EE107 Spring 2019
Lecture 7
Wireless Communication
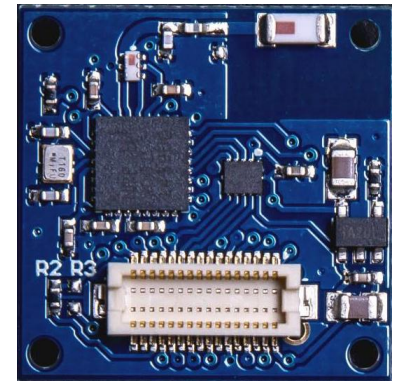
Embedded Networked Systems

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*slides adapted from Aaron Schulman's CSE190

Wireless radios in our project

Wireless radios in our project

- Wireless radios are used for informing a nearby smartphone that the item is lost

- We are using Bluetooth Low Energy the most popular wireless protocol.

Outline

- What are radios
    - How do they work?
- Fundamental characteristics
    - Design tradeoffs
- Common radio standards/protocols for indoor applications
    - Where characteristics fall under (above)
- Emerging radio standards/protocols for outdoor Internet-of-Things applications
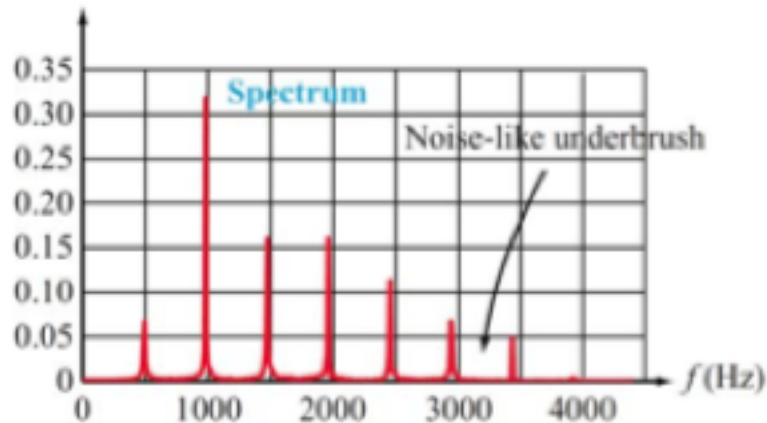   - Why the design requirement of IoT radios is different

What are Radios?

- A device that enables wireless transmission of signals
  - o Electromagnetic wave
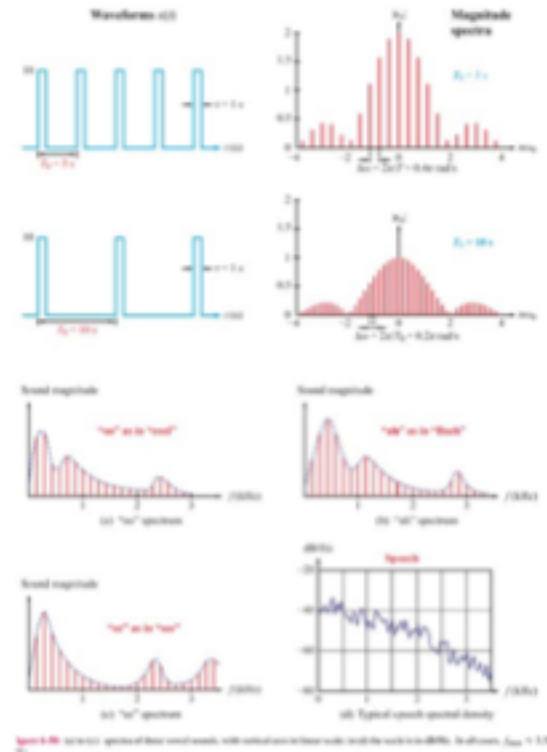 - o Transmitter sends signal to Receiver

How Radios Work - Transmitting

- Modulation
  - Analog/Digital
  - Frequency vs Amplitude vs. Phase, etc.

Fourier Series as period T becomes large:

