Wireless Personal Area Networks (WPANs)

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These slides are available on-line at:
http://www.cse.wustl.edu/~jain/talks/wpans.htm

Overview

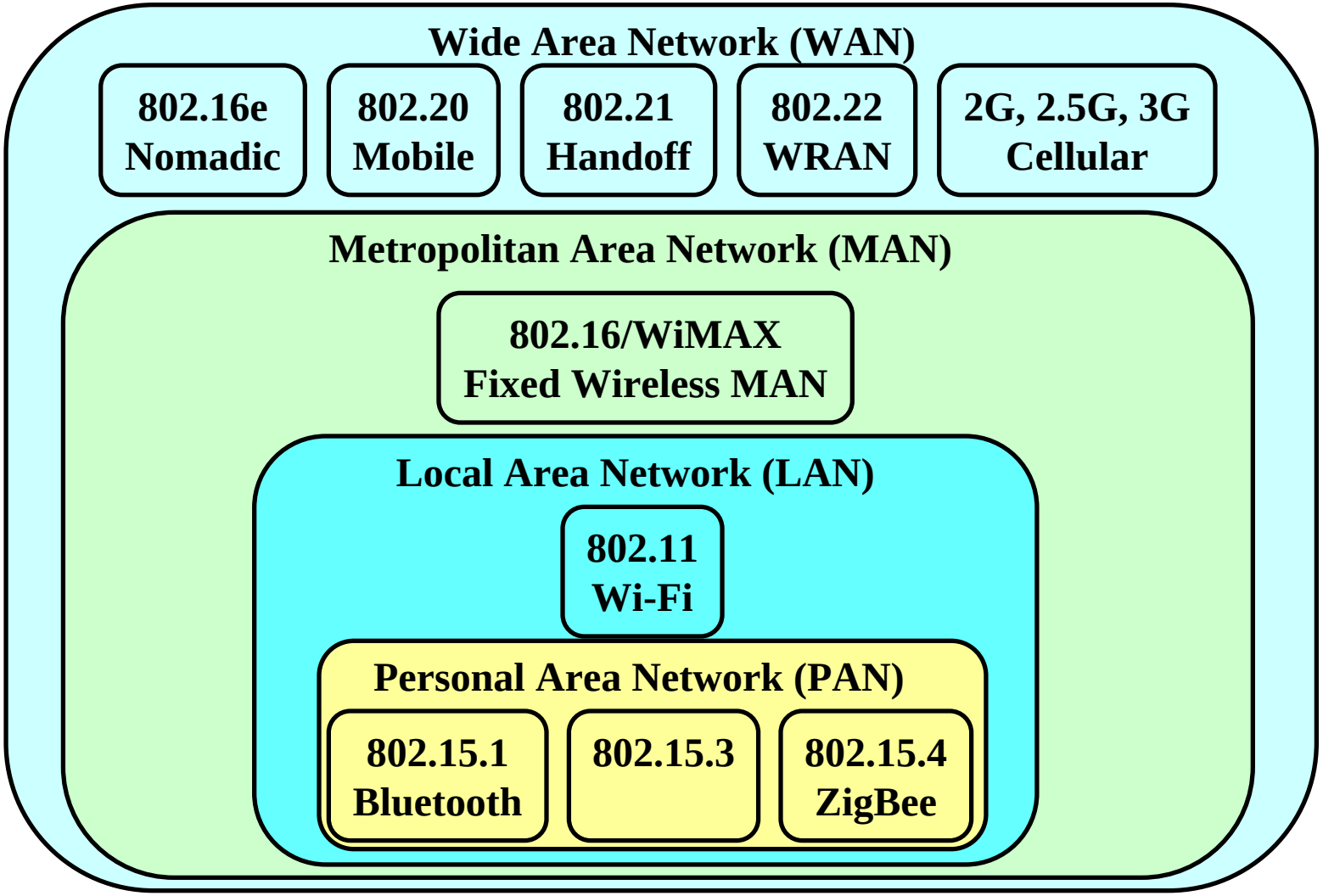
1. Telecommunication Trends
2. Wireless Standards Overview
3. Bluetooth
4. Ultra-Wideband
5. ZigBee

