HELSINKI UNIVERSITY OF TECHNOLOGY
SMARAD Centre of Excellence

WPAN – Wireless Personal Area Networks

S-72.4210 Post-Graduate Course in Radio Communications

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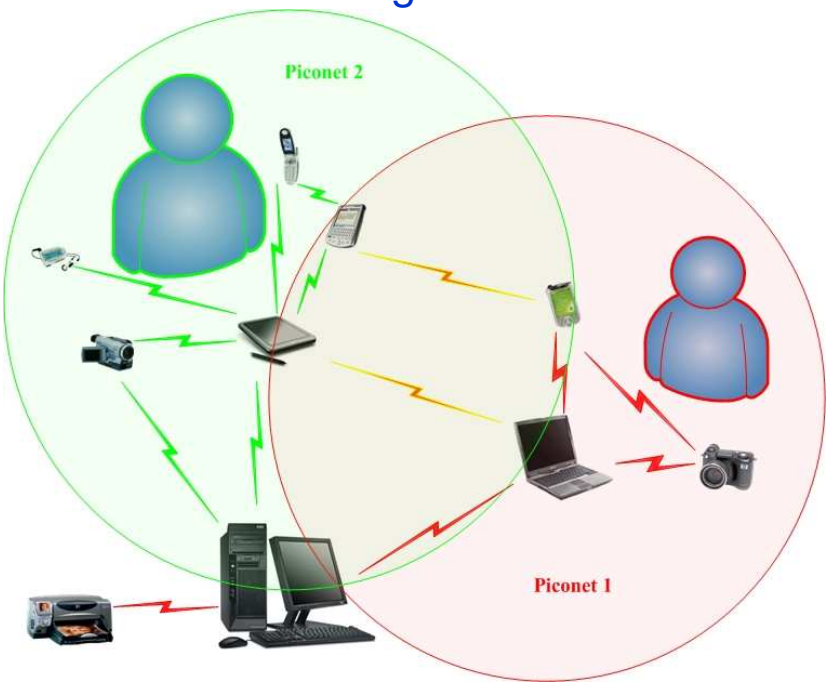
Outline

1. Introduction and applications
2. WPAN Topologies
3. IEEE 802.15 WPAN Working Group
   - Dominating standard – Bluetooth
   - High Rate WPAN IEEE 802.15.3
   - Low Rate WPAN IEEE 802.15.4
   - Mesh WPAN IEEE 802.15.5
4. Conclusions
5. References
6. Homework

Introduction

- WirelessPersonalAreaNetworks
  - Person centered short-range wireless connectivity



Applications

- Applications include
  - Short-range (< 10 m) connectivity for multimedia applications
    - PDAs, Cameras, Voice (hands free devices)
    - High QoS, high data rate (IEEE 802.15.3)
  - Industrial sensor applications
    - Low speed, low battery, low cost sensor networks (IEEE 802.15.4)