Spectrum of a single trumpet playing note "B."
Note that the fundamental frequency is 500 Hz,
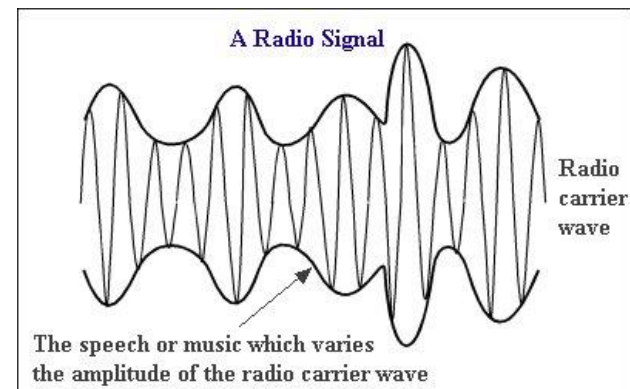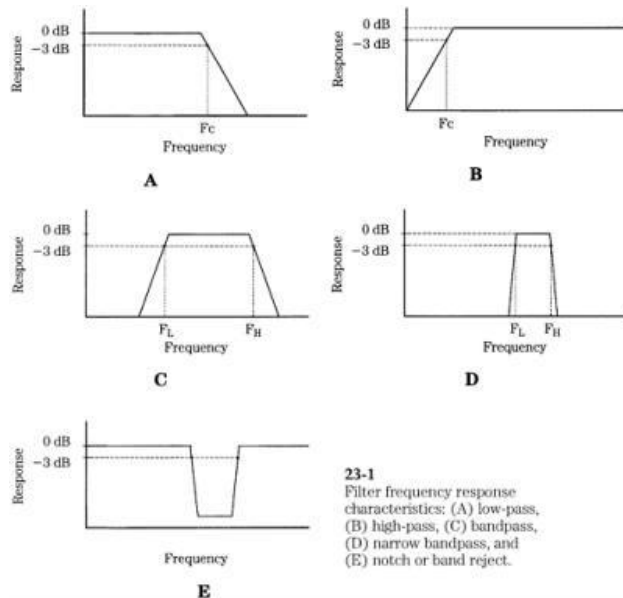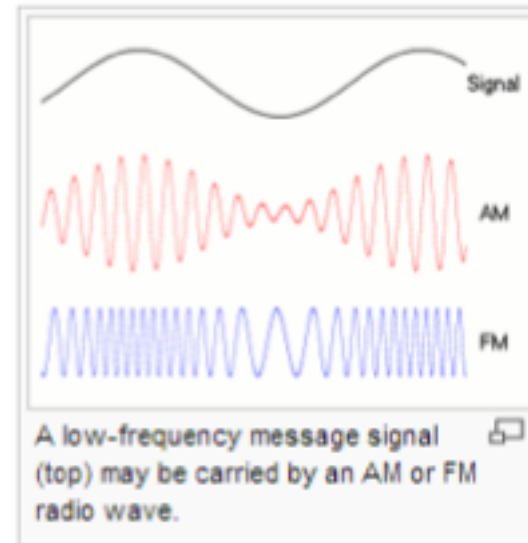with harmonics at 1000, 1500, 2000, etc. Hz.

How Radios Work - Receiving

- Envelope Detection
  - Detect carrier freq.
- Filters
- Demodulation

A low-frequency message signal (top) may be carried by an AM or FM radio wave.

23-1
Filter frequency response characteristics: (A) low-pass, (B) high-pass, (C) bandpass, (D) narrow bandpass, and (E) notch or band reject.

A Radio Signal

Radio carrier wave

The speech or music which varies the amplitude of the radio carrier wave

How Radios Work – Receiving (AM Radio Example)

- Antenna picks up modulated radio waves
- Tuner filters out specific frequency ranges
- Amplitude variations detected with demodulation
- Amplifier strengthens the clipped signal and sends it through the speaker

Antenna

AM Radio

Tuner   Detector   Amplifier   Speaker

©2000 How Stuff Works
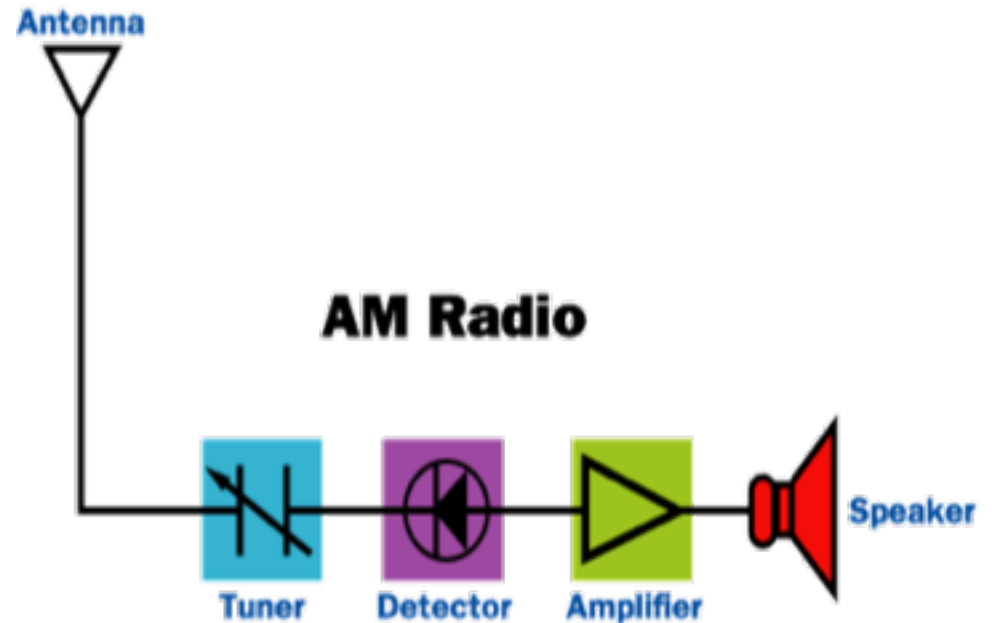
Radio Characteristics

- Why so many protocols for indoor and outdoor applications?
- Types/Advantages/Disadvantages
  - Short vs. long distance
  - High vs. low power/energy
  - High vs. low speeds
  - Large vs. small number of devices
  - Indoor vs. outdoor usages

Common Radio Protocols

Radios for indoor applications

- Design requirements
  - Short range
  - High data rate
  - Small number of devices
- Common radios
  - Bluetooth
  - ZigBee
  - Ant
  - WiFi

Radios for outdoor IoT applications

- Design requirements
  - Long range
  - Low data rate
  - Large number of devices
  - Low energy consumption
- Emerging radios
  - Sigfox
  - Narrow band LTE
  - Backscatter