Telecom Revenue

	Revenue in Billions						
	2003	2004	2005	2006	2007	2008	Annual Growth
Video	0.2	0.3	.05	1.0	1.6	2.5	65.7%
Consumer Broadband	2.8	3.5	4.0	4.2	4.6	4.8	11.4%
Consumer long distance	20.7	18.2	16.0	13.6	11.3	9.2	-15.0%
Business local	26.3	26.7	26.4	26.1	25.8	25.5	-0.6%
Business long distance	26.1	24.5	23.0	21.3	19.7	18.2	-7.0%
Business data	44.8	45.6	46.6	47.1	46.8	45.4	0.3%
Consumer local	46.9	42.2	39.0	36.2	34.0	32.3	-7.25%
Wireless	91.5	108.7	119.2	132.8	144.5	153.6	10.9%
Total	260.7	271.5	277.0	285.0	291.3	294.9	2.5%

- Long distance is disappearing.
- Most of the revenues are going to be from wireless.
- Source: Instat/MDR (Business Week, Feb 28, 2005)

Wireless Standards



Bluetooth Products




Headsets Audio Game Controller Keyboard GPS

- Printers, faxes, digital cameras…
- 720 kbps to 10m
- Competes with infrared, which has a range of 1m, requires line of sight and has a low data rate

Bluetooth

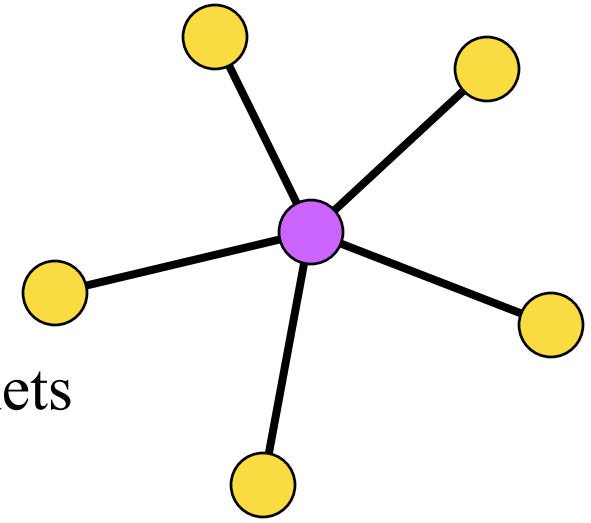
- Started with Ericsson's Bluetooth Project in 1994
- Named after Danish king Herald Blatand (AD 940-981) who was fond of blueberries
- Radio-frequency communication between cell phones over short distances
- Intel, IBM, Nokia, Toshiba, and Ericsson formed Bluetooth SIG in May 1998
- Version 1.0A of the specification came out in late 1999.
- IEEE 802.15.1 approved in early 2002 is based on Bluetooth
- Key Features:
  - Lower Power: 10 μA in standby, 50 mA while transmitting
  - Cheap: $5 per device
  - Small: 9 mm^2 single chips

Bluetooth: Details

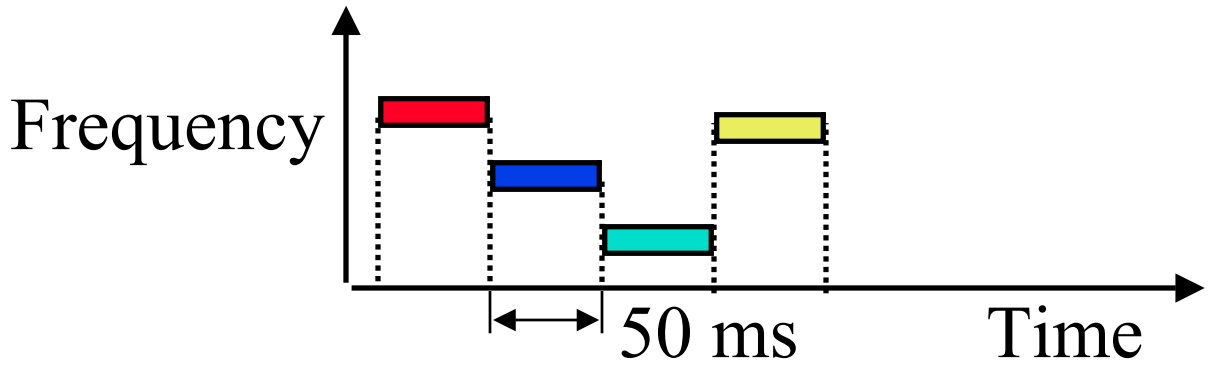
- **Frequency Range:** 2402 - 2480 MHz (total 79 MHz band)
  23 MHz in some countries, e.g., Spain
- **Data Rate:** 1 Mbps (Nominal) 720 kbps (User)
- **Channel Bandwidth:** 1 MHz
- **Range:** Up to 10 m can be extended further
- **RF hopping:** 1600 times/s ⇒ 625 μs/hop
- **Security:** Challenge/Response Authentication. 128b Encryption
- **TX Output Power:**
  - Class 1: 20 dBm Max. (0.1W) – 100m
  - Class 2: 4 dBm (2.5 mW)
  - **Class 3**: 0 dBm (1mW) – 10m
- **Ref:** http://www.bluetooth.com/
  http://www.bluetooth.org/
  http://grouper.ieee.org/groups/802/15/index.html

