Distributed Computer Systems Engineering

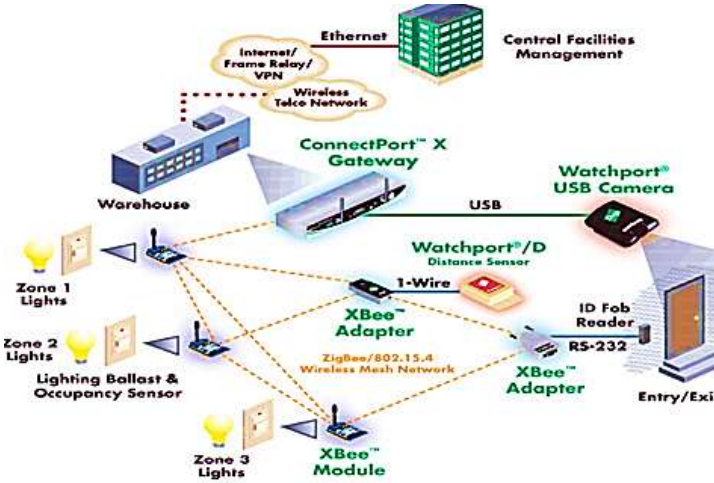
CIS 508: Lecture 8
Wireless Sensor Networks

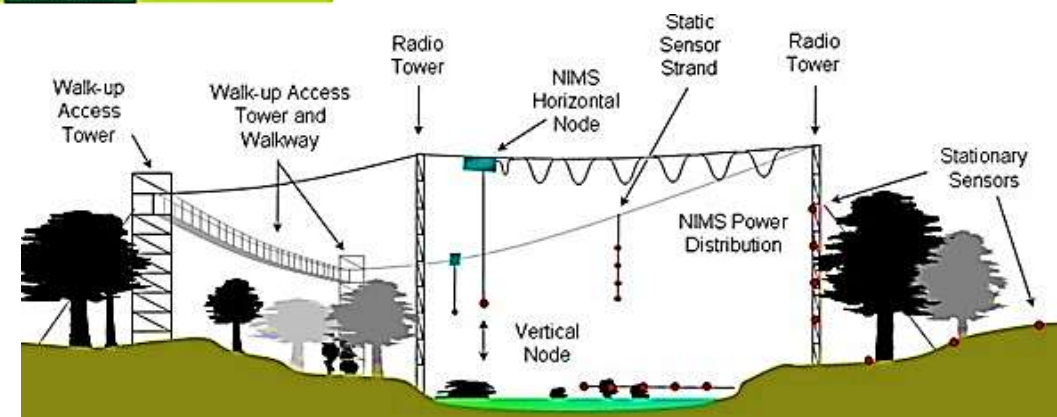
Lecturer: Sid C.K. Chau
Email: ckchau@masdar.ac.ae

What is Wireless Sensor Network

- Spatially distributed autonomous devices
- Integrated with sensing, computing, communication modules
- Flexible for a variety of applications
  - Security, intrusion, military surveillance
  - Environmental monitoring
    - Air pollution, water quality monitoring
    - Natural disaster, forest fire, landslide detection
  - Industrial monitoring
    - Machine health, structural health monitoring
    - Data logging
    - Water/Waste water monitoring

