vandalous attacks. Without protection, these vulnerable resources could become a target.

The objective of this project is to create a low-cost, robust, Wireless Sensor Network (WSN) to enable pervasive, real-time threat sensing, assessing and evaluation to assure the physical security of the Nation’s energy critical infrastructure.

EAT•N
Electrical

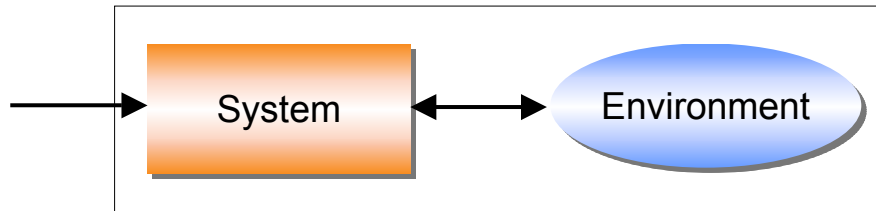
EAT•N
INNOVATION CENTER

EPRI
Electric Power Research Institute

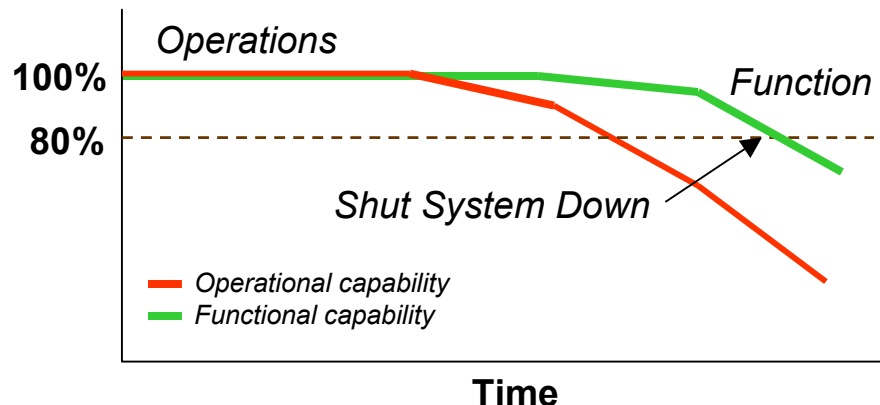
OAK RIDGE NATIONAL LABORATORY

Anticipatory Systems

Decision Boundary



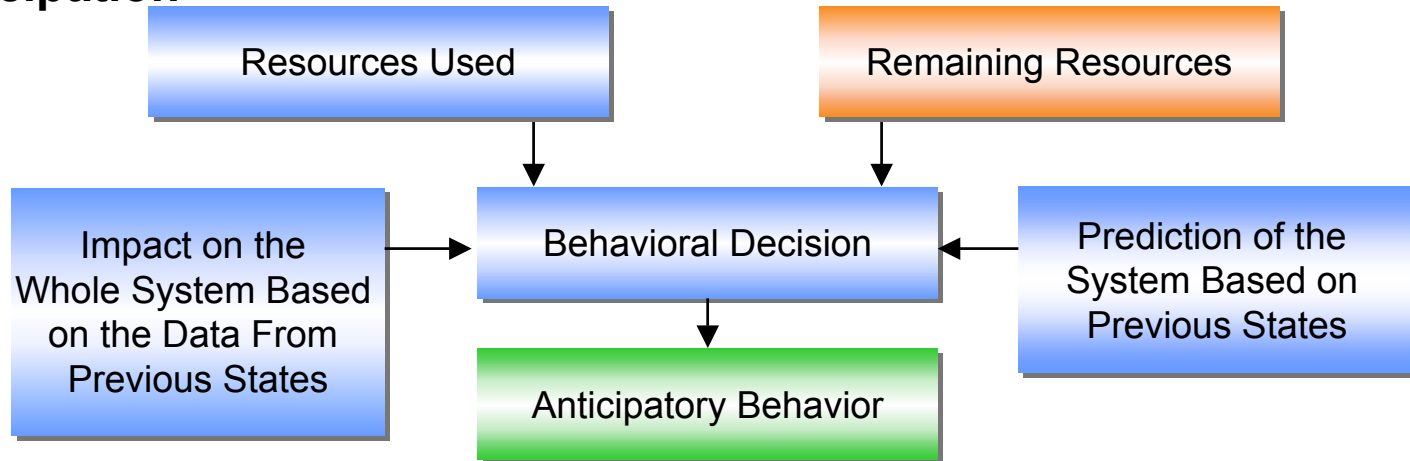
Anticipatory System Response



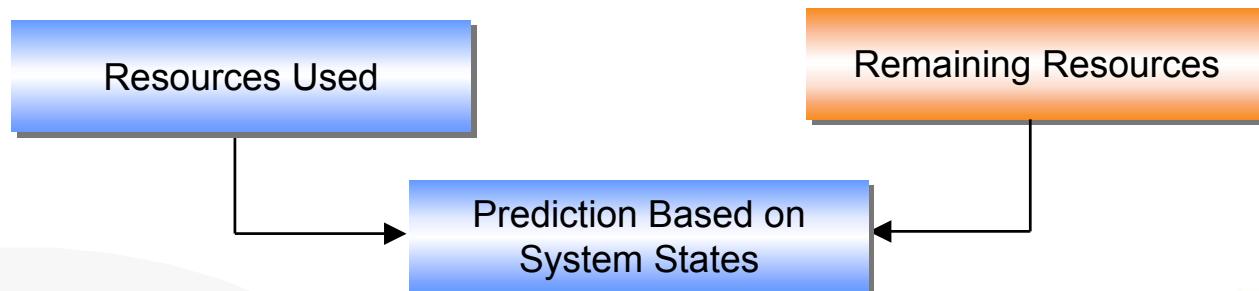
Anticipatory reasoning is based on a system assessing its own operational capability, its impact on the environment, the environment's impact on system, and the system's capability to continue to support mission requirements. In other words, you can have less than 100% operational capability but still maintain required functional capability.

Anticipatory Systems

Anticipation



Prediction



Second Level Challenges

For WSNs based on IEEE 802.15.4
Technology

Second-Level Challenges

- Intra-operability
- 3-D Node Models
- Time Synch Services
- Measure of Performance Optimization
- Power Harvesting
- Adaptable Network Layers
- Benchmarking
- Pairing/Binding
- Context Awareness
- Security

What's after IEEE 802.15.4?

IEEE 802.15.4a

- Defines an alternative PHY (UWB)
 - Precision ranging
 - Extended range
 - Enhanced robustness
 - Mobility
- Amendment to IEEE 802.15.4-2003 standard

IEEE 802.15.4b

- Enhancements and corrections to the existing standard.
 - A method for shared time-base distribution.
 - Support for new frequency allocations for Europe, China, and Japan.
 - Extension of 2.4GHz derivative modulation yielding higher data rates for the lower frequency bands.
 - Mechanism for communicating the revision level.
- Backward compatible with IEEE P802.15.4-2003.

The ZigBee Alliance

- Association of companies working together to enable reliable, cost-effective, low-power, wirelessly networked monitoring and control product based on IEEE 802.15.4
- Consortium of companies defining the protocol layers not defined in IEEE 802.15.4 (aka Upper Layers)
- Marketing arm and certification body for LR-WPAN technology
- More: www.zigbee.org



ZigBee Mission

The ZigBee Alliance is an association of companies working together to enable reliable, cost-effective, low-power, wirelessly networked, monitoring and control products based on an open global standard