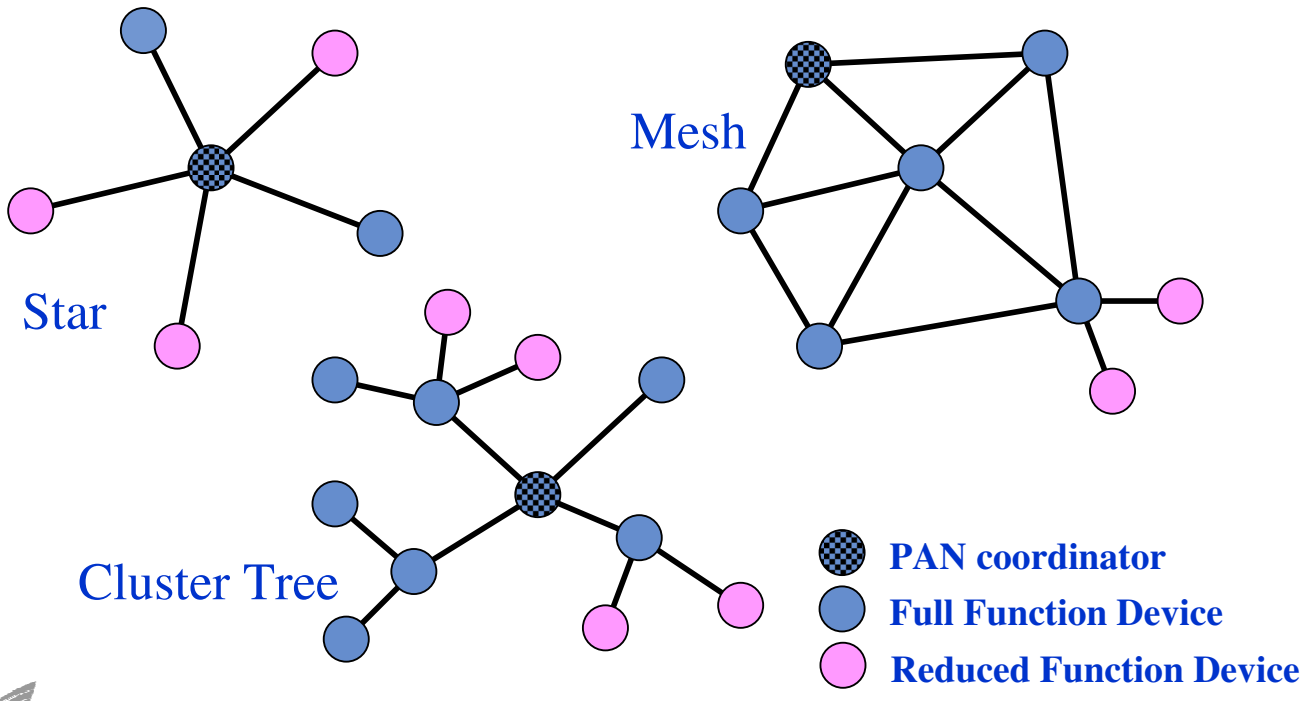
Common goals

- Getting rid of cable connections
- Little or no infrastructure
- Device interoperability