Piconet

- Piconet is formed by a master and many slaves
  - Up to 7 active slaves.
    Slaves can only transmit when requested by master
  - Up to 255 Parked slaves
- Active slaves are polled by master for transmission
- Each station gets a 8-bit parked address
  $\Rightarrow$ 255 parked slaves/piconet
- The parked station can join in 2ms.
- Other stations can join in more time.
- A device can participate in multiple piconets
  $\Rightarrow$ complex schedule

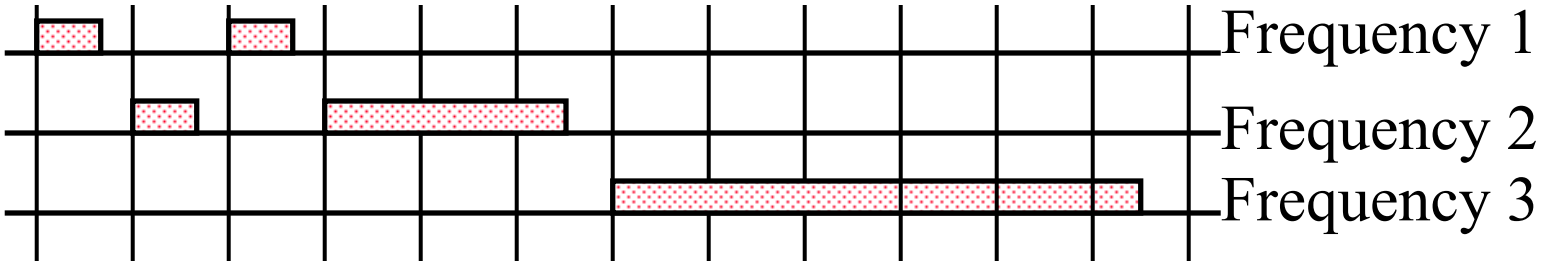


Frequency Hopping Spread Spectrum



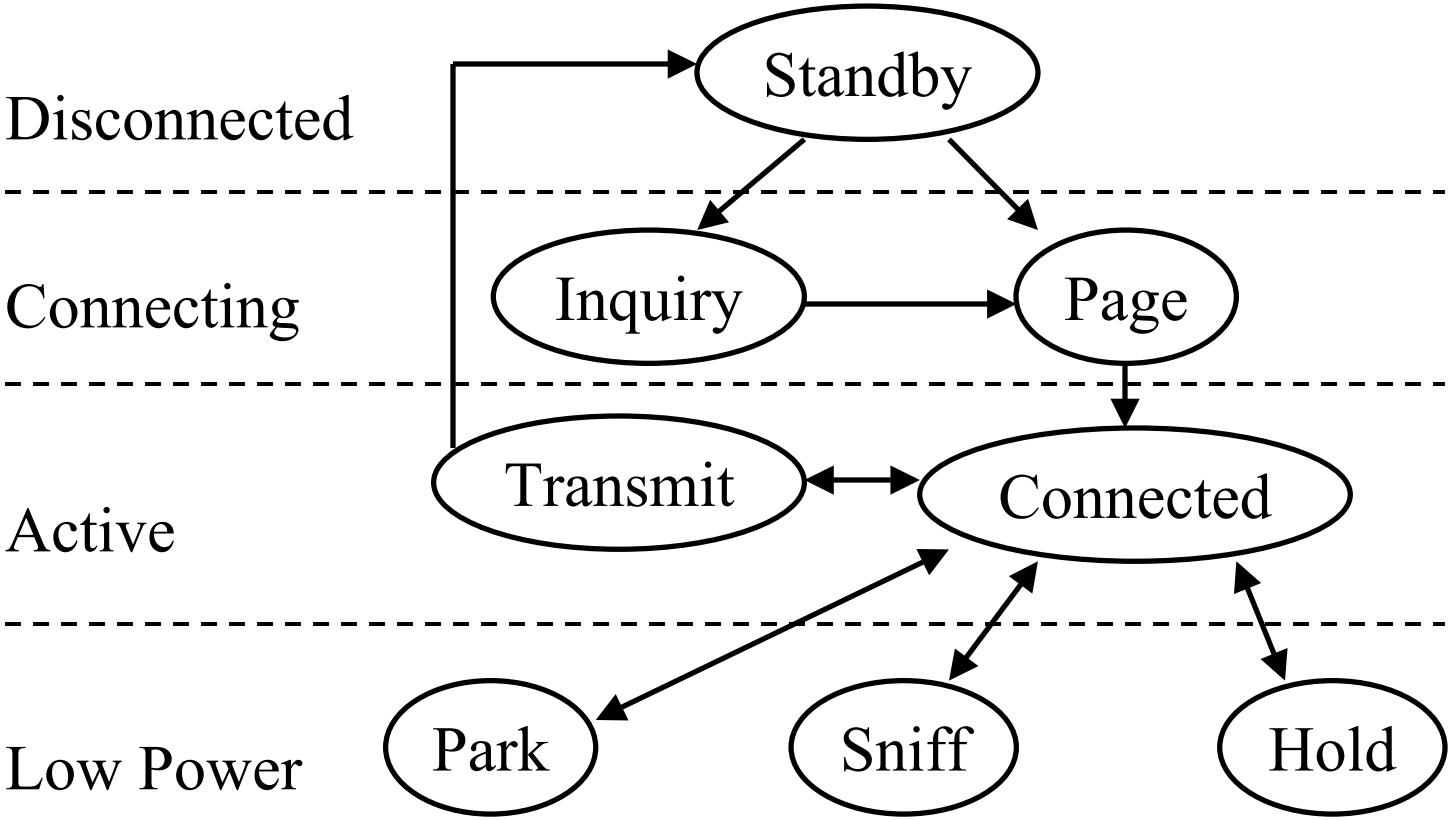
- Pseudo-random frequency hopping
- Spreads the power over a wide spectrum
  ⇒Spread Spectrum
- Developed initially for military
- Patented by actress Hedy Lamarr
- Narrowband interference can't jam

Frequency Hopping Sequences



- 625 μs slots
- Time-division duplex (TDD)
  ⇒ Downstream and upstream alternate
- Master starts in even numbered slots only.
- Slaves start in odd numbered slots only
- *lsb* of the clock indicates even or odd
- Slaves can transmit in one slot right after receiving a packet from master
- Packets = 1 slot, 3 slot, or 5 slots long
