

This lecture is being recorded

18-452/18-750

Wireless Networks and Applications

Lecture 19: PAN

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<http://www.cs.cmu.edu/~prs/wirelessS21/>

Outline

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

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)
 - » IEEE 802.15.6 – Body Area Networking
 - » IEEE 802.15.7 – Visible Light Communication

Some Common Themes

- **Master/slave notion**
 - » Or simple node versus coordinator
- **Use of “piconets”**
 - » Small groups of devices managed by a master or coordinator
 - » Supports only small numbers of devices - scalability is not a concern
 - » These are typically not general networks (e.g., Ethernet)
- **Support for QoS**
 - » Want to support voice and other media
- **But there are many variants in how this functionality is supported**

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 1-3 Mbps connections
 - » 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**

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 2.1
- **Not designed to carry heavy traffic loads**

Bluetooth Standards

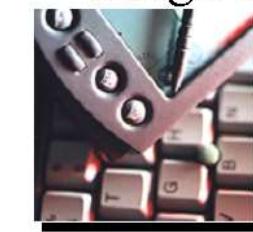
- **Core specifications: defines the layers of the Bluetooth protocol architecture**
 - » Radio - air interface, txpower, modulation, FH
 - » Baseband - power control, addressing, timing, connections..
 - » Link manager protocol (LMP) - link setup & mgmt, incl. authentication, encryption, ...
 - » Logical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

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 cable attachments for connection



Usage scenarios: Headset



Usage scenarios: Synchronization



Some Example Profiles

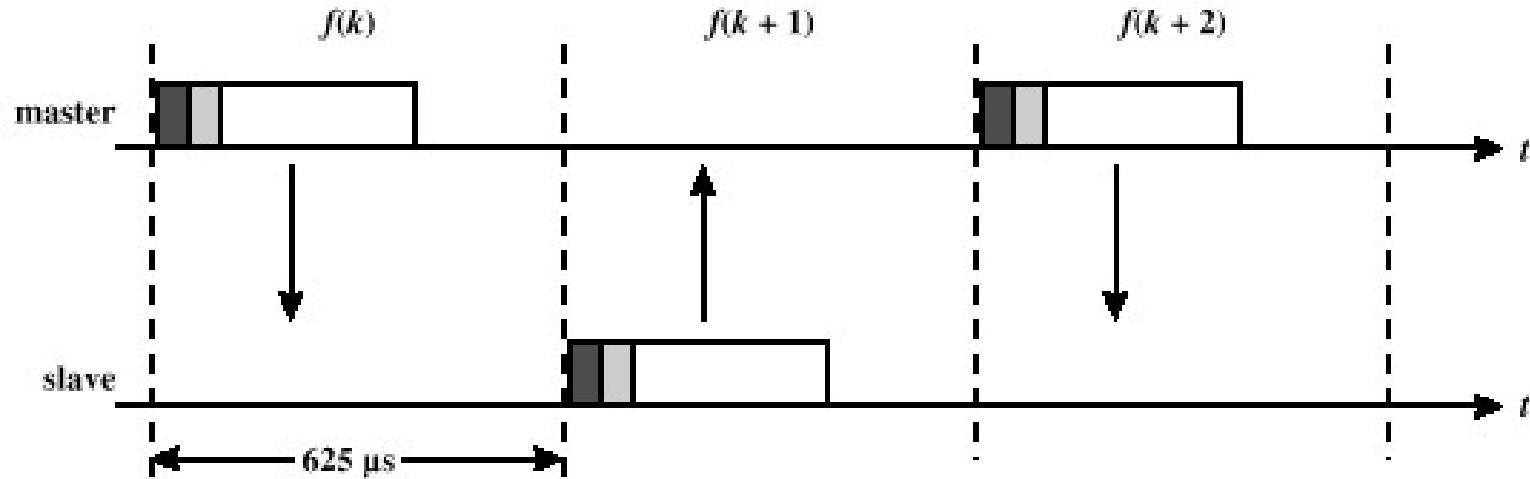
- **Audio/video profile**
- **Fax profile**
- **Basic printing profile**
- **Serial port profile**
- **PAN profile**
- **Phone book access profile**
- **Headset profile**
- **LAN access profile**
- **Service discovery profile**
- **Cordless phone profile**