Wireless Sensor Networks

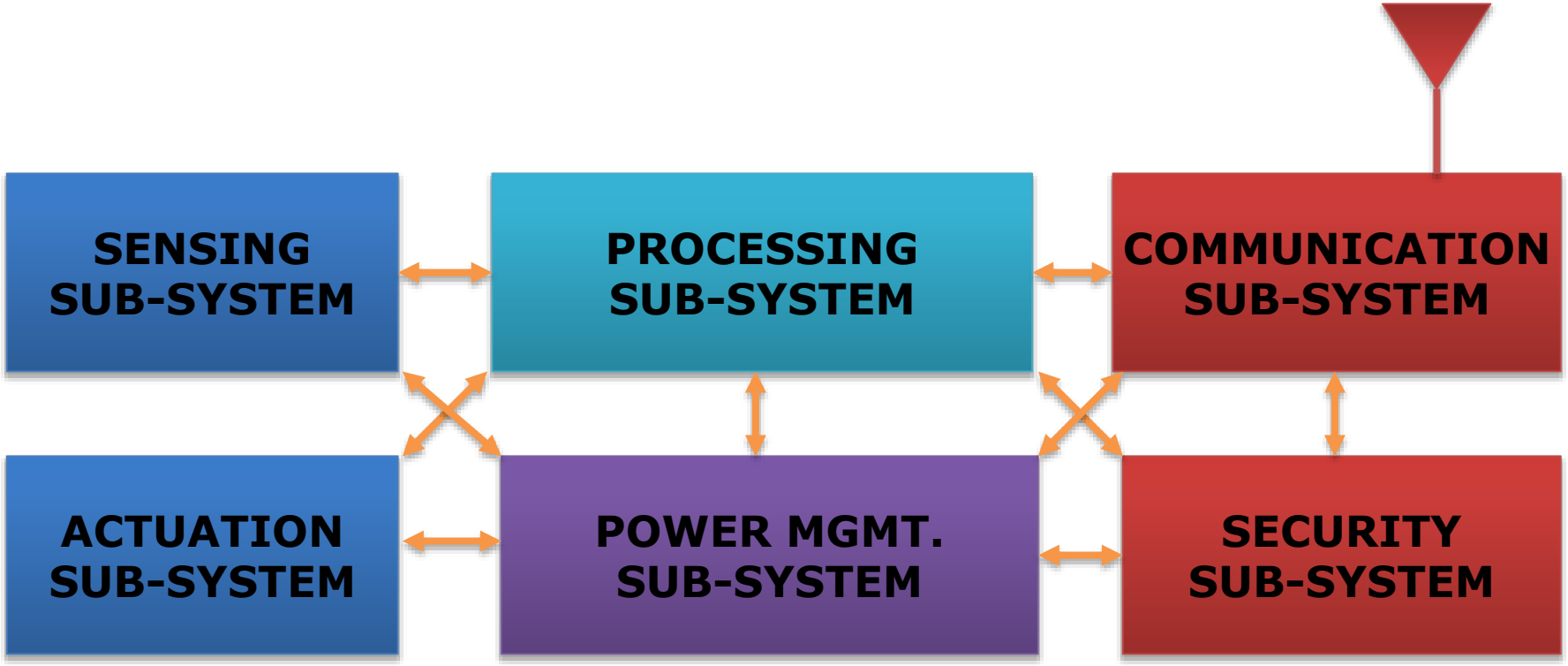




Sensor Network Requirements

- Low power consumption
  - Only by internal batteries or energy harvesting
- Ability to cope with node failures
  - Cheap components or unpredictable environment
- Mobility of nodes
- Communication failures
- Scalability to large scale of deployment
  - Add or remove nodes without re-configuration
- Ability to withstand harsh environmental conditions
  - Temperature, water, damages by external factors
- Ease of use

Wireless Sensor Architecture



Wireless Sensor Mote

- Transceiver 400 MHz
  - Line-of-sight
  - Short range
  - Unlicensed spectrum operation
- Microcontroller
  - ATmega 128 - 16 MHz, 128KB Flash, 4 KB RAM
  - Low power, sleep modes
- TinyOS
  - Energy-efficient OS
  - For event-driven programming