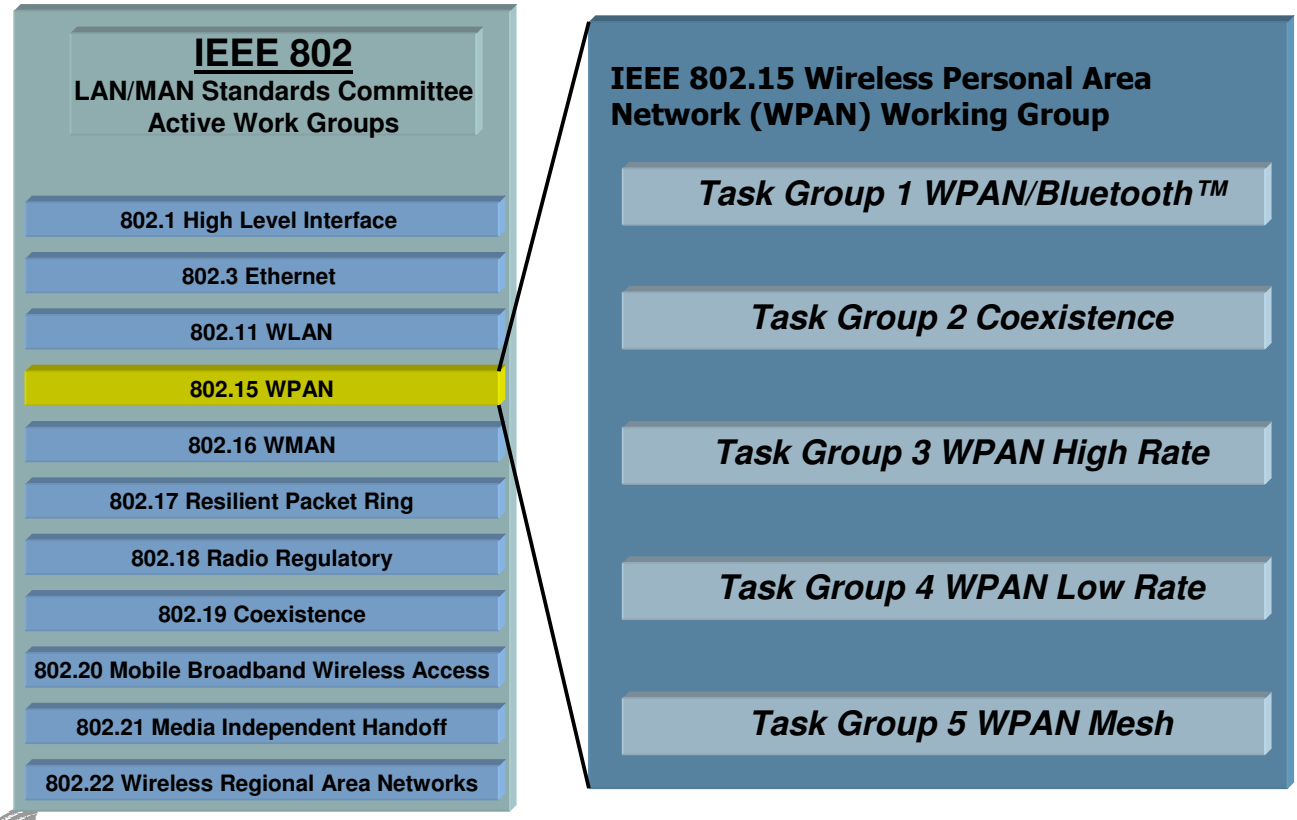
Acronyms and abbreviations

CAP	contention access period
CFP	contention-free period
CSMA-CA	carrier sense multiple access with collision avoidance
CSS	chirp spread spectrum
CTA	channel time allocation
DEV	a short for single device in WPAN piconet
GTS	guaranteed time slot
FFD	full-function device
LR-WPAN	low-rate wireless personal area network
MAC	medium access control
MCTA	management CTA
PAN	personal area network
PHY	physical layer
PPDU	PHY protocol data unit
QoS	quality of service
RFD	reduced-function device
UWB	ultra wide band
WLAN	wireless local area network
WMAN	wireless metropolitan area network
WPAN	wireless personal area network

WPAN Topologies [6]



IEEE 802.15 WPAN Working Group



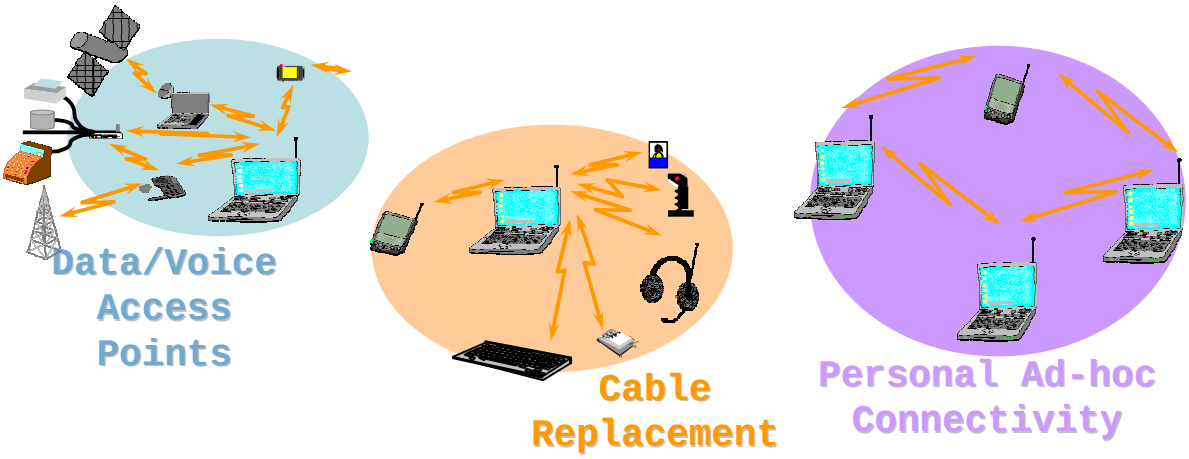
IEEE 802.15 WPAN Standards

IEEE 802.15 (WPAN) standards (table from [1])