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

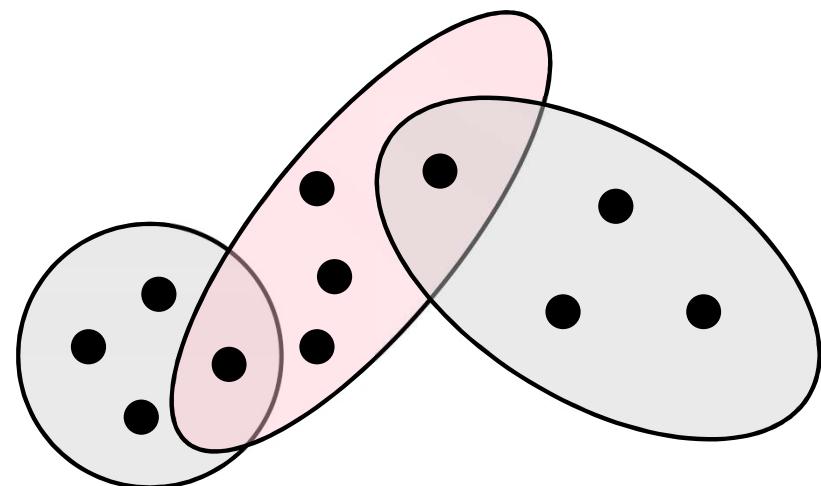
Sharing the Channel

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

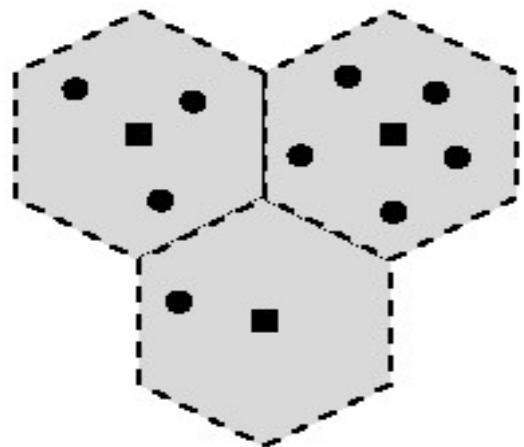


Piconets are Basis for Topology

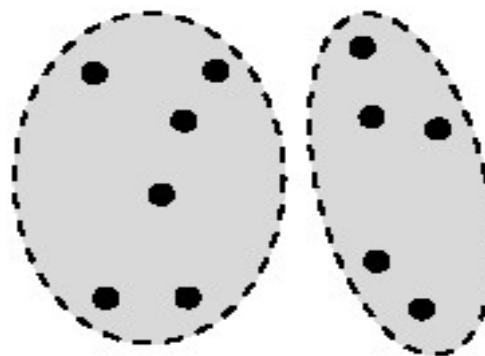
- **Master with up to 7 active slaves**
 - » Slaves only communicate with master
 - » Slaves must wait for permission from master
- **Master picks radio parameters**
 - » Channel, hopping sequence, timing, ...
- **Scatternets can be used to build larger networks**
 - » A slave in one piconet can also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



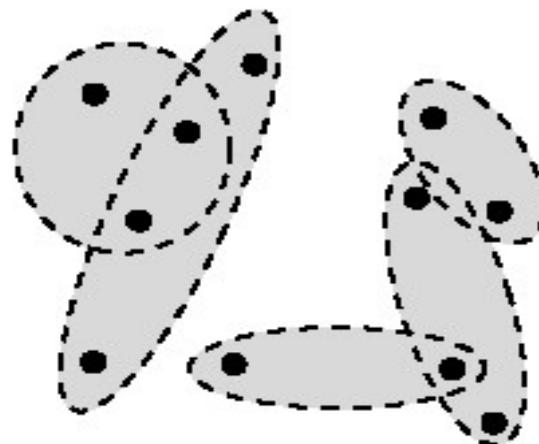
Wireless Network Configurations



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



(b) Conventional ad hoc systems



(c) Scatternets

Bluetooth Piconet

- **A collection of devices connected via Bluetooth technology in a master-slave network**
 - » Master functions as the piconet coordination (PNC)
 - » Can have a master and 1-7 slaves
- **Joining of piconet involves three steps**
 - » Master advertises its presence
 - » Slave can submit a join request (typically initiated by user)
 - » Master accepts request and establishes connection
- **All Bluetooth devices are identical, but play a master or slave role when connecting**
 - » Roles can be reversed
 - » Example: headsets connects as master to phone but then becomes slave