Applications

Remote control

**Consumer
Electronics**

**Residential
and light
Commercial**

Lighting control
Home awareness
Access control
HVAC

Human
interface
devices

**PC
Peripherals**



**Building
Automation**

Lighting control
Access control
HVAC

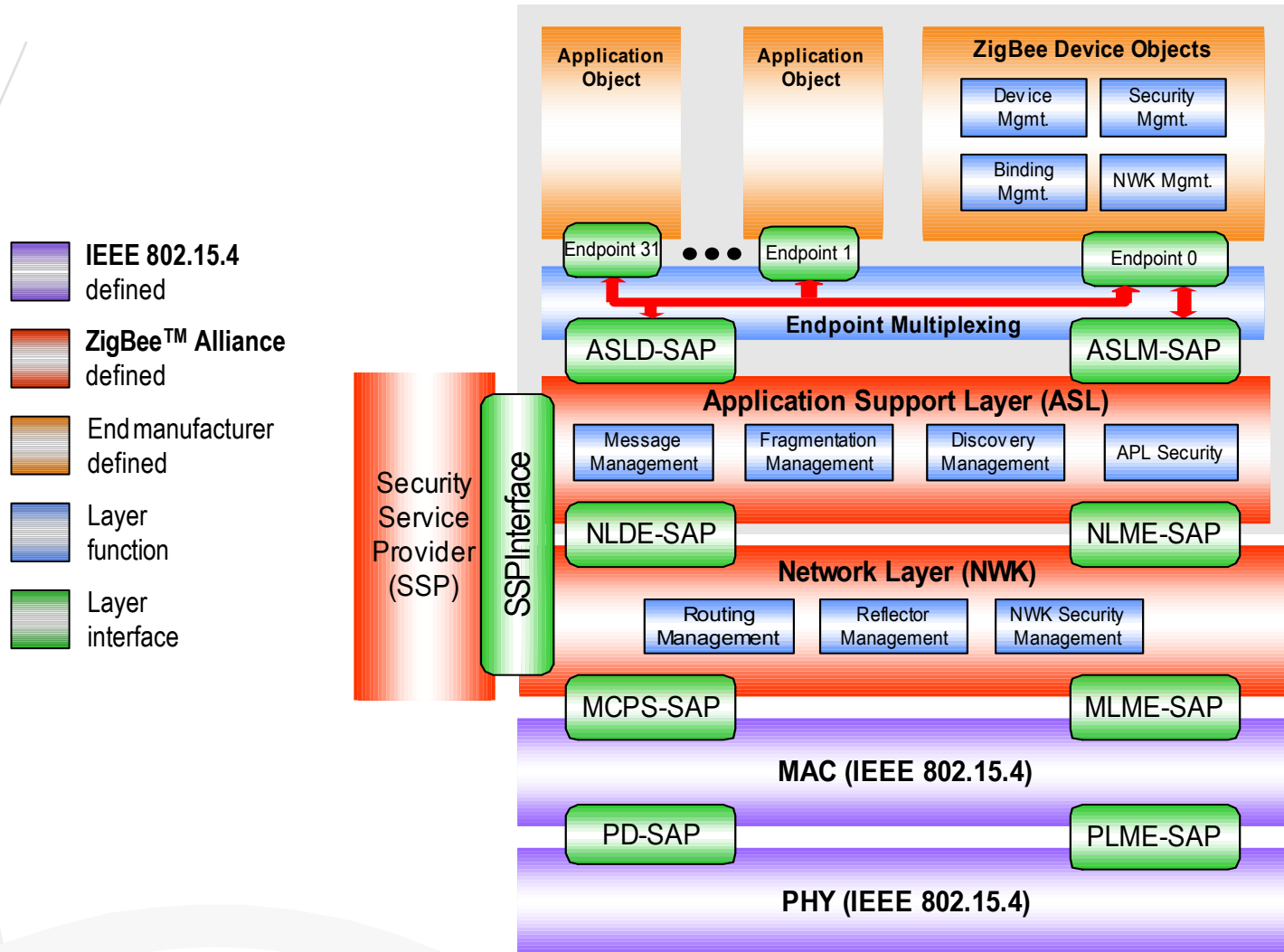
Fitness monitoring
Patient monitoring

**Personal
Health Care**

**Industrial
Control**

Asset management
Process control
Energy management

ZigBee Stack Architecture



Wireless Industrial Network Alliance

- A coalition of industrial end-user companies, technology suppliers, industry organizations, software developers, system integrators.