Crossbow mote with battery

802.15.4 Platforms

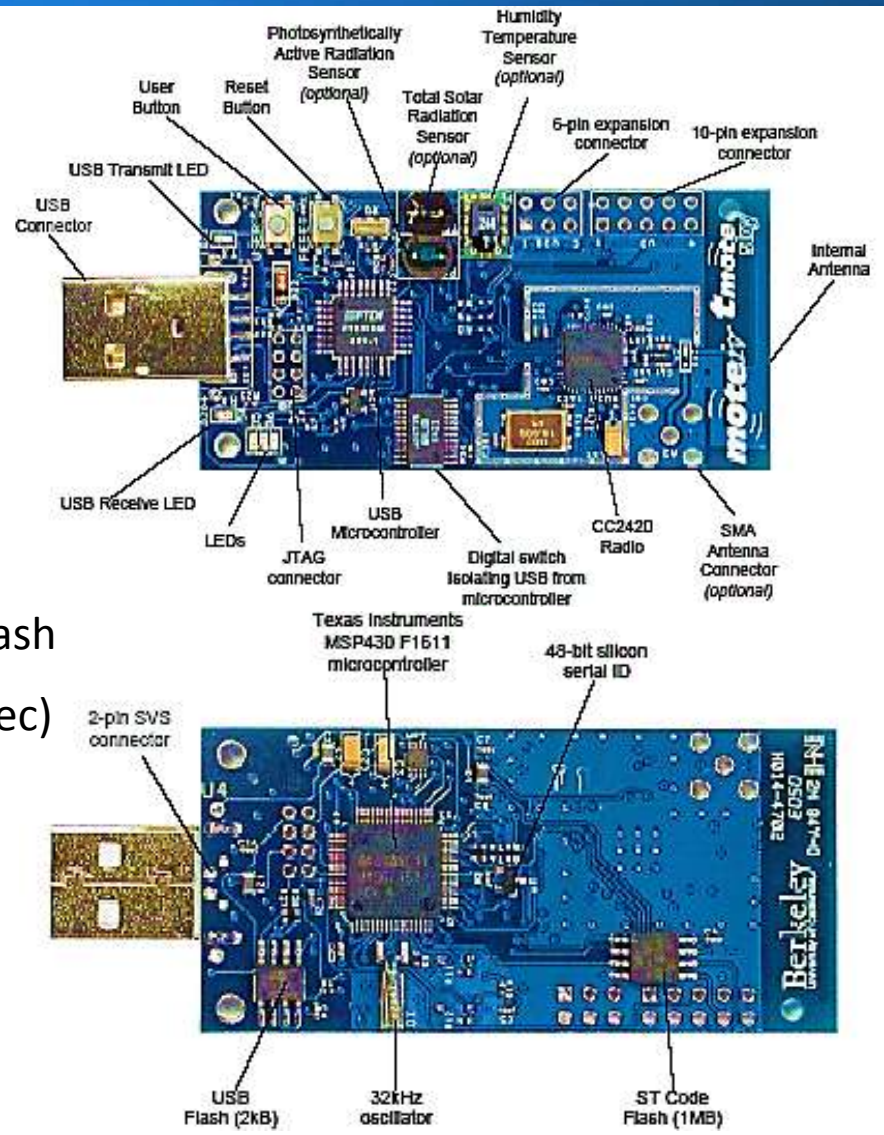
- Focused on low power
- Sleep - Majority of the time
  - Telos: 2.4mA
  - MicaZ: 30mA
- Wakeup
  - Telos: 290ns typical, 6ms max
  - MicaZ: 60ms max internal oscillator, 4ms external
- Process
  - Telos: 4MHz 16-bit
  - MicaZ: 8MHz 8-bit
- TI MSP430
  - Ultra low power
    - 1.6mA sleep, 460mA active, 1.8V operation
- Standards Based
  - IEEE 802.15.4, USB
- IEEE 802.15.4
  - CC2420 radio, 250kbps, 2.4GHz ISM band
- Program over USB, Standard connector header

UCB Telos

Xbow MicaZ

Tmote Sky

- Standards
  - USB
  - IEEE 802.15.4
    - CC2420, 250kbps at 2.4GHz
- Features
  - TI MSP430
    - 10kB RAM, 4Mhz 16-bit RISC, 48K Flash
    - 12-bit ADC and DAC (200ksamples/sec)
    - DMA transfers while CPU off
  - Integrated antenna
  - Standard IDC connectors