Bluetooth

- Radio band: 2.4-2.48 GHz

- Average 1 Mbps - Up to 3 Mbps
- Supports point-to-point and point-to-multipoint
  - Creates personal area networks (PANs/Piconets)
  - Connects up to 8 devices simultaneously
- Minimal interference between devices
  - Devices alter frequencies arbitrarily after packet exchanges -up to 1600 times/second - frequency hopping
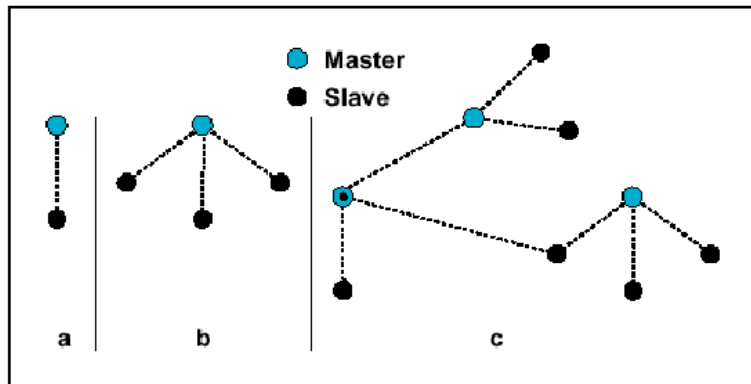- 3 classes of Bluetooth

Figure 1.2: Piconets with a single slave operation (a), a multi-slave operation (b) and a scatternet operation (c).

Class	Maximum Power	Operating Range
Class 1	100mW (20dBm)	100 meters
Class 2	2.5mW (4dBm)	10 meters
Class 3	1mW (0dBm)	1 meter

Bluetooth Applications

- Wireless communication between devices
  - Mobile phones, laptops, cameras, gaming controllers, computer peripherals, etc
- Short range sensor transmission
- Share multimedia - pictures, video, music
- A2DP - Advanced Audio Distribution Profile
  - Stream audio wirelessly

Bluetooth low energy

From 2001 – 2006 Nokia asked:

How do we design a radio that can transmit short bursts of data for months or years *only being powered by a coin cell battery?*

The answer is: Keep the radio asleep mode most of the time!

1. Advertise on only one of three channels
2. Transmit quickly at 1 Mbit/s
3. Make the minimum time to send data only 3 msec
4. Make a very predictable time when the device accepts connections
5. Limit the max transmit power to 10 mW
6. However, don't sacrifice security: AES 128-bit

What tradeoffs were made?

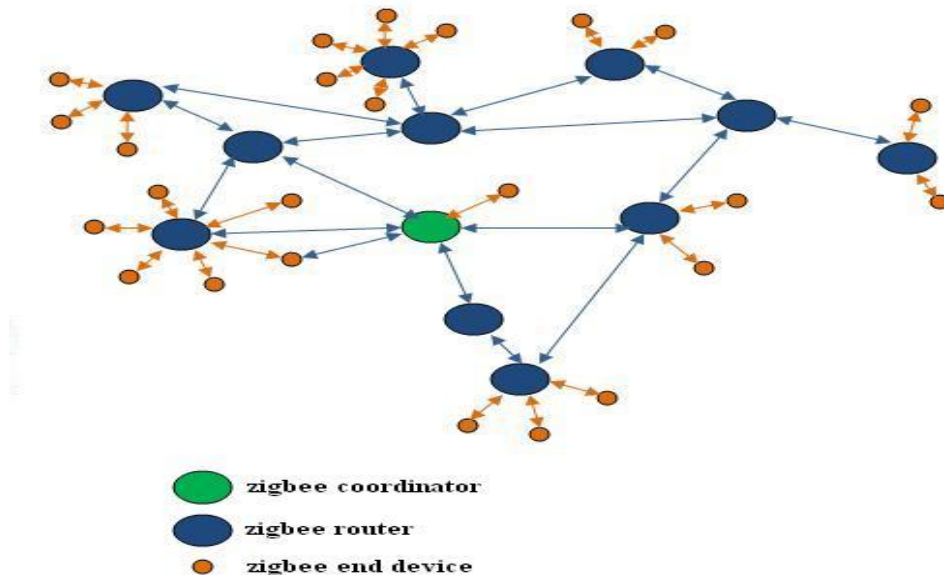The protocol is designed for transmitting tiny data