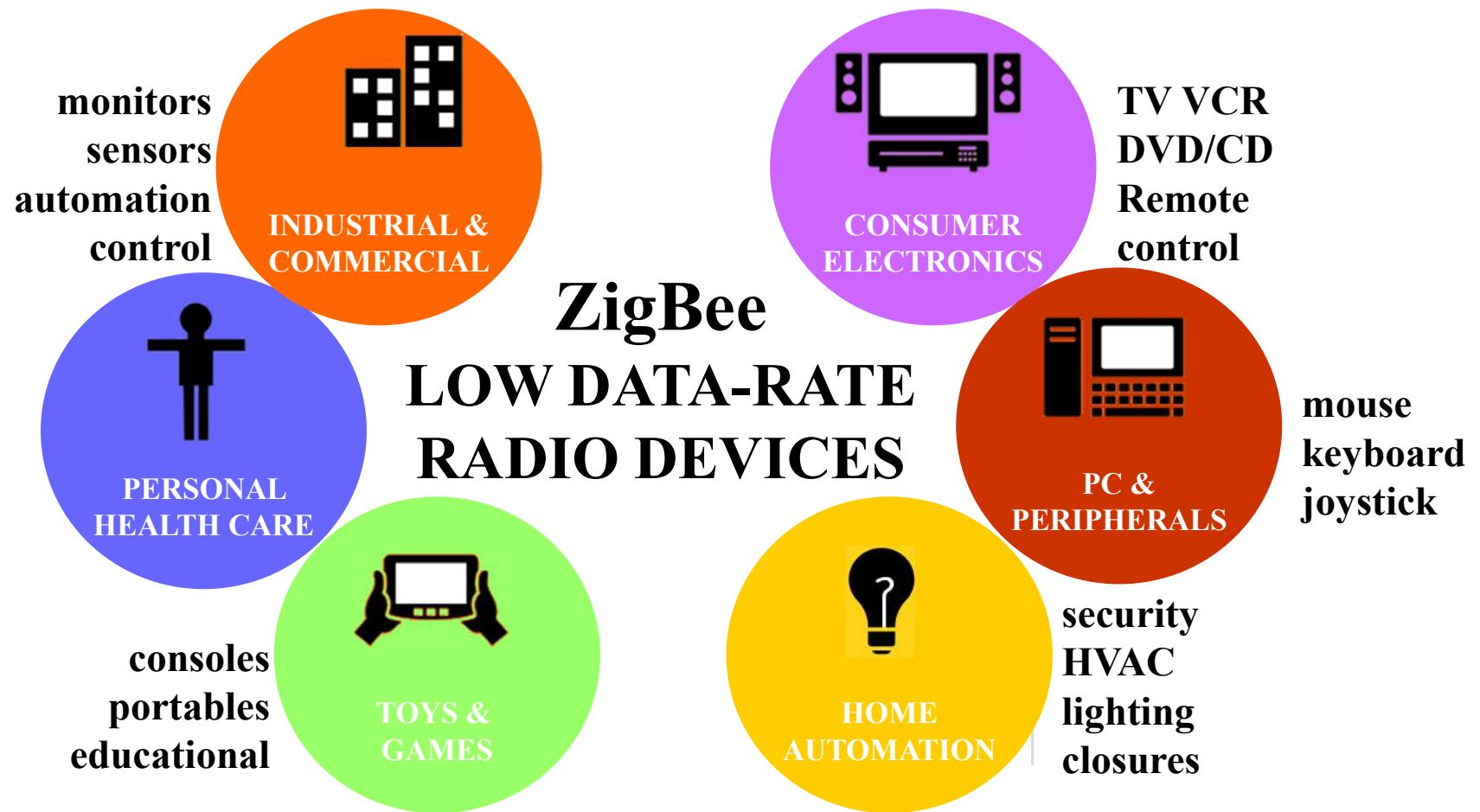
Configuring a Piconet

- **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 Hoping Synchronization) packet.**

IEEE 802.15.4 - Overview

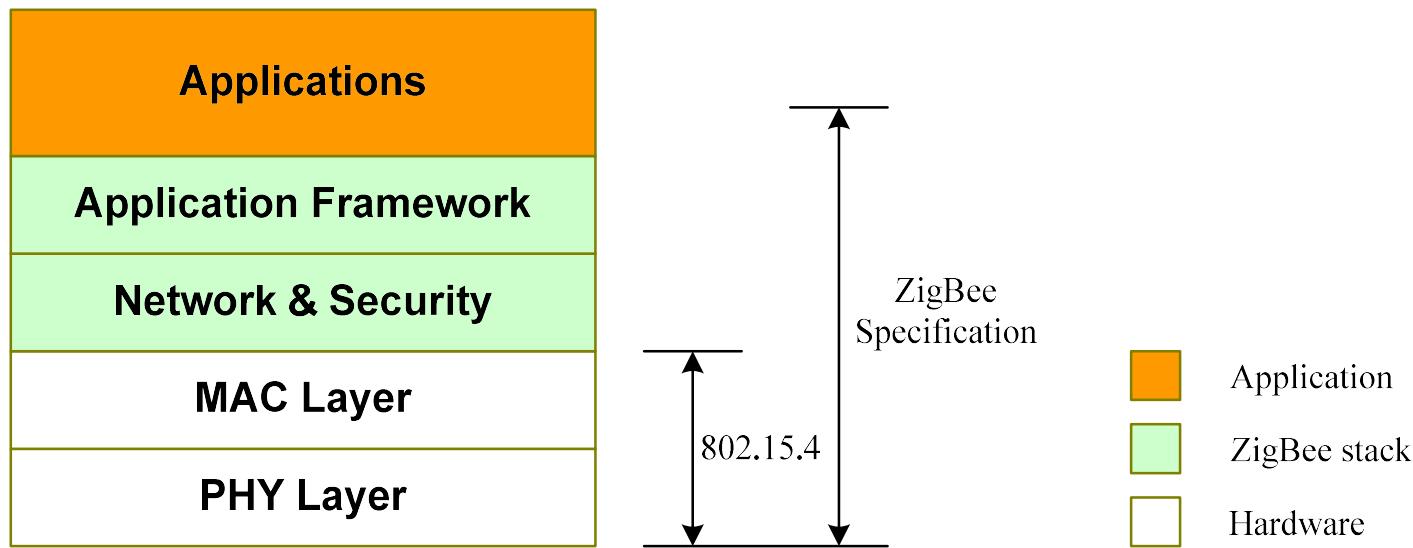
- **Low Rate WPAN (LR-WPAN)**
- **Simple and low cost**
- **Low power consumption**
 - » Years on lifetime using standard batteries
- **Mostly in sensor networks**
- **Data rates: 20-250 kbps**
- **Operates at multiple frequencies**
 - » 868 Mhz, 915 Mhz, 2.4 GHz
- **Blends elements from 802.15.3 and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