Power Consumption

Operation	Telos	Mica2	MicaZ
Minimum Voltage	1.8V	2.7V	2.7V
Mote Standby (RTC on)	5.1 μA	19.0 μA	27.0 μA
MCU Idle (DCO on)	54.5 μA	3.2 mA	3.2 mA
MCU Active	1.8 mA	8.0 mA	8.0 mA
MCU + Radio RX	21.8 mA	15.1 mA	23.3 mA
MCU + Radio TX (0dBm)	19.5 mA	25.4 mA	21.0 mA
MCU + Flash Read	4.1 mA	9.4 mA	9.4 mA
MCU + Flash Write	15.1 mA	21.6 mA	21.6 mA
MCU Wakeup	6 μs	180 μs	180 μs
Radio Wakeup	580 μs	1800 μs	860 μs

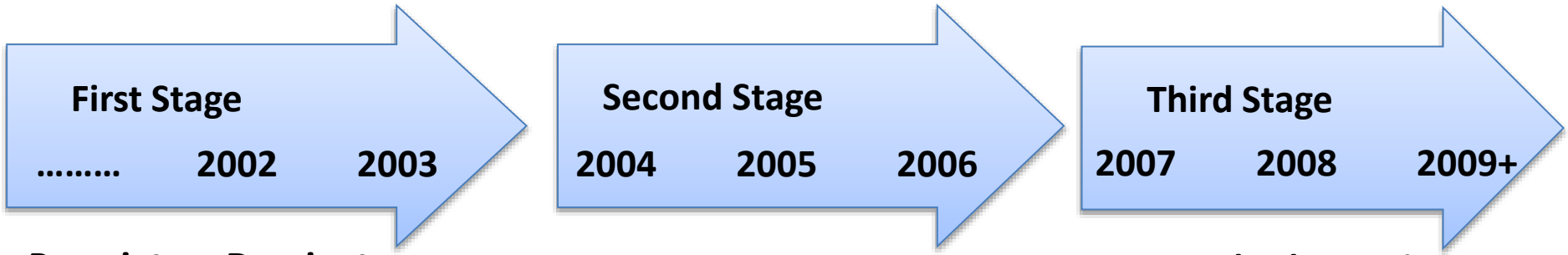
Operating Systems for Wireless Sensor

- Less complex than general-purpose operating systems
  - Resemble embedded systems
  - Need for low costs and low power (access to low-power microcontrollers)
  - Lacks sophisticated memory management
- TinyOS is first operating system specifically designed for wireless sensor networks
  - Event-driven programming model, instead of multithreading
  - Programs composed of event handlers and tasks with run-to-completion semantics
  - When external event occurs (e.g. an incoming data packet or a sensor reading) TinyOS signals the appropriate event handler to handle the event
  - Event handlers can post tasks that are scheduled by the TinyOS kernel some time later.
- Other WSN OSes: LiteOS, Contiki, RIOT

Evolution of Wireless Sensor

- Advances in wireless technology
  - Cost effective and small footprint hardware: MEMS, VLSI
  - Efficient wireless communication design, like ZigBee
- Boom of applications (military, civilian, environmental)
- Cultural changes
  - Wireless devices are everywhere
  - Emerging network embedded systems, cyber-physical systems, internet-of-things
  - Open source software
- Advances in Computer Science
  - Efficient small operating system
  - Efficient compilers

Evolution of Industry



- Proprietary Dominates
- IEEE 802.15.4 Emerges
- System Integrator Focus
- Leading Edge OEMs
- $.1 - $1B Industry
- $1,000 - $100 Unit Cost

- Proprietary Fades
- ZigBee Emerges
- Semiconductor Focus
- Early Adopter OEMs
- $1 - $10B Industry
- $100 - $10 Unit Cost