- The frequency hop is skipped during a packet.

Bluetooth Operational States



Bluetooth Operational States (Cont)

- **Standby**: Initial state
- **Inquiry**: Master sends an inquiry packet. Slaves scan for inquiries and respond with their address and clock after a random delay (CSMA/CA)
- **Page**: Master in page state invites devices to join the piconet. Page message is sent in 3 consecutive slots (3 frequencies). Slave enters page response state and sends page response including its device access code.
- Master informs slave about its clock and address so that slave can participate in piconet. Slave computes the clock offset.
- **Connected**: A short 3-bit logical address is assigned
- **Transmit**:

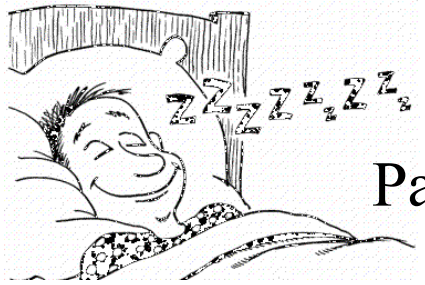
Energy Management in Bluetooth

Three inactive states:

1. **Hold**: No ACL. SCO continues. Node can do something else: scan, page, inquire
2. **Sniff**: Low-power mode. Slave listens only after fixed sniff intervals.
3. **Park**: Very Low-power mode. Gives up its 3-bit active member address and gets an 8-bit parked member address.

- Packets for parked stations are broadcast to 3-bit zero address.