- 4 operations: Read, Write, Notify, Indicate
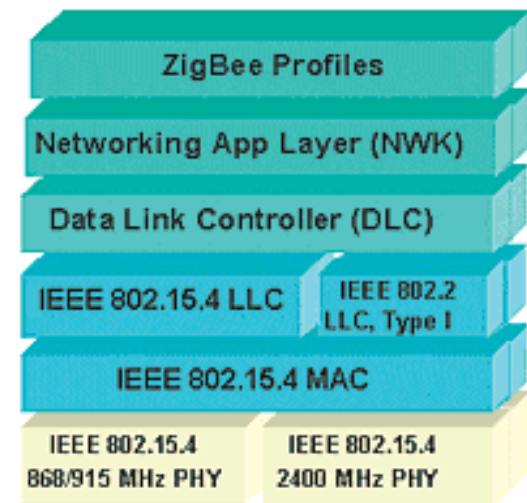- Maximum of 20 bytes of data per packet
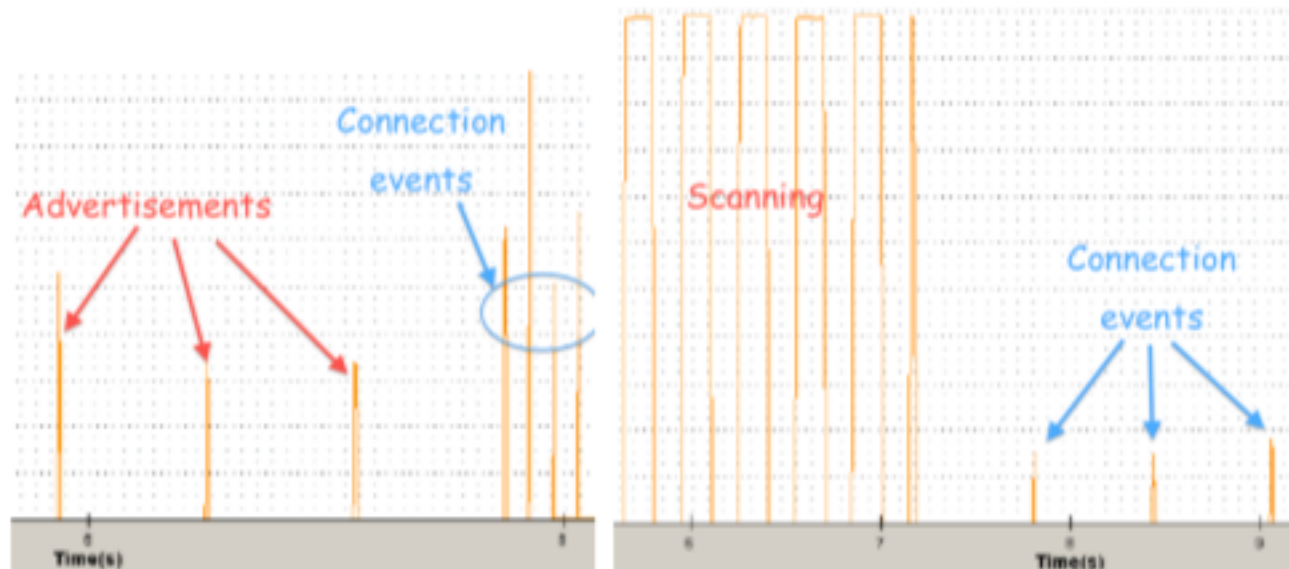
From: How Low Energy is Bluetooth Low Energy - Siekkinen et al.

Zigbee/802.15.4

- Zigbee is built on top of 802.15.4
- Radio bands: 868MHz in Europe, 915MHz in US and Australia. 2.4GHz else worldwide.
- Low data-rate - 250 kbps, low power – Up to 1000 days
- Transmits over longer distances through mesh networks

- ● zigbee coordinator
- ● zigbee router
- ∘ zigbee end device

Zigbee/802.15.4 mesh network and device types

ZigBee Profiles

Networking App Layer (NWK)

Data Link Controller (DLC)

| IEEE 802.15.4 LLC | IEEE 802.2 LLC, Type I |

IEEE 802.15.4 MAC

| IEEE 802.15.4 868/915 MHz PHY | IEEE 802.15.4 2400 MHz PHY |

Why ZigBee?

- Low Power, Cost, and Size

- Straightforward configuration

- Good support and documentation
  - Lots of products already on the market

- Mesh Networking

- Lends itself well to many different applications

- Very low wakeup time
  - 30mS (Zigbee) vs. up to 3S (Bluetooth)

Or maybe not…

- ## Competes with Wi-Fi for bandwidth..