- Aims at Improving the understanding of the benefits of using wireless in industrial applications
- Improving the confidence in wireless technology and access to solutions
- Focusing on the end user

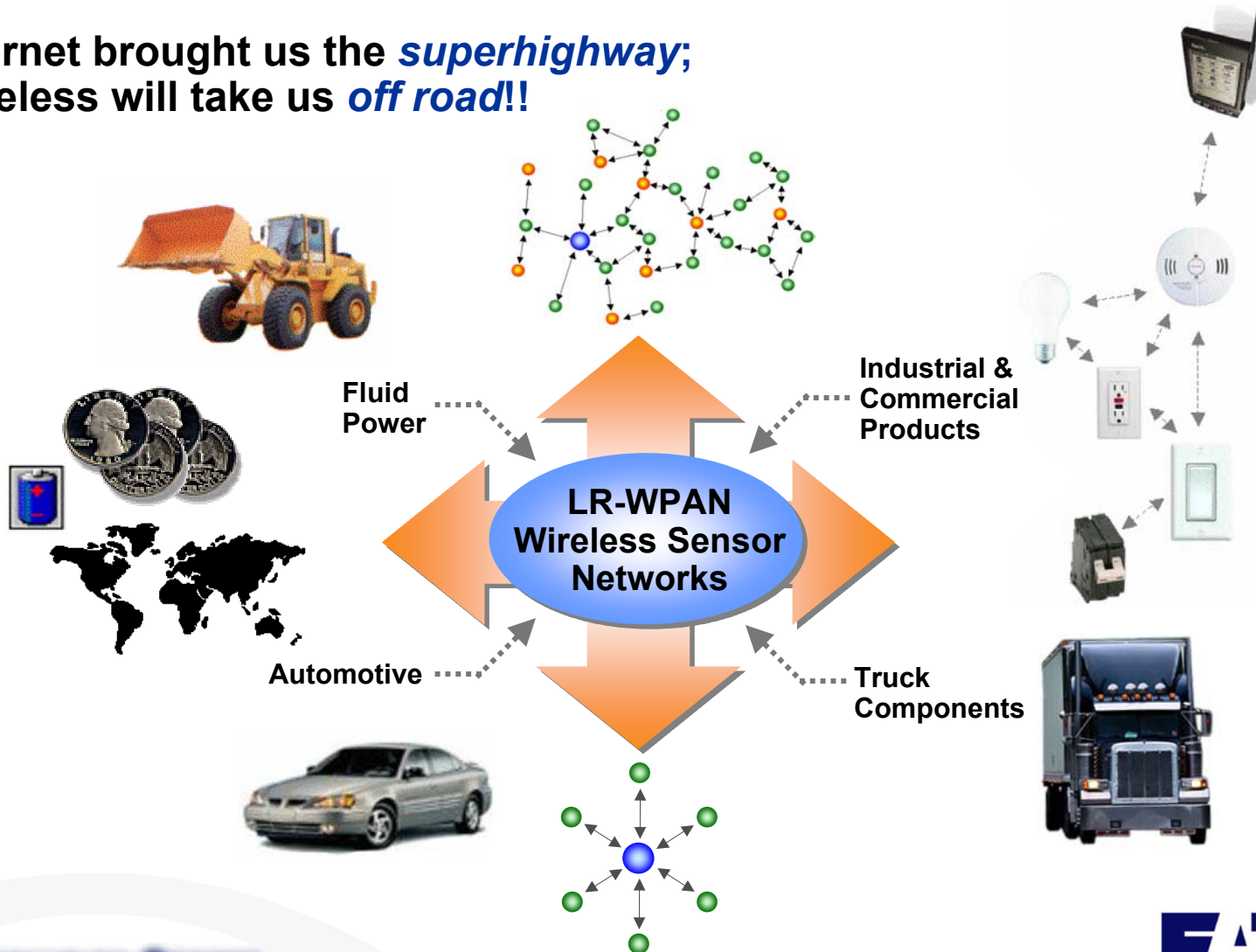
WINA Charter

WINA works to accelerate the adoption of wireless technologies in the industrial sector:

- Identify, recommend, and certify appropriate wireless technologies
- Focus on customer requirements
- Promote effective standards, regulations, and practices
- Quantify and communicate the benefits and potential impacts of wireless technologies

Wireless Sensor Network

Internet brought us the *superhighway*;
Wireless will take us *off road!!*





Thank you!

Industrial Perspective on Wireless Sensor Networks.

Motivation, Drivers, The Future & Challenges Faced: Behavioral Network Models, Tractable Networks, QoS and so on.