IEEE standard	Topic	Data throughput	Suitable applications	QoS needs
802.15.1	Bluetooth	1Mbp	Cell phones, Computers, Personal Digital Assistants (PDAs)/Handheld Personal Computers (HPCs), printers, microphones, speakers, headsets, bar code readers, sensors, displays, pagers, and cellular & Personal Communications Service (PCS) phones.	QoS suitable for voice applications
802.15.2	Coexistence of Bluetooth and 802.11b	N/A	N/A	N/A
802.15.3	High-rate WPAN	>20Mbps	Low power, low cost solutions for portable consumer of digital imaging and multimedia applications	Very high QoS
802.15.4	Low-rate WPAN	< 0.25 Mbps	Industrial, agricultural, vehicular, residential, medical applications, sensors and actuators with very low power consumption and low cost	Relaxed needs for data rate and QoS

Bluetooth - Dominating standard

- Bluetooth is the base for IEEE Std 802.15.1-2002 (rev. 2005)
  - Data rate of 1 Mb/s (2 or 3 Mb/s with enhanced data rate)
  - Robust short range communications

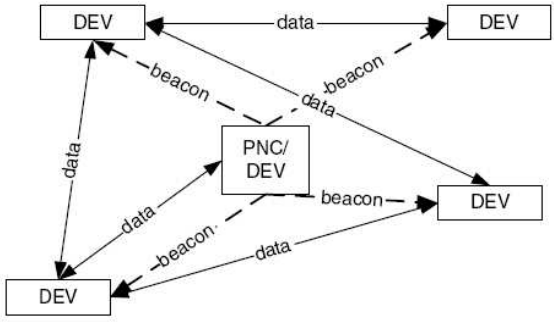


IEEE 802.15 WPAN High Rate (HR) Task Group 3

- Task Group 3
  - First high rate WPAN standard: IEEE Std 802.15.3-2003 (HR-WPAN)
- Task Group 3a
  - Alternative PHY using UWB
- Task Group 3b
  - Improved implementation and interoperability of the IEEE Std 802.15.3 MAC
  - Expected outcome during 2006
- Task Group 3c
  - WPAN at mm-waves (57-64 GHz)

IEEE Std 802.15.3-2003 (HR) (1)

- WPAN with high data rate (HR) IEEE Std 802.15.3-2003
  - Data rates from 11 Mbps to 55 Mbps
  - Ad hoc peer-to-peer networks (piconets)
  - Each piconet is controlled by piconet coordinator (PNC)
    - Sends beacon for piconet information and timing
    - Controls superframe structures



IEEE Std 802.15.3-2003 (HR) (2)