802.15.4 applications



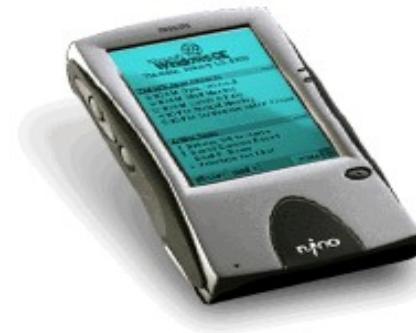
Zigbee/802.15.4 architecture

- 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



802.15.4 devices

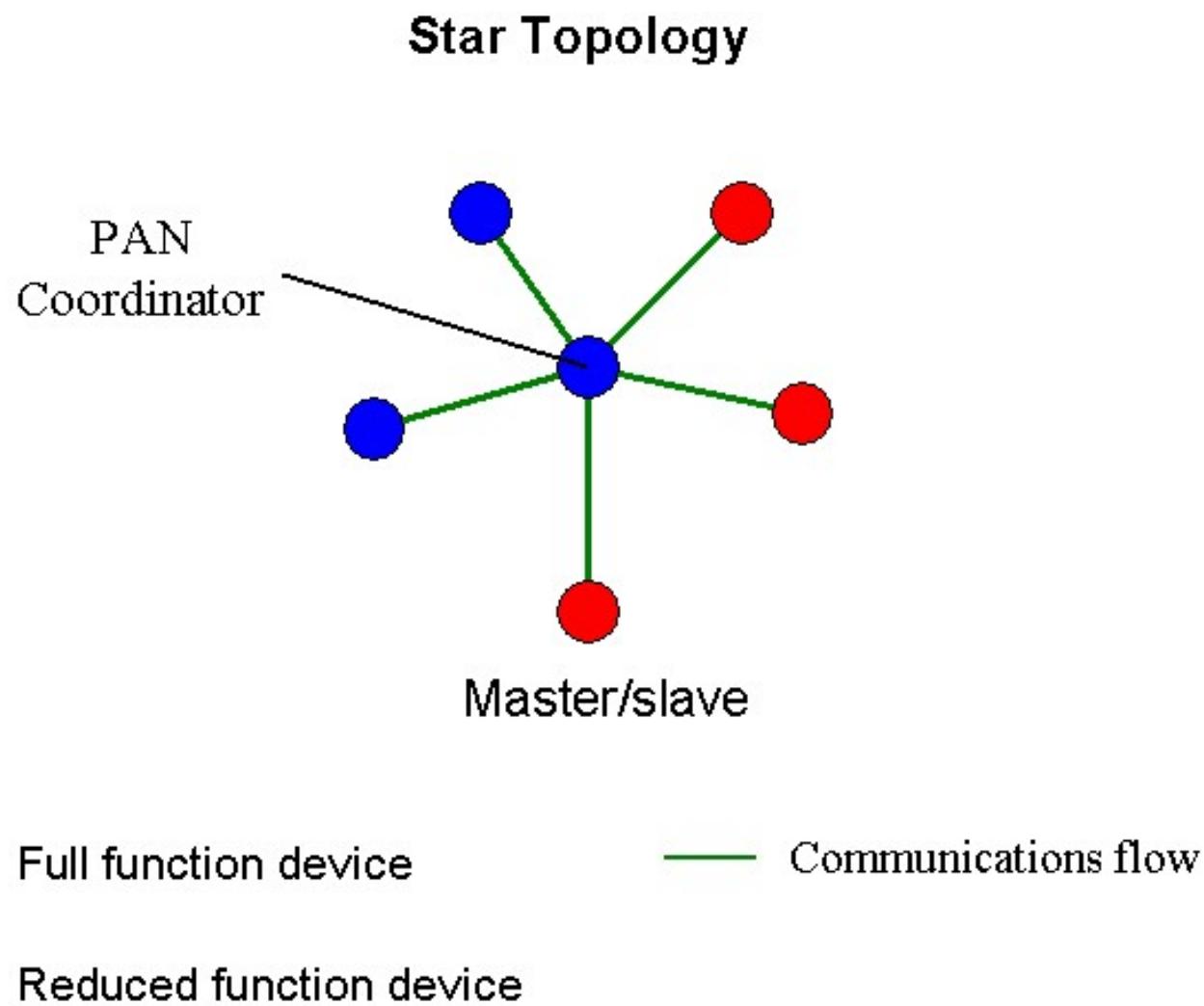
- **Full function device (FFD)**
 - Any topology
 - Network coordinator capable
 - Talks to any other device
- **Reduced function device (RFD)**
 - Limited to star topology
 - Cannot become a network coordinator
 - Talks only to a network coordinator
 - Very simple implementation