 – Only four usable bands in Wi-Fi intensive scenarios

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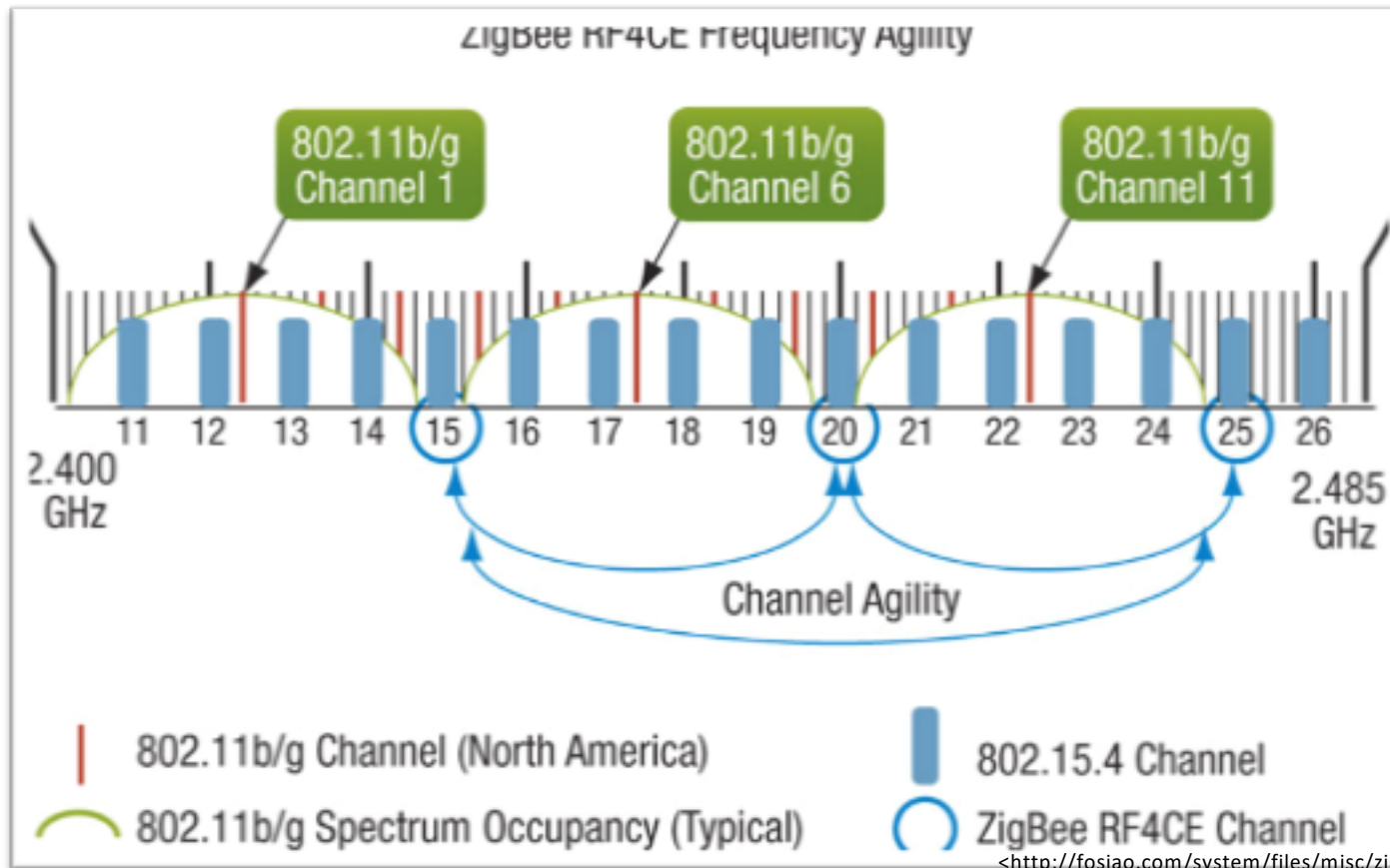
Zigbee is usually used in mesh networks

• A mesh network consists of a series of nodes.

• Each node must acquire and transmit its own data, as well as act as a relay for other nodes to propagate data.

• ZigBee devices often form Mesh Networks.

• Examples: Wireless light switching, Music school practice rooms.

Mesh Networking

Coordinator
Router
End Device
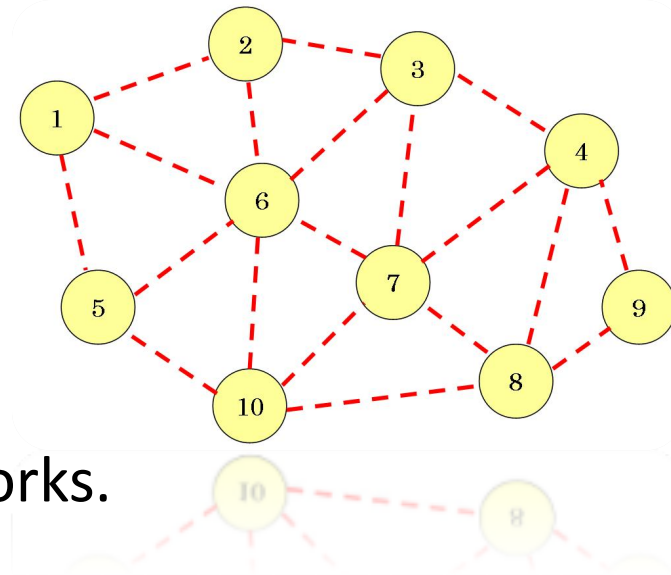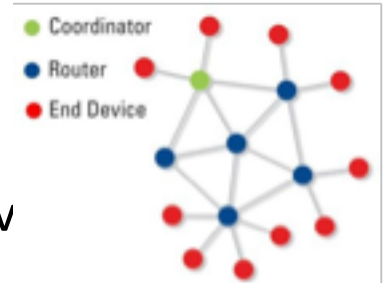
- Advantages of Mesh Networking:
  - Allows devices to communicate to multiple other dev the network.
  - Multiple paths to destination – greater flexibility against interference.
  - Allows overall network to grow to larger physical sizes than possible with point-to-point networks.

