

18-452/18-750
Wireless Networks and Applications
Lecture 18: PAN

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Spring Semester 2018
<http://www.cs.cmu.edu/~prs/wirelessS18/>

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IEEE 802.15: Personal Area Networks

- Target deployment environment: communication of personal devices working together
 - » Short-range
 - » Low Power
 - » Low Cost
 - » Small numbers of devices
- Four groups of standards:
 - » IEEE 802.15.1 – “Bluetooth”
 - » IEEE 802.15.2 – Interoperability (e.g. WiFi)
 - » IEEE 802.15.3 – High data rate WPAN (WiMedia)
 - » IEEE 802.15.4 – Low data rate WPAN (ZigBee)

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Outline

- 802.15 protocol overview
- Bluetooth
- Personal Area Networks – 802.15
 - » Applications and positioning
 - » Bluetooth
 - » High speed WPAN
 - » Zigbee
 - » Other
- UWB

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Some Common Themes

- Master/slave notion
 - » Or simple node versus coordinator
- Use of “piconets”
 - » Small groups of devices managed by a master or coordinator
 - » Scalability is not a concern
- Support for QoS
 - » Want to support voice and other media
- But many variants in how this functionality is supported

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Bluetooth

- Think USB, not Ethernet
 - » Cable replacement technology
- Originally defined as IEEE 802.15.1, but standard is now maintained by the Bluetooth Special Interest Group
 - » Created by Ericsson
- Some features:
 - » Up to 1 Mbps connections (original version)
 - » 1600 hops per second FHSS
 - » Includes synchronous, asynchronous, voice connections
 - » Piconet routing
- Small, low-power, short-range, cheap, versatile radios
- Used as Internet connection, phone, or headset
- Master/slave configuration and scheduling

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IEEE 802.15.1

- Adopted the Bluetooth MAC and PHY specifications
- IEEE 802.15.1 and Bluetooth are almost identical regarding physical layer, baseband, link manager, logical link control and adaptation protocol, and host control interface
- Range of up to 30 feet, uses FHSS
- Data transfer rates of up to 1 Mbps
 - » Up to 3 Mbps for version 2
- Not designed to carry heavy traffic loads

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Bluetooth Standards

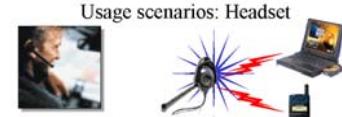
- Core specifications: defines the layers of the Bluetooth protocol architecture
 - » Radio - air interface, txpower, modulation, FH
 - » Baseband - power control, addressing, timing, connections..
 - » Link manager protocol (LMP) - link setup & mgmt, incl. authentication, encryption, ...
 - » Logical link control and adaptation protocol (L2CAP) - adapts upper layer to baseband
 - » Service discovery protocol (SDP) – device info, services and characteristics.

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Bluetooth “Profiles”

- Profile specifications describe the use of BT in support of various applications
 - » Includes which parts of the core specification are mandatory, optional or not applicable
- Data and voice access points
 - » Real-time voice and data transmissions
- Cable replacement
 - » Eliminates need for numerous cable attachments for connection



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Some Example Profiles

- Audio/video profile
- Fax profile
- Basic printing profile
- Serial port profile
- PAN profile
- Phone book access profile
- Headset profile
- LAN access profile
- Service discovery profile
- Cordless phone profile

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Frequency Hopping in Bluetooth

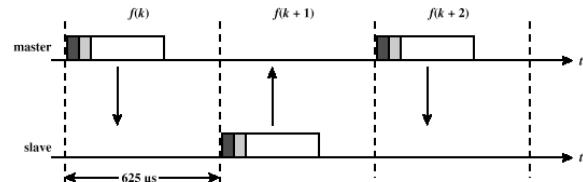
- Provides resistance to interference and multipath effects
- Provides a form of multiple access among co-located devices in different piconets
- Total bandwidth divided into 79 1MHz physical channels
- FH occurs by jumping from one channel to another in pseudorandom sequence
- Hopping sequence shared with all devices on piconet
 - » Remember that all communication is with the master, i.e., only one transmitter at any time