Roles

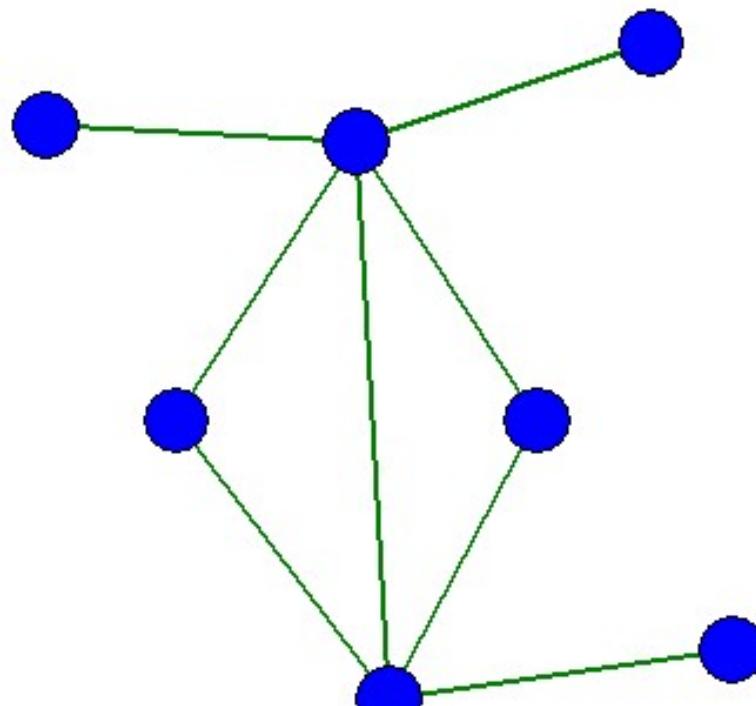
- **Devices (RFD or FFD)**
 - » must be associated to a coordinator
- **Coordinators (FFD)**
 - » can operate in peer-to-peer mode
 - » can form a PAN coordinated by a PAN coordinator
- **PAN Coordinator (FFD)**
- **Coordinator**
 - » manages a list of associate devices
 - » devices need to associate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