- Mesh Characteristics:
  - *Self-forming* – ZigBee devices can establish
  communication pathways when new devices appear.
  - *Self-healing* – If a node is removed from the network
  (either intentionally or not) the remaining network will
  look to establish alternate routes of communication.
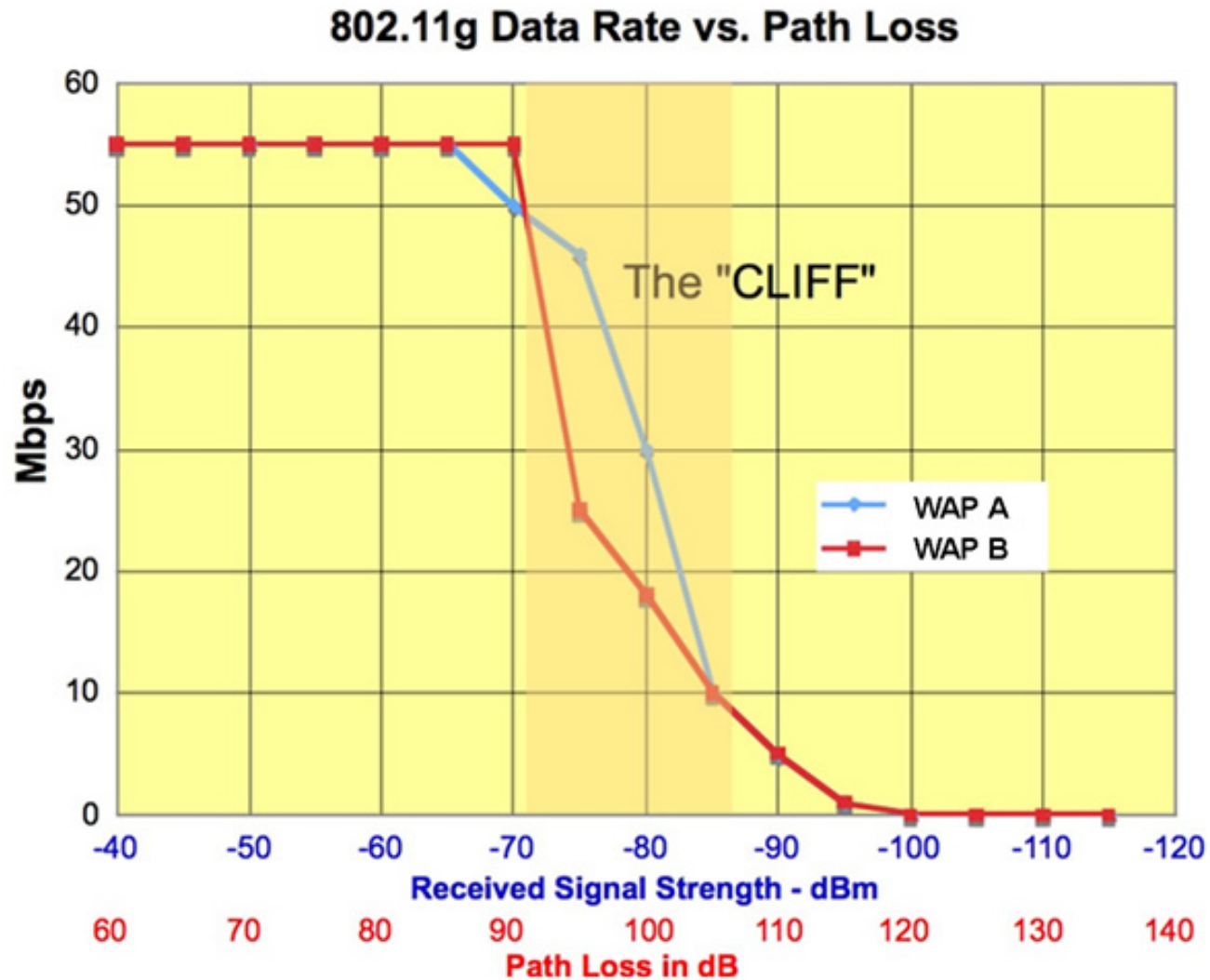
Zigbee/802.15.4 Applications