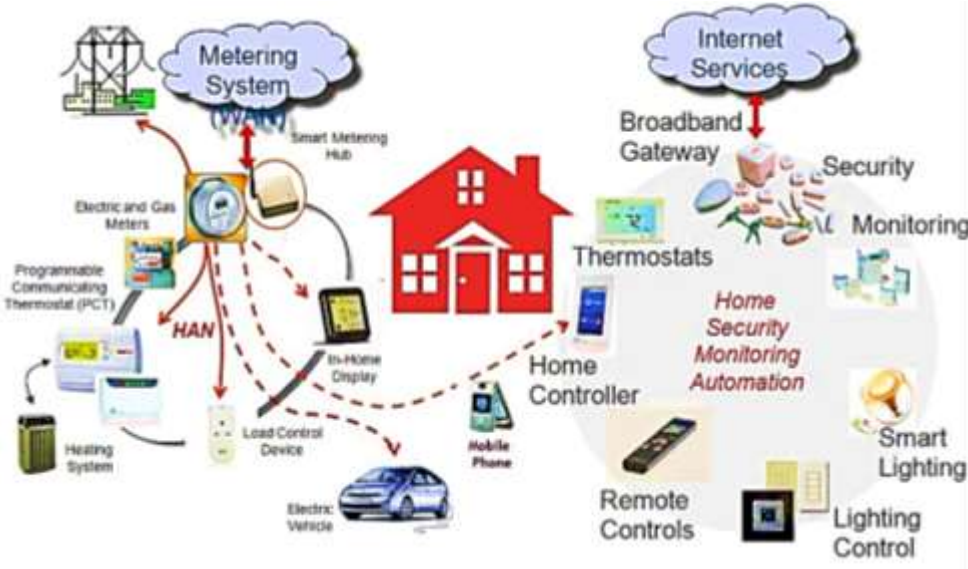
- Standards Dominate
- IEEE 1451.5 Emerges
- OEM Focus
- Wireless Ubiquitous
- $10 - $100B+ Industry
- $10 - $1 Unit Cost

What is ZigBee

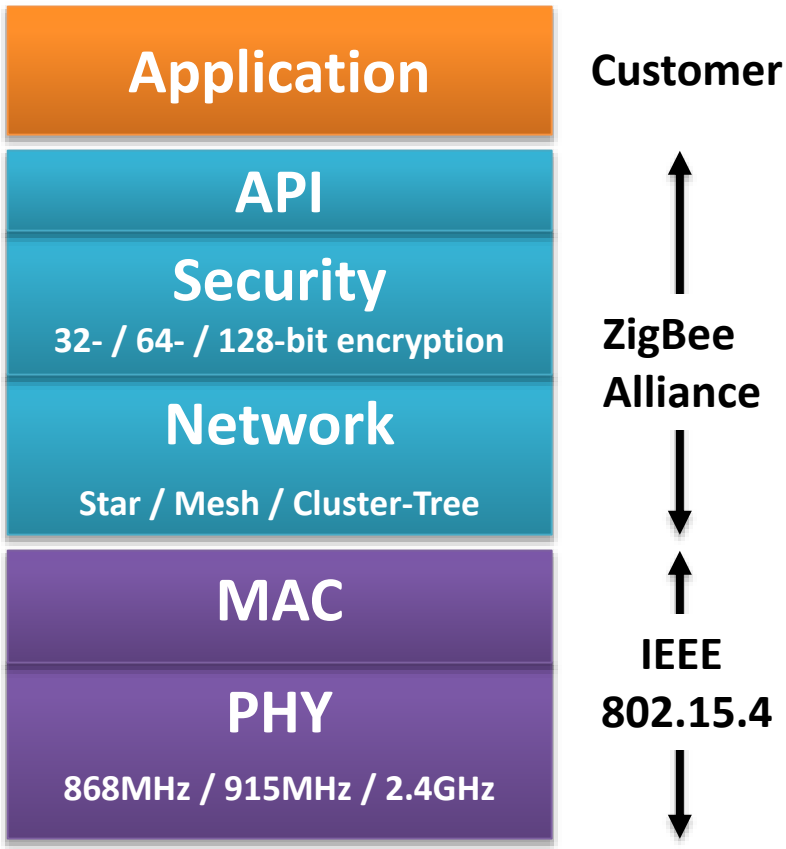
- Specification for a suite of high level communication protocols used to create personal area networks with small, low-power digital radios
- Based on an IEEE 802.15 standard
- For applications that require only a low data rate, long battery life, and secure networking
- Intended to be simpler and less expensive than other WPANs, such as Bluetooth or Wi-Fi
- Secured by 128 bit symmetric encryption keys
- Home automation applications, transmission distances range: 10-100 meters line-of-sight