IEEE 802.15.4 - Star

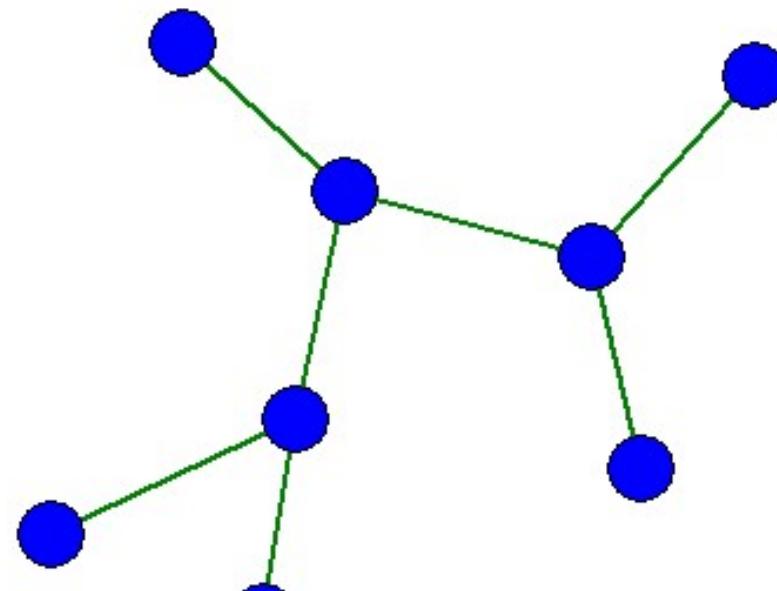


IEEE 802.15.4 – Peer-to-Peer

Peer-Peer Topology



Point to point



Cluster tree

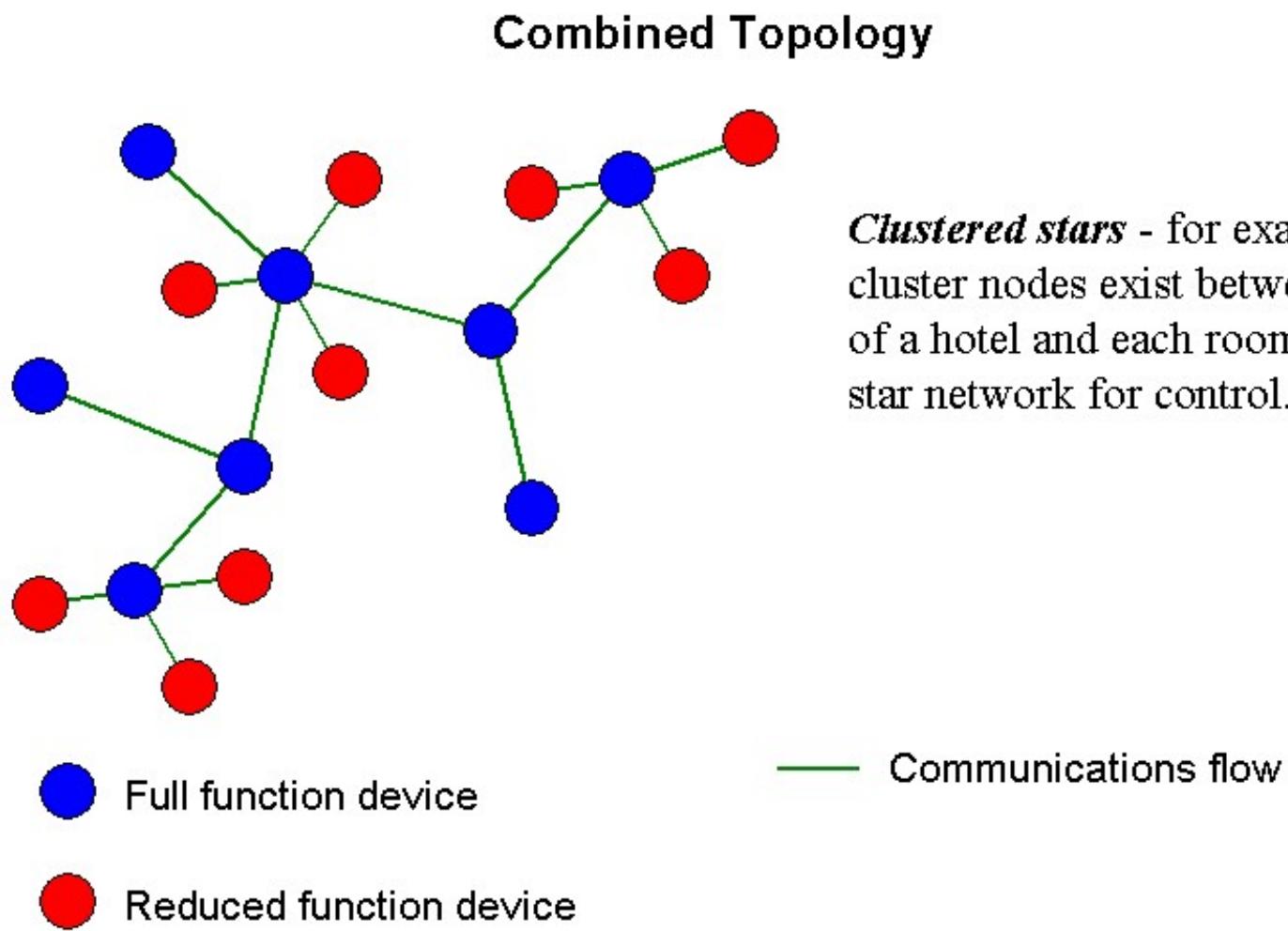


Full function device



Communications flow

IEEE 802.15.4 - Combined



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

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

802.15.4 superframe structure

Beacon



Active period

Inactive period

Outline

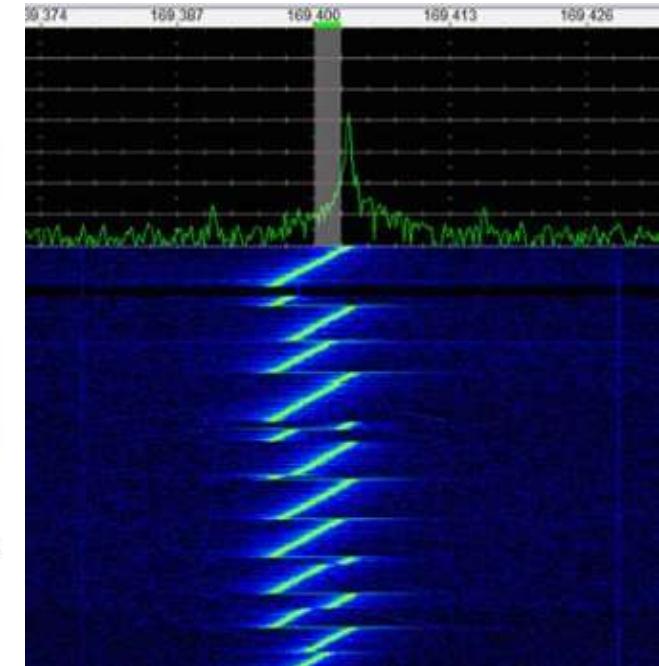