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Sharing the Channel

- Bluetooth devices use time division duplex (TDD)
- Access technique is TDMA
- FH-TDD-TDMA



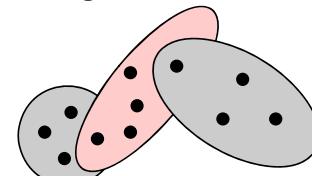
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Piconets are Basis for Topology

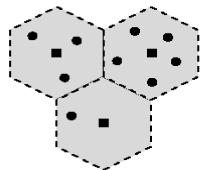
- Master with up to 7 active slaves
 - » Slaves only communicate with master
 - » Slaves must wait for permission from master
- Master picks radio parameters
 - » Channel, hopping sequence, timing, ...
- Scatternets can be used to build larger networks
 - » A slave in one piconet can also be part of another piconet
 - » Either as a master or as a slave
 - » If master, it can link the piconets

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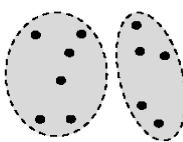


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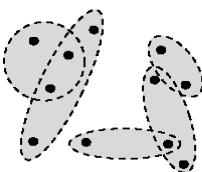
Wireless Network Configurations



(a) Cellular system (squares represent stationary base stations)



(b) Conventional ad hoc systems



(c) Scatternets

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Bluetooth Piconet

- A collection of devices connected via Bluetooth technology in a master-slave network
 - » Master functions as the piconet coordination (PNC)
- The piconet starts with two connected devices, and may grow to eight connected devices
 - » Devices are added by the master
- All Bluetooth devices are peer units and have identical implementations, but they play a master or slave role when connecting
 - » Roles can be reversed
 - » Example: headsets connects as master to phone but then becomes slave

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Forming a piconet

- Needs two parameters:
 - » Hopping pattern of the radio it wishes to connect.
 - » Phase within the pattern i.e. the clock offset of the hops.
 - » Effectively defines a channel that must be unique to the piconet – master must scan for other piconets first
- The global ID defines the hopping pattern.
- The master shares its global ID and its clock offset with the other radios which become slaves.
- The global ID and the clock parameters are exchanged using a FHS (Frequency Hopping Synchronization) packet.

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IEEE 802.15.4 - Overview

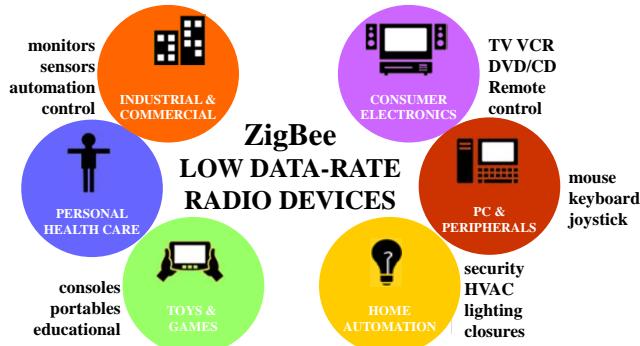
- Low Rate WPAN (LR-WPAN)
- Simple and low cost
- Low power consumption
 - » Years on lifetime using standard batteries
- Mostly in sensor networks
- Data rates: 20-250 kbps
- Operates at multiple frequencies
 - » 868 MHz, 915 MHz, 2.4 GHz
- Blends elements from 802.15.3 and 802.11
- Many versions exist for different application domains

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802.15.4 applications

<http://www.csie.nctu.edu.tw/~yctseng/WirelessNet06-02/zigbee-802-15-4.ppt>



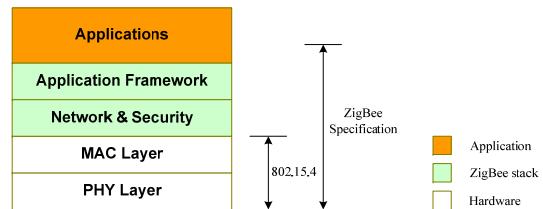
ZigBee LOW DATA-RATE RADIO DEVICES

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Zigbee/802.15.4 architecture