- Single carrier of 15 MHz bandwidth and trellis coding

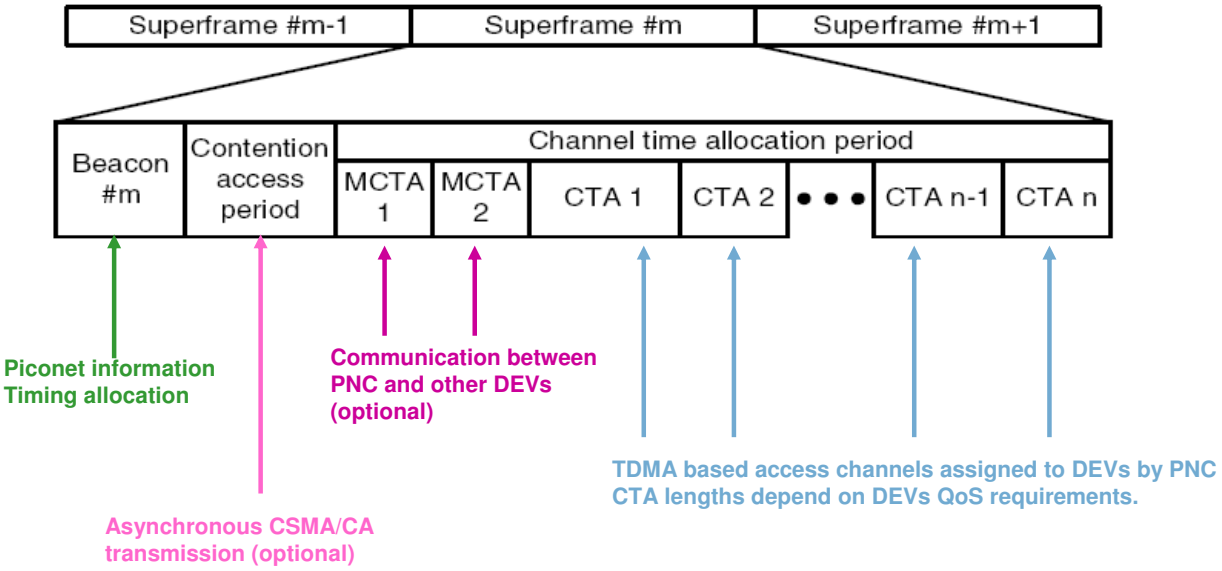
Modulation type	Coding	Data rate
QPSK	8-state TCM	11 Mb/s
DQPSK	none	22 Mb/s
16-QAM	8-state TCM	33 Mb/s
32-QAM	8-state TCM	44 Mb/s
64-QAM	8-state TCM	55 Mb/s

- Frequency band of 2.4-2.4835 GHZ
  - Coexistence with 802.11b
    - Passive scanning
    - Dynamic channel selection
    - A channel plan that minimize channel overlap
    - Transmit power control

CHNL_ID	Center frequency	High-density	802.11b coexistence
1	2.412 GHz	X	X
2	2.428 GHz	X	
3	2.437 GHz		X
4	2.445 GHz	X	
5	2.462 GHz	X	X

IEEE Std 802.15.3-2003 (HR) (3)

- Piconet timing is based on superframes



IEEE 802.15 WPAN Task Group 3a

- In 2003 Task Group 3a was formed for even higher data rates utilizing UWB at 3.1 – 10.6 GHz
- Two candidate proposals were merged (out of 23)
  1. MultiBand OFDM (MB-OFDM)
     - Supported by WiMedia Alliance (HP, Intel, Microsoft, Nokia etc.)
     - Data rates from 53.3 Mbps to 480 Mbps
     - 122 sub-carriers, QPSK modulation
  2. Direct sequence-UWB (DS-UWB)
     - Supported by UWB Forum (Motorola, Mitsubishi, U.S. Navy etc.)
     - Data rates from 28 Mbps to 1320 Mbps
     - Direct sequence spreading (DSS) for pulses of binary phase shift keying (BPSK) and quatemary bi-orthogonal keying (4BOK)
- Project was dissoluted in Jan 2006 after long lasting fight between the two proposals

IEEE 802.15 WPAN Task Group 3c

- mm-WPAN
  - High bandwidth (57-64 GHz) -> high data rate (2 Gbps required, 3 Gbps desired)
    - Replacement of all cables, e.g., HDTV video from receiver to projector
  - Allows high coexistence with current systems
    - No competitors yet on the same band
  - High free space loss
    - Good for frequency re-use
    - Fits to WPAN consept (< 10 m distance)
  - Standard expected to be released during 2007 with first implementations during 2008

IEEE 802.15 WPAN Low Rate (LR) Task Group 4

- Task Group 4
  - LR-WPAN Standard: IEEE Std 802.15.4-2003 (LR WPAN)
  - Also known as ZigBee
- Task Group 4a
  - Alternative PHYs: UWB Impulse Radio and Chirp Spread Spectrum (CSS)
- Task Group 4c
  - Specific enhancements and clarifications to the IEEE Std 802.15.4-2003

IEEE Std 802.15.4-2003 (LR) (1)