Sniff 

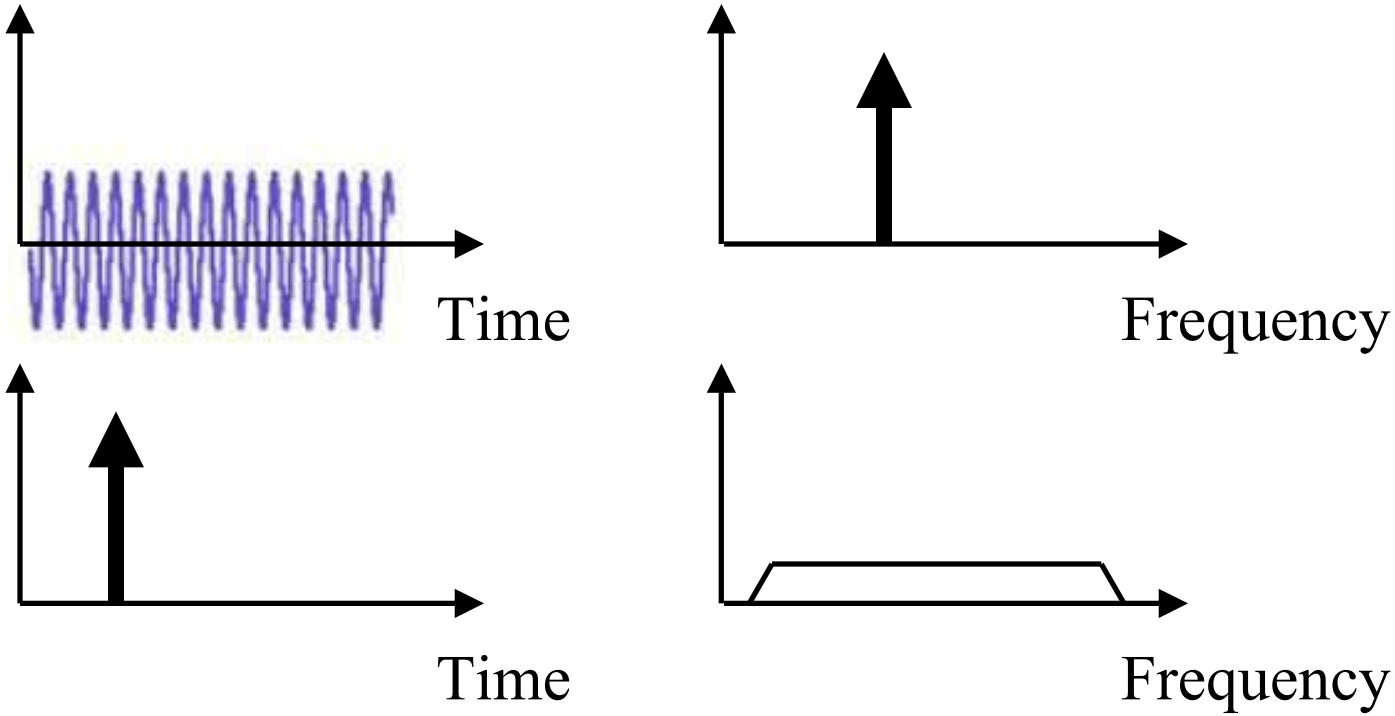


Park

Power per MB

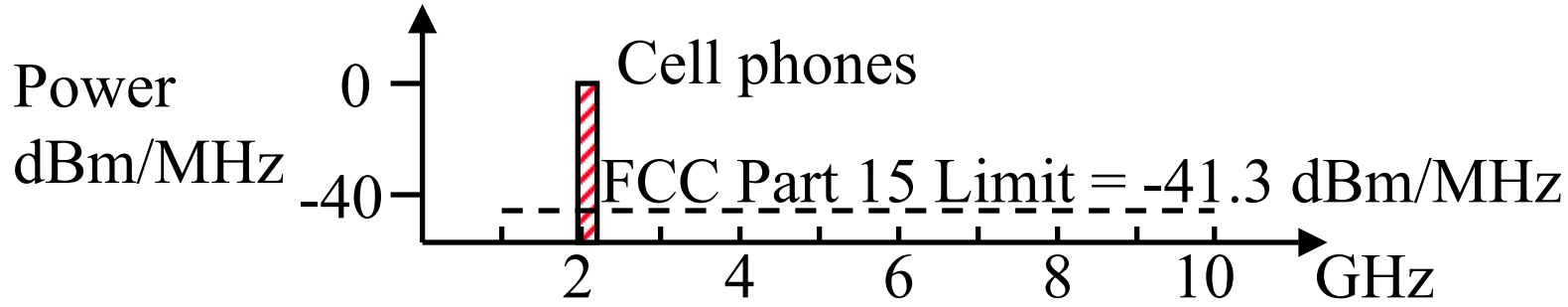
Type	Bit rate	TX Power	mJoules/MB
802.11b	11Mb	50mW	36.4
802.11g	54Mb	50mW	7.4
802.11a	54Mb	200mW	29.6
802.15.1	1Mb	1mW	8.0
802.15.3	55Mb	200uW	0.03