- ZigBee Alliance**
 - 45+ companies: semiconductor mfrs, IP providers, OEMs, etc.
 - Defining upper layers of protocol stack: from network to application, including application profiles
 - First profiles published mid 2003
- IEEE 802.15.4 Working Group**
 - Defining lower layers of protocol stack: MAC and PHY
 - PHY based on DSSS – runs at 250 Kbps in 2.4 GHz band
 - Links are encrypted



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802.15.4 devices

- 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



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Roles

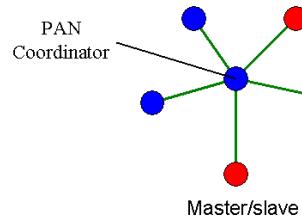
- Devices (RFD or FFD)**
 - must be associated to a coordinator
- Coordinators (FFD)**
 - can operate in peer-to-peer mode
 - can form a PAN coordinated by a PAN coordinator
- PAN Coordinator (FFD)**
- Coordinator**
 - manages a list of associate devices
 - devices need to associate and disassociate
 - allocates short addresses
 - beacon frames (in beacon mode)
 - processes requests for fixed time slots

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IEEE 802.15.4 - Star

Star Topology



● Full function device
● Reduced function device

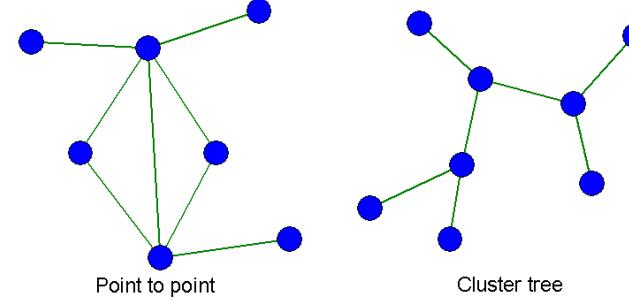
— Communications flow

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IEEE 802.15.4 - Peer-to-Peer

Peer-to-Peer Topology



● Full function device

— Communications flow

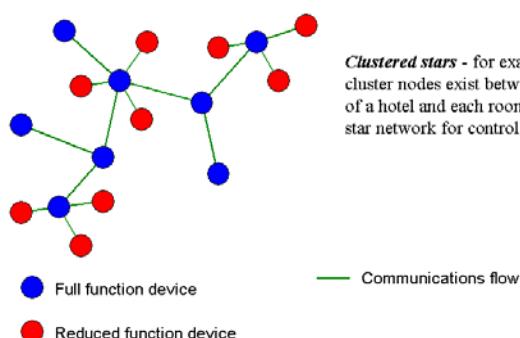
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IEEE 802.15.4 - Combined

Combined Topology

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



— Communications flow

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IEEE 802.15.4 - MAC

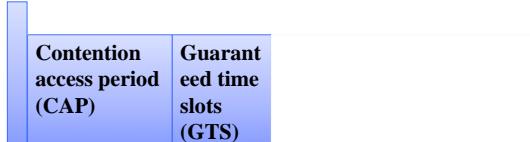
- One PAN coordinator & multiple RFDs/FFDs
 - » Association/disassociation
- CSMA-CA channel access
 - » Reliable delivery of data
- Optional superframe structure with beacons
 - » GTS mechanism
- AES-128 security
- QoS – 3 traffic types
 - » Periodic data: e.g. Sensor data
 - » Intermittent data: generated once a while, e.g. light switch traffic
 - » Repetitive low latency data: E.g. Mouse device traffic

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802.15.4 superframe structure

Beacon



Active period

Inactive period

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Low Power Technologies

- Battery life times of years or even decades
 - » Ubiquitous deployment of sensors
 - » Internet of Things (IoT), automation, ...
 - » Replacing batteries is labor intensive
- Bluetooth Low Energy
 - » Not backwards compatible; deployed in some phones
 - » Profiles for healthcare, proximity sensing, alerts, keyboard/mice/..., ..
 - » 2.4 GHz but simpler modulation schemes