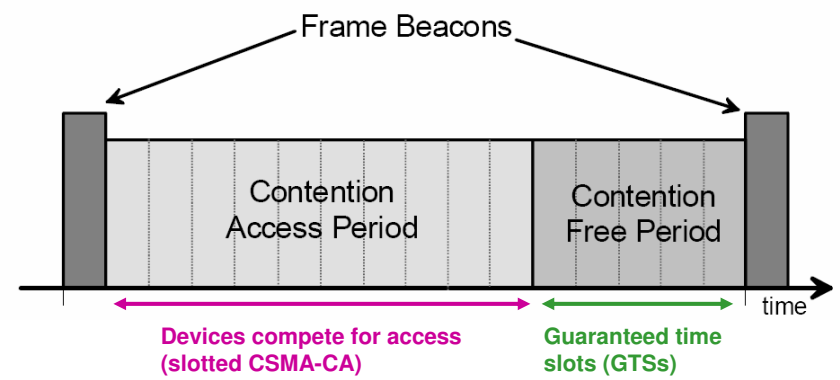
- WPAN for low data rate (LR-WPAN) IEEE Std 802.15.4-2003
  - Low complexity
  - Multi-month to multi-year battery life
  - Peer-to-peer and star topologies
  - Data rates from 20 kb/s (@868 MHz) to 250 kb/s (@2450 MHz)
- Applications
  - Sensors, interactive toys (joysticks etc.), remote controls

PHY (MHz)	Frequency band (MHz)	Spreading parameters		Data parameters		
		Chip rate (kchip/s)	Modulation	Bit rate (kb/s)	Symbol rate (ksymbol/s)	Symbols
868/915	868–868.6	300	BPSK	20	20	Binary
	902–928	600	BPSK	40	40	Binary
2450	2400–2483.5	2000	O-QPSK	250	62.5	16-ary Orthogonal

Frequency bands and data rates for IEEE Std 802.15.4

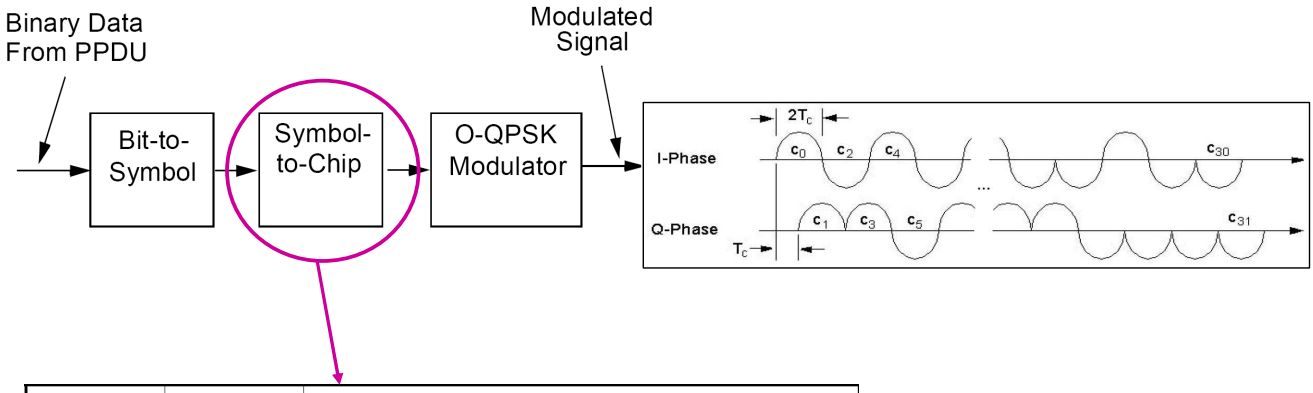
IEEE Std 802.15.4-2003 (LR) (2)

- Two types of devices
  - Full-function (FFD) and reduced-function (RFD)
- FFD can perform as PAN coordinator
  - Controls an optional superframe structure
    - Provides beacons for synchronization and optional guaranteed time slots for low-latency applications