- Wireless environmental sensors
  - Temperature, pressure, sound, luminous intensity
- Medical devices
  - Glucose meters, heart monitors
- Household automation
  - Security/temperature controllers
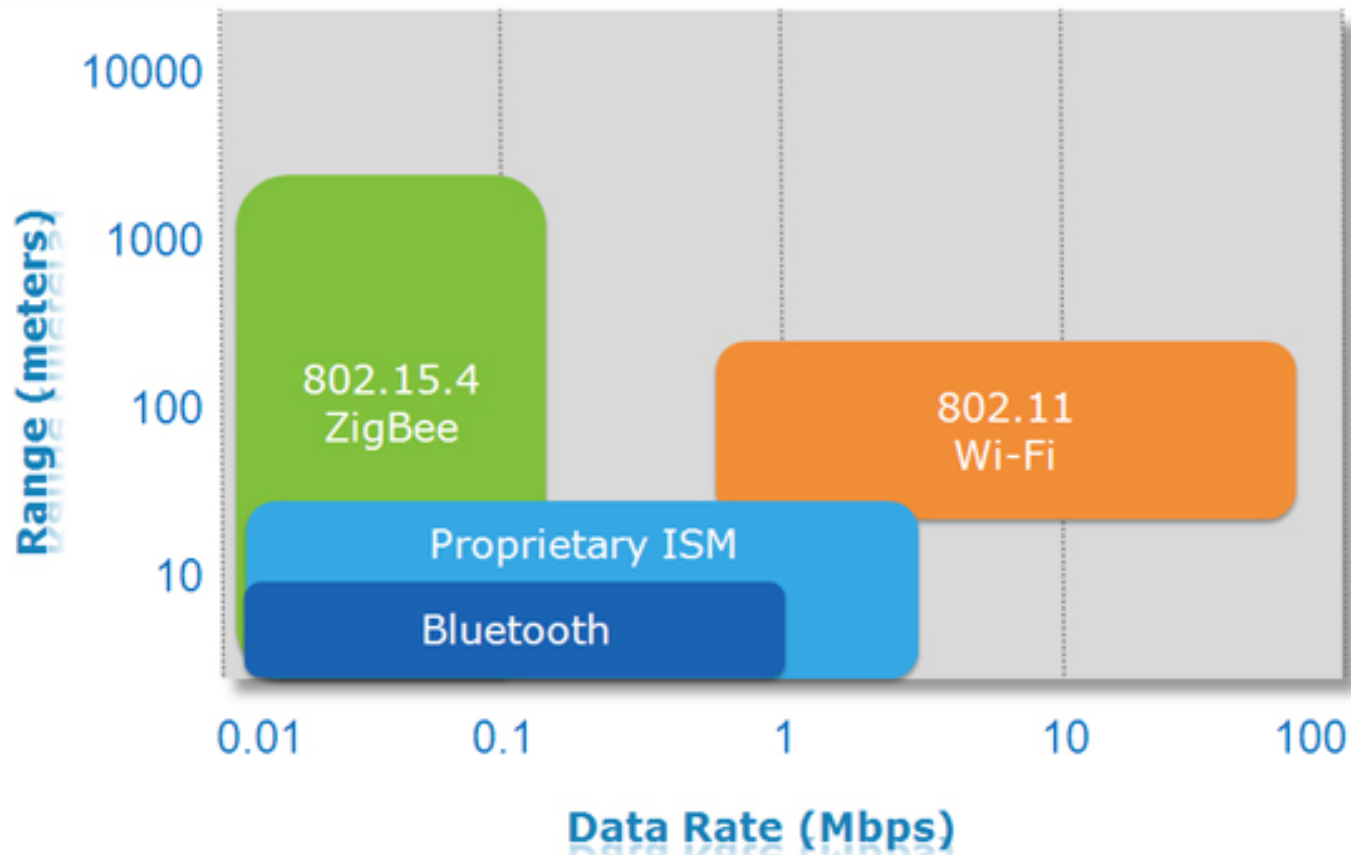 - Smoke/motion detectors
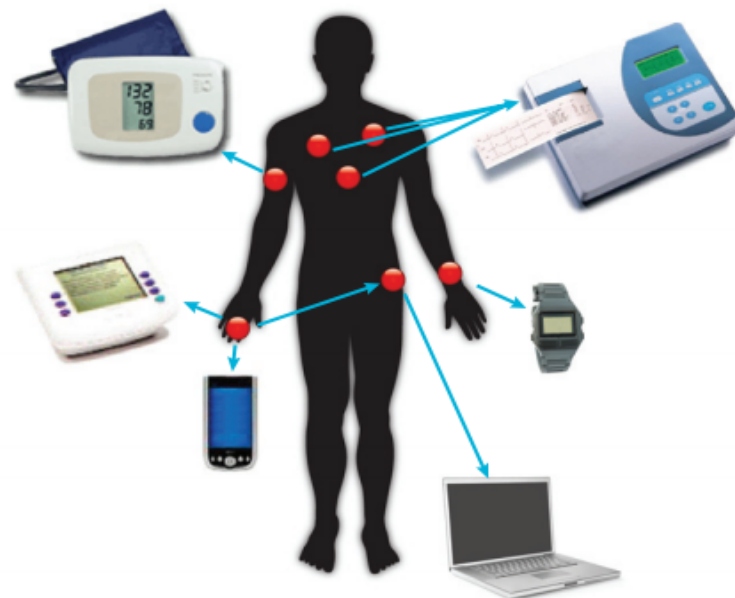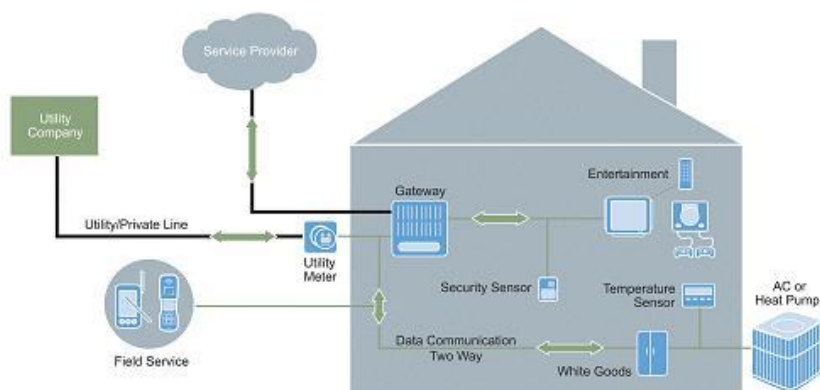
WiFi

- Dual Bands: 2.4GHz and 5GHz
- 802.11a/b/g/n
  - Cost vs Speed vs Interference tradeoff
- Roaming
- Global standard
- High speed
  - Up to 300 Mbps
- High power consumption
  - Concern for mobile devices
- Range
  - Up to 100m

WiFi – example (802.11g)

802.11g Data Rate vs. Path Loss

Protocol Comparisons

Protocol Comparisons

	Bluetooth	Zigbee/802.15.4	WiFi
Speed	Moderate	Low	High
Range	Moderate - High	High	High
Power Consumption	Low - Moderate	Low	High

Design requirement of outdoor radios for IoT applications

- Can we use WiFi/Bluetooth/ZigBee/Ant radios to support IoT applications deployed outdoor?
    - Can we achieve kilo meter communication distance?
    - Can we support 3~5 years lifetime with a coin battery?
    - Can we support the communication with thousands of IoT devices with the coverage of a base station?
    - We only need to transmit 100 bits per second data compared to the mega bits per second case in WiFi