Applications of ZigBee

- Building Automation
  - Security, HVAC
  - Lighting Control, Access Control
- Personal Health Care
  - Patient Monitoring
  - Fitness Monitoring
- Industrial Control
  - Asset Management, Process Control
  - Environmental Energy Management
- Consumer Electronics
  - TV, DVD Remote
  - PC & Peripherals, Mouse, Keyboard
- Residential/Light Commercial Control
  - Security
  - Lawn & Garden Irrigation



IEEE 802.15.4 and ZigBee



ZigBee Alliance

- Software
- Network, Security & Application layers
- Brand management

IEEE 802.15.4

- Hardware
- Physical & Media Access Control layers

IEEE 802.15.4

- Ultra Low complexity/cost/power consumption
- Data reliability
- Low data rate
  - Data rates of 20 kbps and up to 250 kbps
  - Star or Peer-to-Peer network topologies
  - Support for Low Latency Devices
  - CDMA-CA Channel Access
  - Handshaking
  - Low Power Usage consumption
  - 3 Frequencies bands with 27 channels
  - Extremely low duty-cycle (<0.1%)

802.15.4 Frequency Bands

BAND	COVERAGE	DATA RATE	CHANNELS
2.4 GHz	ISM Worldwide	250 kbps	16
915 MHz	ISM Americas	40 kbps	10
868 MHz	Europe	20 kbps	1

Media Access Control

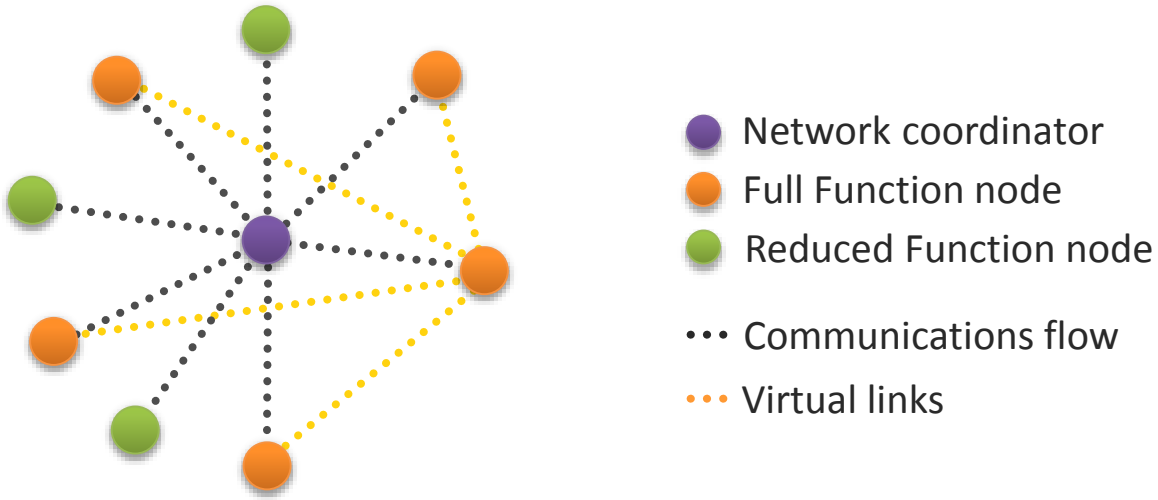
- Direct Sequence Spread Spectrum (DSSS)
  - 2.4 GHz
    - 32-chip PN codes, Chip modulation is MSK at 2.0 Mchips/s
  - 868/915 MHz
    - 15-chip m-sequence, Chip modulation is BPSK at 0.3 Mchips/s
- Code Division Media Access w/ Collision Avoidance (CDMA-CA)
- Bi-Directional Communications (Duplex)
- Dynamic Device Addressing
- Fully Handshaked Protocol
- Optional Guaranteed Time Slots
- 2.4 GHz - 16-ary orthogonal
- 868/915 MHz - differential encoding