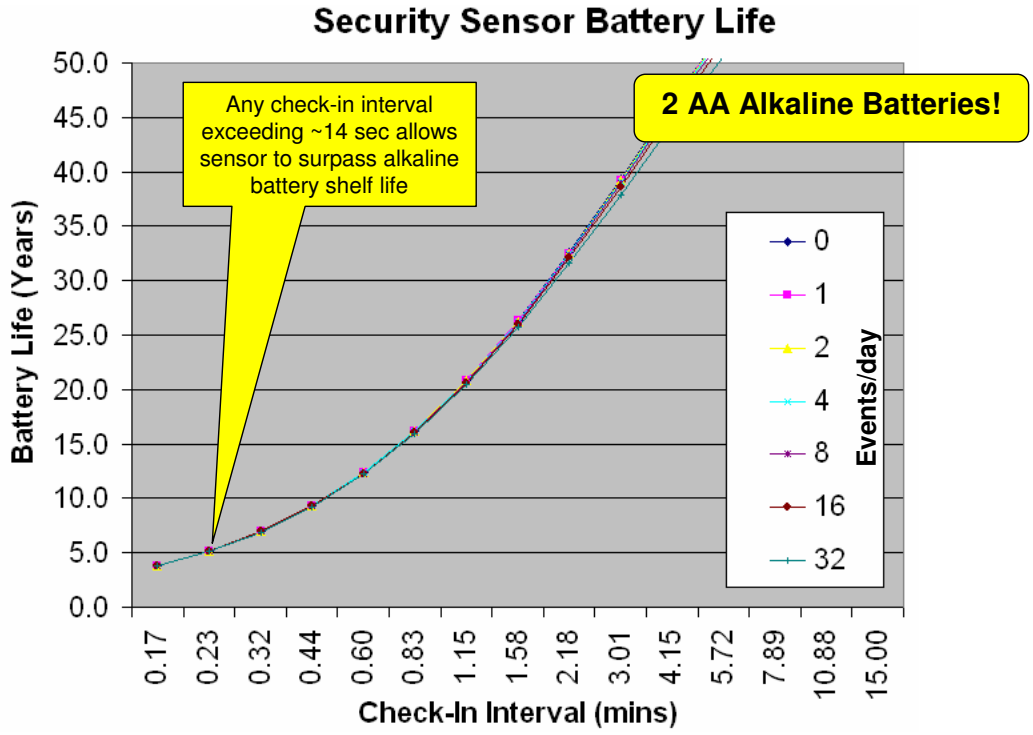
IEEE Std 802.15.4-2003 (LR) (3)

- Modulation and spreading (@ 2450 MHz)



Data symbol (decimal)	Data symbol (binary) (b_0, b_1, b_2, b_3)	Chip values ($c_0\ c_1 \dots c_{30}\ c_{31}$)
0	0 0 0 0	1 1 0 1 1 0 0 1 1 1 0 0 0 0 0 1 1 0 1 0 1 0 0 1 0 0 0 1 0 1 1 1 0
1	1 0 0 0	1 1 1 0 1 1 0 1 1 0 0 1 1 1 0 0 0 0 0 1 1 0 1 0 1 0 0 1 0 0 0 1 0
2	0 1 0 0	0 0 1 0 1 1 1 0 1 1 0 1 1 0 0 1 1 1 0 0 0 0 0 1 1 0 1 0 1 0 0 1 0

Battery Life Case Study –Peel 'N Stick Security Sensors (Current IEEE 802.15.4 compliant hardware)



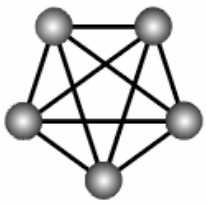
Source: [5]

Differences: Bluetooth vs. ZigBee (TG4) [7]

- **Modulation technique**
  Bluetooth: Frequency Hopping Spread Spectrum (FHSS)
  ZigBee: Direct Sequence Spread Spectrum (DSSS)
- **Protocol stack size**
  Bluetooth: 250K bytes
  ZigBee: 28K bytes
- **Battery**
  Bluetooth: Intended for frequent recharging
  ZigBee: Not rechargeable (one reason batteries will last for up to 10 years)
- **Maximum network speed**
  Bluetooth: 1M bit/sec
  ZigBee: 250K bit/sec
- **Network range**
  Bluetooth: 1 or 100 meters, depending on radio class
  ZigBee: Up to 70 meters
- **Typical network join time**
  Bluetooth: 3 seconds
  ZigBee: 30 milliseconds