Ultra-Wideband



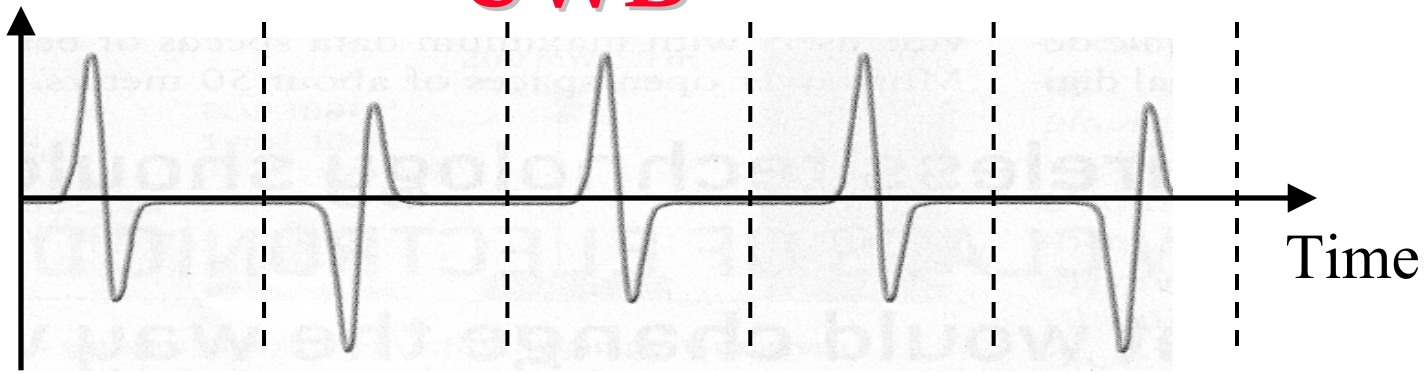
- An impulse in time domain results in a ultra wide spectrum in frequency domain and essentially looks like a white noise to other devices

Ultra-Wideband (UWB)



- FCC rules restrict the maximum noise generated by a wireless equipment (0 dBm = 1mW, -40 dBm = 0.1 μW)
- It is possible to generate very short (sub-nano sec) pulses that have spectrum below the allowed noise level
  ⇒ Possible to get Gbps using 10 GHz spectrum
- FCC approved UWB operation in 2002
- UWB will be used for high-speed over short distances
  ⇒ Wireless USB
- UWB can see through trees and underground (radar)
  ⇒ collision avoidance sensors, through-wall motion detection
- Position tracking: cm accuracies. Track high-value assets

UWB



- Sub-nanosecond impulses are sent many million times per second
- Became feasible with high-speed switching semiconductor devices
- Pulse width = 25 to 400 ps
- Impulses may be position, amplitude, or polarity modulated
- 0.25 ns Impulse ⇒ 4 B pulses/sec ⇒ 100's Mbps
- Two leading proposals: DS-UWB and MB-OFDM