Transceiver Characteristics

- Transmit Power
  - Capable of at least 1 mW
  - Power reductions capability required if > 16 dBm (reduce to < 4dBm in a single step)
- Receiver Sensitivity
  - -85 dBm (1 % Packet Error Rate)
- RSSI measurements
  - Packet Strength indication
  - Clear channel assessment
  - Dynamic channel selection

Basic Network Characteristics

- 65,536 network (client) nodes
- Optimized for timing-critical applications
  - Network join time: 30 ms
  - Sleeping slave changing to active: 15 ms
  - Active slave channel access time: 15 ms



Topology Models

- Star Networks (Personal Area Network)
  - Home automation
  - PC Peripherals
  - Personal Health Care
- Peer-to-Peer (ad hoc, self organizing & healing)
  - Industrial control and monitoring
  - Wireless Sensor Networks
  - Intelligent Agriculture

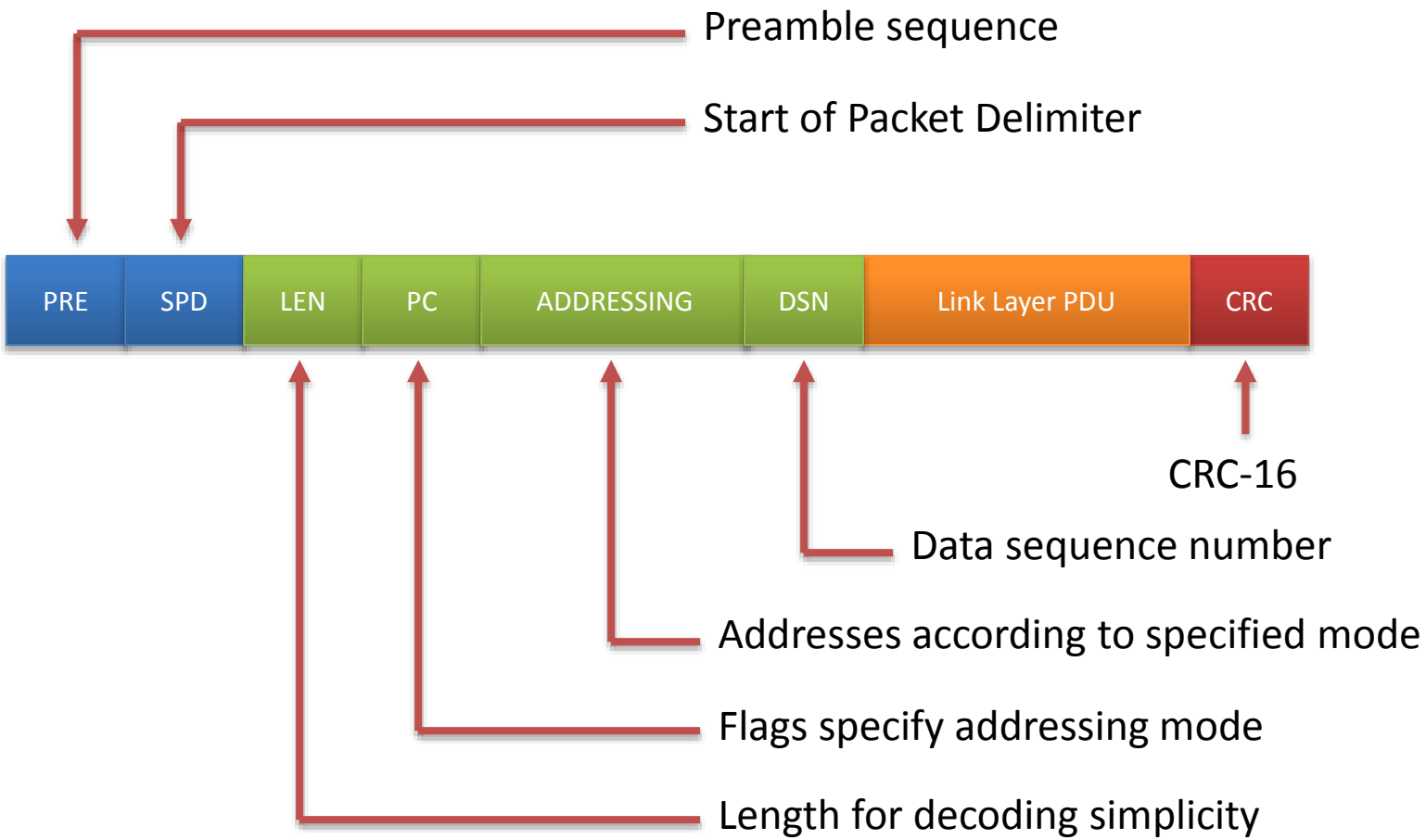
Device Classes

- 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
  - Very simple implementation

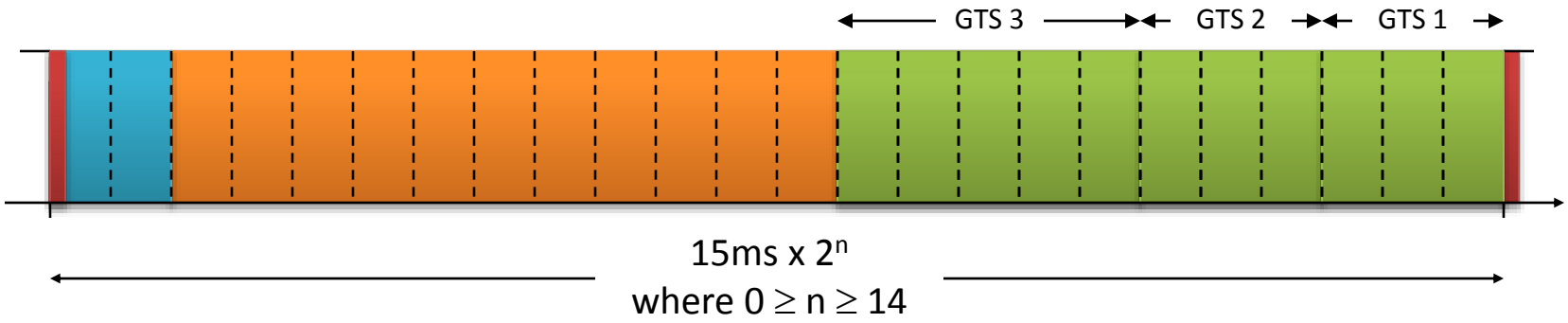
Comparisons

Feature(s)	IEEE 802.11b	Bluetooth	ZigBee
Power Profile	Hours	Days	Years
Complexity	Very Complex	Complex	Simple
Nodes/Master	32	7	64000
Latency	Enumeration upto 3 seconds	Enumeration upto 10 seconds	Enumeration 30ms
Range	100 m	10m	70m-300m
Extendability	Roaming possible	No	YES
Data Rate	11Mbps	1Mbps	250Kbps
Security	Authentication Service Set ID (SSID)	64 bit, 128 bit	128 bit AES and Application Layer user defined

Packet Structure



Optional Frame 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].

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)

Programming with TinyOS

Stay tuned …

References

- Course: Distributed Embedded Systems (UCLA)
  - http://nesl.ee.ucla.edu/courses/csm213b/2008sum/CSM213B_%28Summer_2008%29/Lectures.html
- Course: Wireless Sensor Networks (Michigan)
  - http://web.eecs.umich.edu/~prabal/teaching/eecs598-w10/
- Course: Introduction to Wireless Sensor Networks (Ohio)
  - http://www.cse.ohio-state.edu/~anish/788-12.html