IEEE 802.15 WPAN Task Group 5 (TG5)

- PHY and MAC layer mechanisms for mesh networking

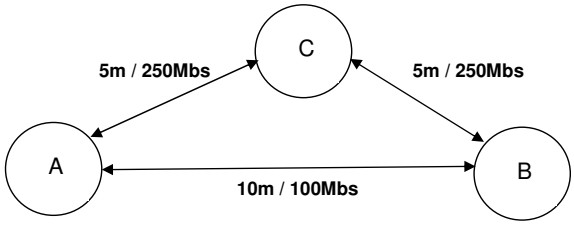


Mesh network

- Mesh topology allows:
  I. Network coverage extension
  II. Enhanced reliability via route redundancy
  III. Easier network configuration
  IV. Battery life due to fewer retransmissions

IEEE 802.15.5 WPAN Mesh

- Additional promises made by the Mesh Task Group:
  - Extends distance and communication speed
  - Allows effortless installation of a communications infrastructure
  - Self-configures, is self diagnostic and self-healing
  - Provides resiliency, with no single point of failure



Enhancing communication speed

Conclusions

- IEEE 802.15 WPAN Work Group was introduced
  - WPAN standards under active development
    - Increasing data rates to be expected
    - Low power consumption
    - Self-configuring networks
    - Coexistense of 802.11 is an issue
- Future WPAN interests
  - mm-wave systems (@ 60 GHz)
  - Mesh networks (relaying)
  - MIMO?
    - Not (yet) implicitly included in IEEE 802.15 framework
    - Enables enhanced reliability (diversity techniques) and capacity (spatial multiplexing)

References

[1] IEEE 802.15 Working Group for WPAN, http://ieee802.org/15/index.html

[2] R. Prasad and L. Gavrilovska, "Research Challenges for Wireless Personal Area Networks", http://www.eng.ukm.my/~micc2001/html/prasad.pdf

[3] T. Siep, "IEEE 802.15.1 Tutorial", Texas Instruments, http://grouper.ieee.org/groups/802/15/pub/2001/Jan01/01046r1P802-15_WG-802-15-1-TG1-Tutorial.ppt

[4] G. Roberts, "IEEE 802.15 Overview of WG and Task Groups ", STMicroelectronics, http://grouper.ieee.org/groups/802/15/pub/2003/Jan03/03053r0P802-15_PC-Overview-of-WG15-and-Task-Groups.ppt

[5] F. Martin, et. All, "IEEE 802.15.4 PHY Capabilities", May 2004, http://grouper.ieee.org/groups/802/15/pub/04/15-04-0227-03-004a-ieee-802-15-4-phy-layer-and-implementation.ppt

[6] Ed Callaway, Motorola, "ZigBee Tutorial", July 2003, http://grouper.ieee.org/groups/802/15/pub/03/15-03-0305-00-0040-zigbee-tutorial.ppt

[7] D. Rotella and R. Rotella, "IEEE 802.15.3a", http://faculty.eng.fiu.edu/~zhuha/tnc6270/presentations_slides/IEEE802153a.ppt

Homework

I. In the IEEE Std 802.15.4 (Low Rate WPAN), the Offset-QPSK (O-QPSK) modulation is used for channels at 2.4 GHz. Explain how O-QPSK differs from QPSK and what is the advantage of using it.

II. Assuming you have the following device pairs/groups you wish to connect wireless:

a) Video projector + HDTV receiver + Digital video camera (within 5 m distance)

b) Hands free headset + IP telephone (e.g. Skype) + Webcam + PC

c) 4 joysticks + Video game console

Please explain briefly which of the presented WPAN solutions would you select for communication inside each of the groups (a-c). (The selected solution does not have to be currently on the market.)