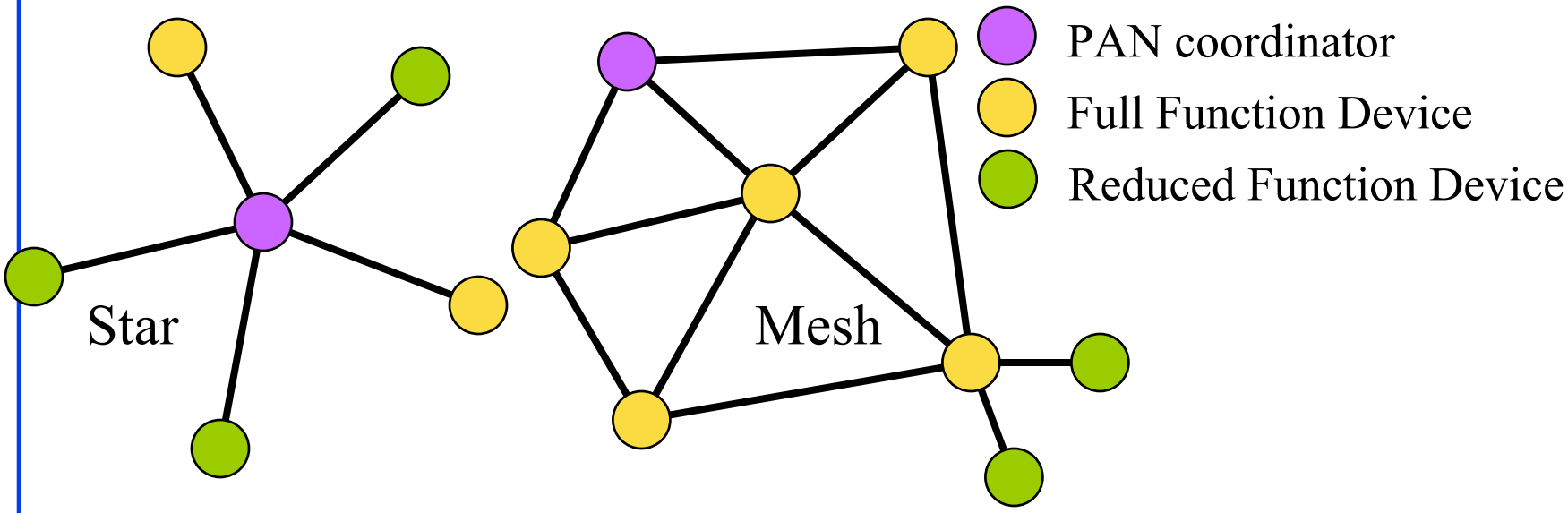
Advantages of UWB

- Very low energy consumption: Good Watts/Mbps
- Line of sight not required. Passes through walls.
- Sub-centimeter resolution allows precise motion detection
- Pulse width much smaller than path delay
  $\Rightarrow$ Easy to resolve multipath
  $\Rightarrow$ Can use multipath to advantage
- Difficult to intercept (interfere)
- All digital logic $\Rightarrow$ Low cost chips
- Small size: 4.5 mm2 in 90 nm process for high data rate designs