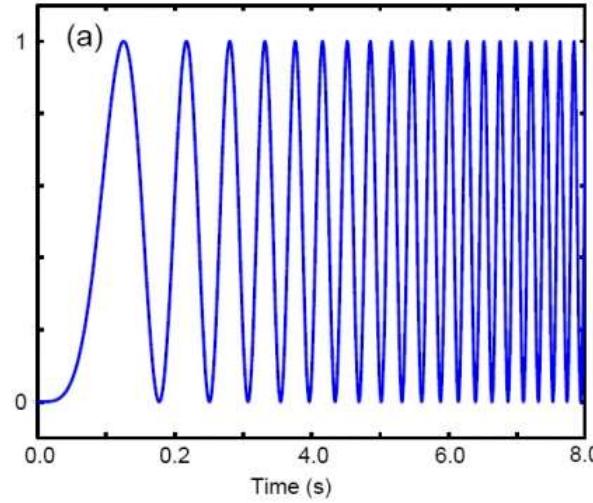
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 - » Zigbee
 - » Other
- **UWB**

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

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

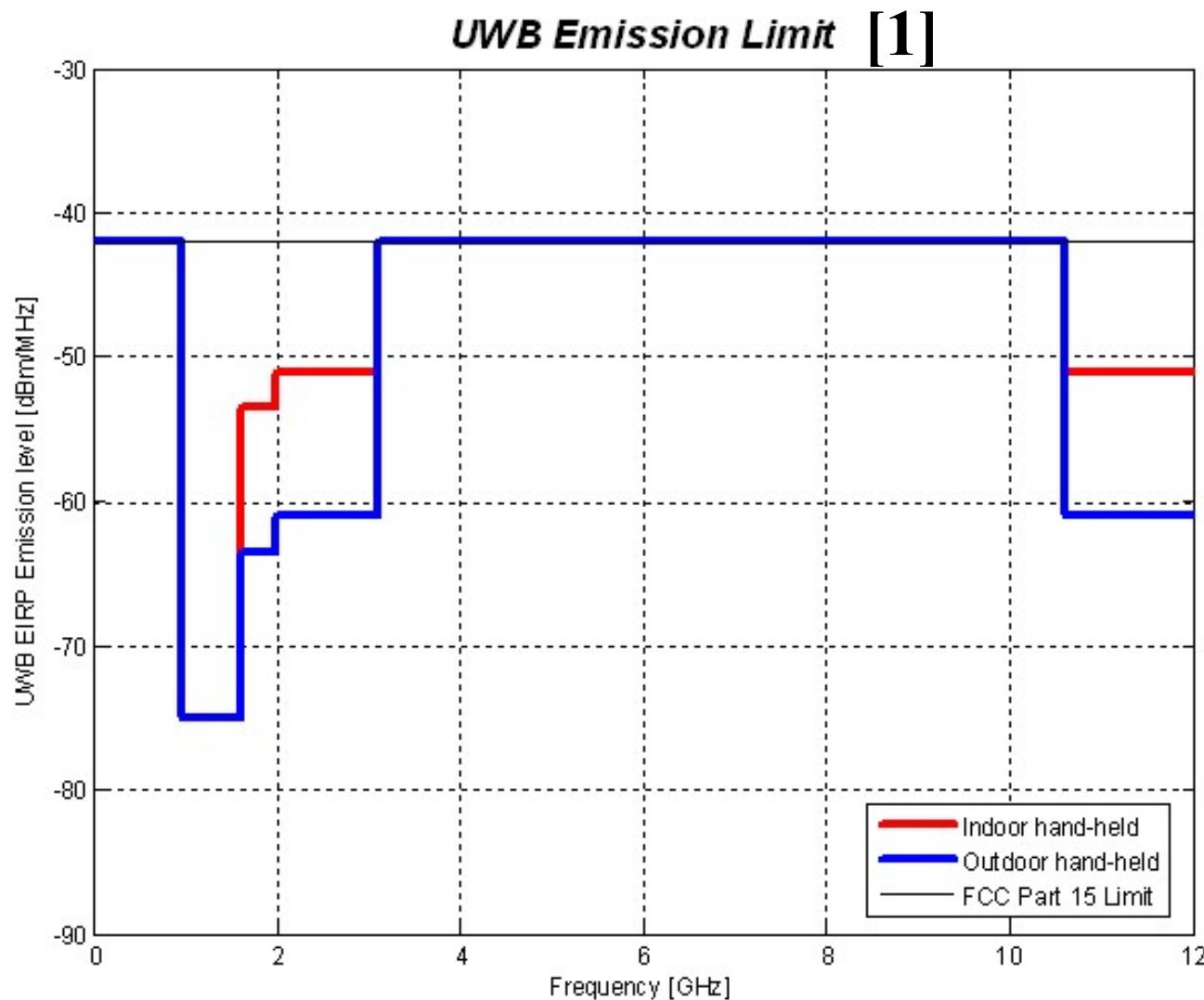
$$C = B \log_2(1 + \text{SNR})$$

- **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 so it will not affect other users**
 - » Can be used in most licensed frequency bands (with FCC permission, of course)