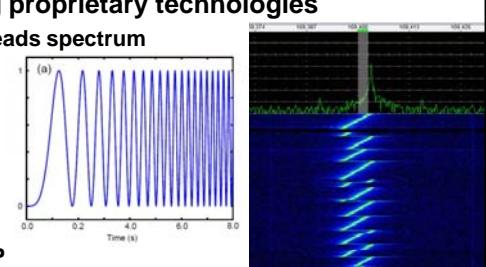
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Low-Power Wide-Area Networks (LPWAN)

- Longer range to simplify deployment
 - » “Metropolitan” area – city-wide sensor network
 - » Single base station covers large area and many sensors
- Many competing proprietary technologies
 - » LoRa: chirp spread spectrum
 - » Sigfox
 - » Star topology, 900 MHz, ..
 - LTE-MTC
 - » Machine Type Communication
 - » Defined by 3GPP

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Ultra WideBand

$$C = B \log_2(1 + \text{SNR})$$

- Can achieve high throughputs with low SNR by using a high B
- Motivation is the 802.15.3a (high rate PAN) standards effort
 - » Targets high speed, short distance communication
- But where do I find this much spectrum?
- Use a transmit power that is low enough to so it will not affect other users
 - » Can be used in most licensed frequency bands (with FCC permission, of course)

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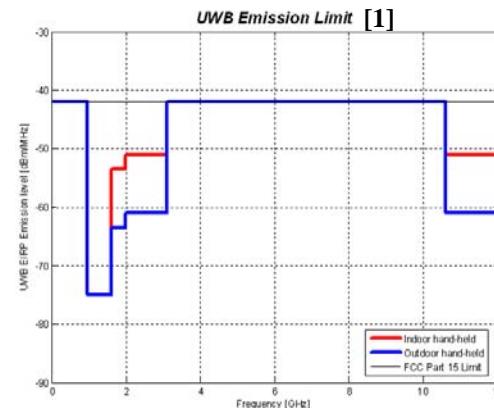
FCC UWB Rules

- UWB technically defined as:
 - » Width of signal > 500 MHz, or $B_f = 2 \frac{f_H - f_L}{f_H + f_L} > 0.2$
- Approved for 3.1 GHz to 10.6 GHz
- Power limit is -41.3 dBm/MHz
 - » Note that the limit is not on the total signal but across the part of the spectrum that is used
- Results in a frequency mask that must be satisfied
- Certain narrow bands must be filtered out
 - » E.g. certain radio astronomy bands
 - » Depends on the country

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FCC Regulations



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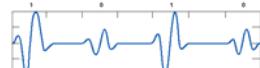
Example Technology: Basic Impulse Information Modulation

Pulse length ~ 200ps; Energy concentrated in 2-6GHz band;
Voltage swing ~100mV; Power ~ 10uW

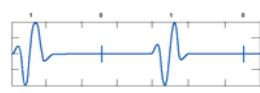
- Pulse Position Modulation (PPM)



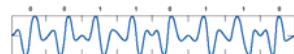
- Pulse Amplitude Modulation (PAM)



- On-Off Keying (OOK)



- Bi-Phase Modulation (BPSK)

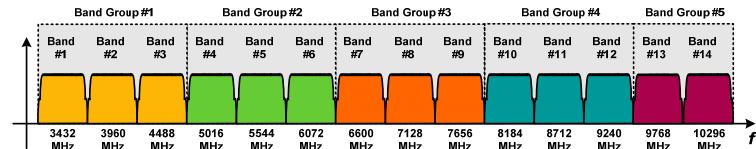


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Multi-band OFDM

- Divide the spectrum into bands of 528 MHz.



- » Transmitter and receiver process smaller bandwidth signals.
- » Can spread symbols across multiple bands (FH)
- » Can avoid bands based on local regulations

- Use of OFDM offer additional advantages

- » Proven technology that is known to be efficient
- » Can selectively disable subcarriers to protect narrow band signals
- » For example: 128 tones of 5.125 MHz

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Discussion

- UWB was included in 802.15 standards
- 802.15.3a was going to use UWB but never materialized
 - » Fight between two competing proposals
 - » Example on previous slide is one of them
- Also added as 802.15.4a to the low power PAN group
 - » Provides for 3 “narrower” bands
 - » Not clear it is used

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