ZigBee

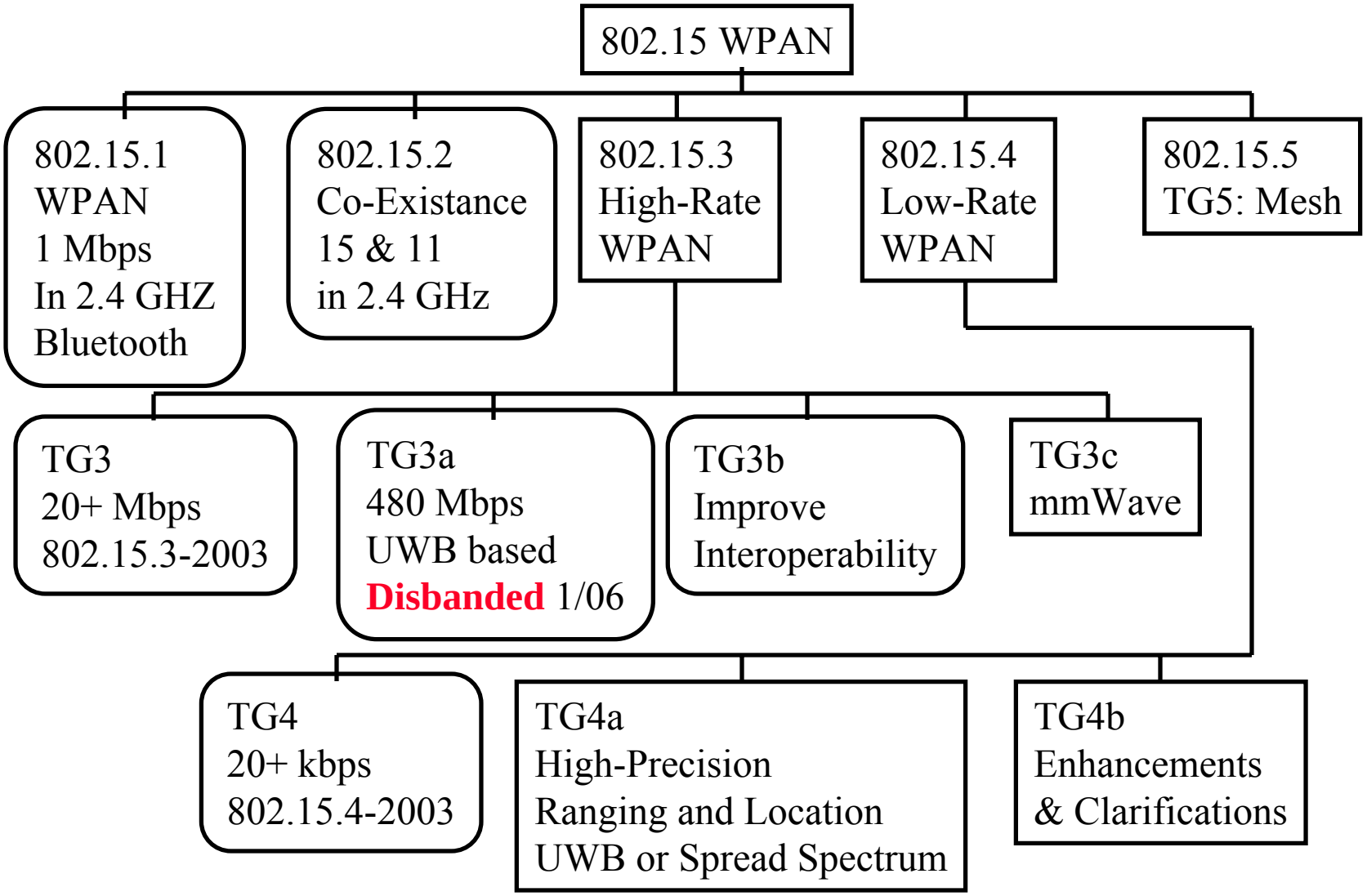
- Ultra-low power, low-data rate, industrial monitoring and control applications requiring small amounts of data, turned off most of the time (<1% duty cycle),
  e.g., wireless light switches, meter reading, patient monitoring
- IEEE 802.15.4
- Less Complex. 32kB protocol stack vs 250kB for Bluetooth
- Range: 1 to 100 m, up to 65000 nodes.
- Tri-Band:
  - 16 Channels at 250 kbps in 2.4GHz ISM
  - 10 Channels at 40 kb/s in 915 MHz ISM band
  - One Channel at 20 kb/s in European 868 MHz band
- Ref: ZigBee Alliance, http://www.ZigBee.org

Network Topology



- Two types of devices:
  - Full Function Devices (FFD) for network routing and link coordination
  - Reduced Function Devices (RFD): Simple send/receive devices

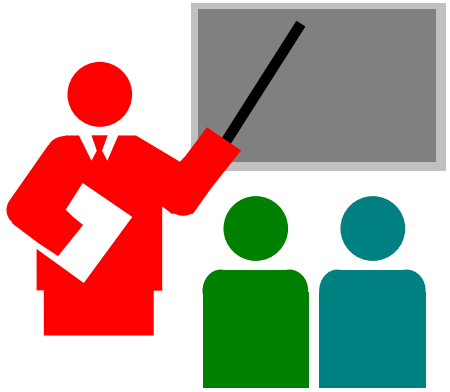
IEEE 802.15 WPAN Activities



Millimeter Wave WPANs

- Millimeter = Approx. 60 GHz and up
- 9.9 GHz allocated by FCC between 57 to 95 GHZ
- License based on interference protection on a link-by-link basis for outdoor use
- No license required for indoor use
- Can send multi-gbps over short distances
- Wireless Gigabit Ethernet

Summary



1. Wireless personal area networks are used for 1-10m communications
2. Medium rate: Bluetooth – 720 kbps, uses Frequency hopping, has application specific profiles
3. High rate: UWB – 480 Mbps, 528 MHz bands,
4. Low rate: ZigBee – 20 kbps, longer distance, includes routing

References

- See Reading list http://www.cse.wustl.edu/~jain/cse574-06/reading.htm