FCC UWB Rules

- **UWB technically defined as:**
 - » Width of signal > 500 MHz, or
- **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

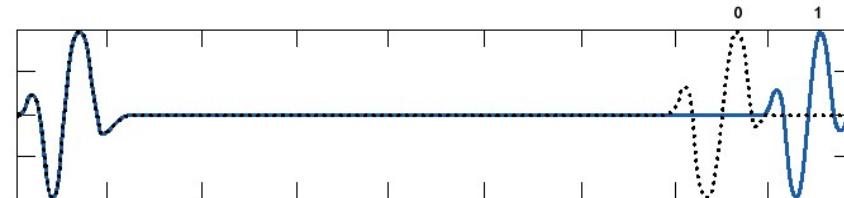
FCC Regulations



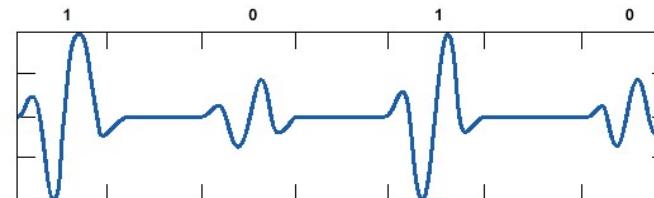
Example Technology: Basic Impulse Information Modulation

Pulse length $\sim 200\text{ps}$; Energy concentrated in 2-6GHz band;
Voltage swing $\sim 100\text{mV}$; Power $\sim 10\text{uW}$

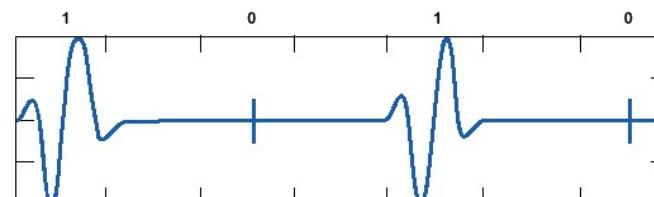
- **Pulse Position Modulation (PPM)**



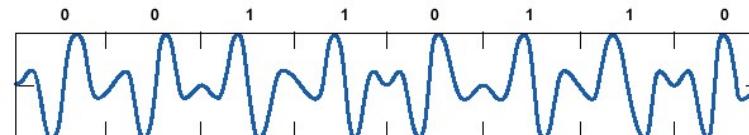
- **Pulse Amplitude Modulation (PAM)**



- **On-Off Keying (OOK)**

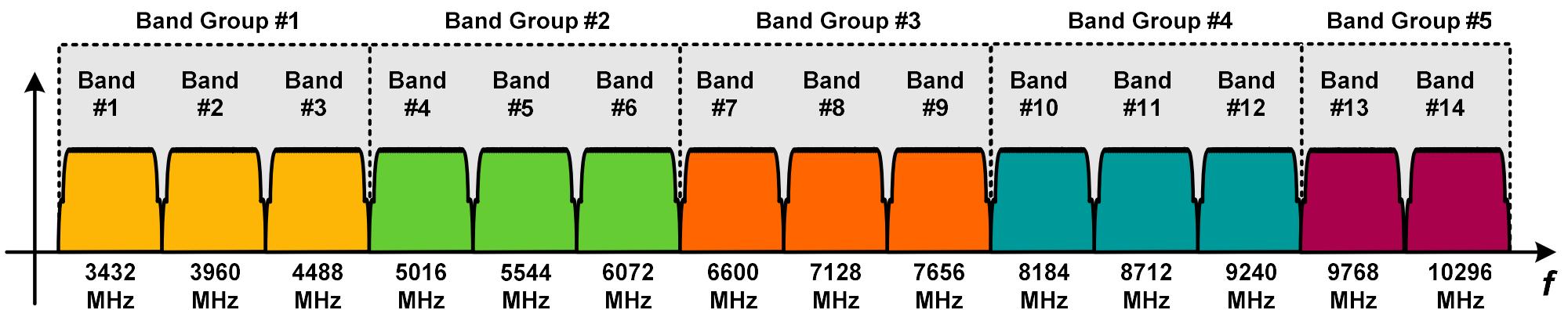


- **Bi-Phase Modulation (BPSK)**



Multi-band OFDM

- Divide the spectrum into bands of 528 MHz.



- 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

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