    We are wiling to trade data rate for range, lifetime, and the number of devices supported.
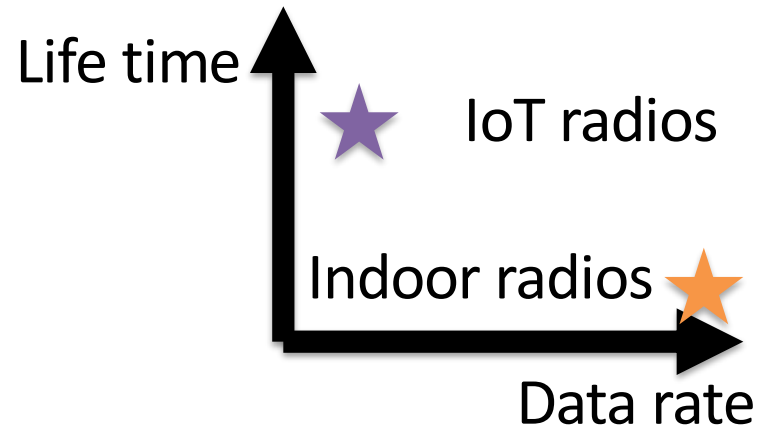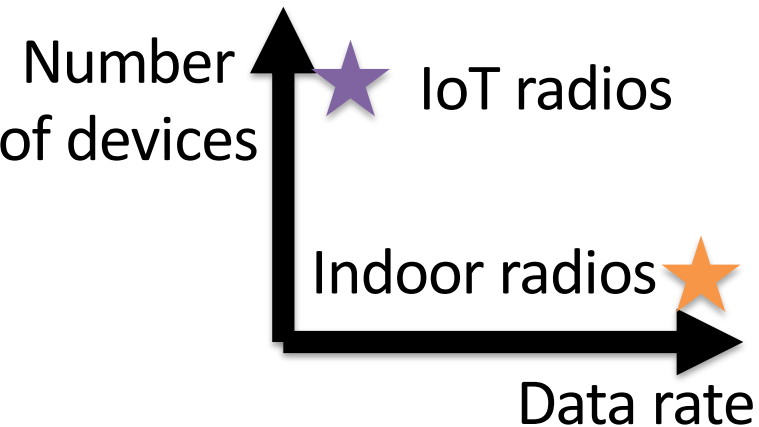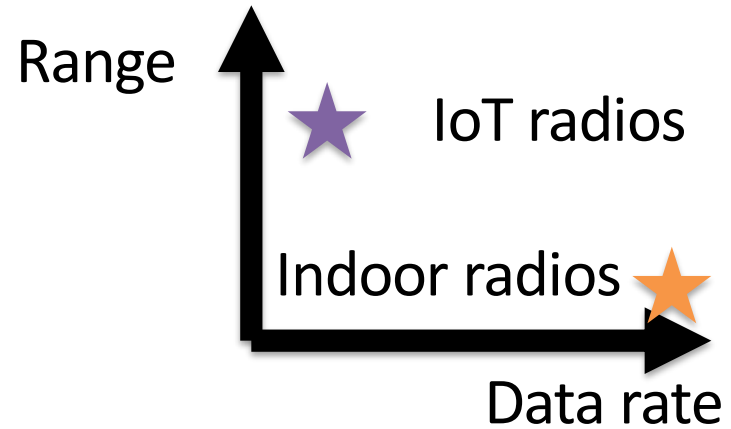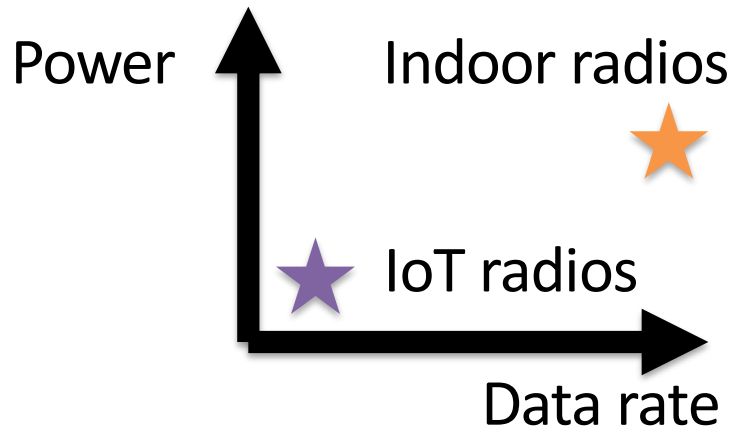
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Design requirement of outdoor radios for IoT applications

Power ↑   Indoor radios ⭐

⭐ IoT radios

→ Data rate

Range ↑   ⭐ IoT radios

Indoor radios ⭐

→ Data rate

Number of devices ↑ ⭐ IoT radios

Indoor radios ⭐

→ Data rate

Life time ↑   ⭐ IoT radios

Indoor radios ⭐

→ Data rate

SIGFOX

- Deploy its own base stations to support IoT applications
  - Kilo meter communication distance
  - Connect thousands of devices
  - 100 bits per second date rate
 - 5 years life time

SIGFOX

- REPETITION OF THE MESSAGE
  - Each message sent 3 times
  - Repetition at 3 different time slot = time diversity
  - Repetition at 3 different frequencies = frequency diversity

- COLLABORATIVE NETWORK
  - Network deployed and operated to have 3 base stations coverage at all times = space diversity

- MINIMIZATION OF COLLISIONS
  - Probability of collisions are highly reduced
  - Ultra Narrow Band
  - 3 base stations at 3 different locations

Ultra Narrow Band

- Reduce the transmitted signal bandwidth
  - Reduced noise power
  - Therefore, we can reduce the transmission power
  - Therefore, we can reduce the power consumption of radio communication

Ultra Narrow Band
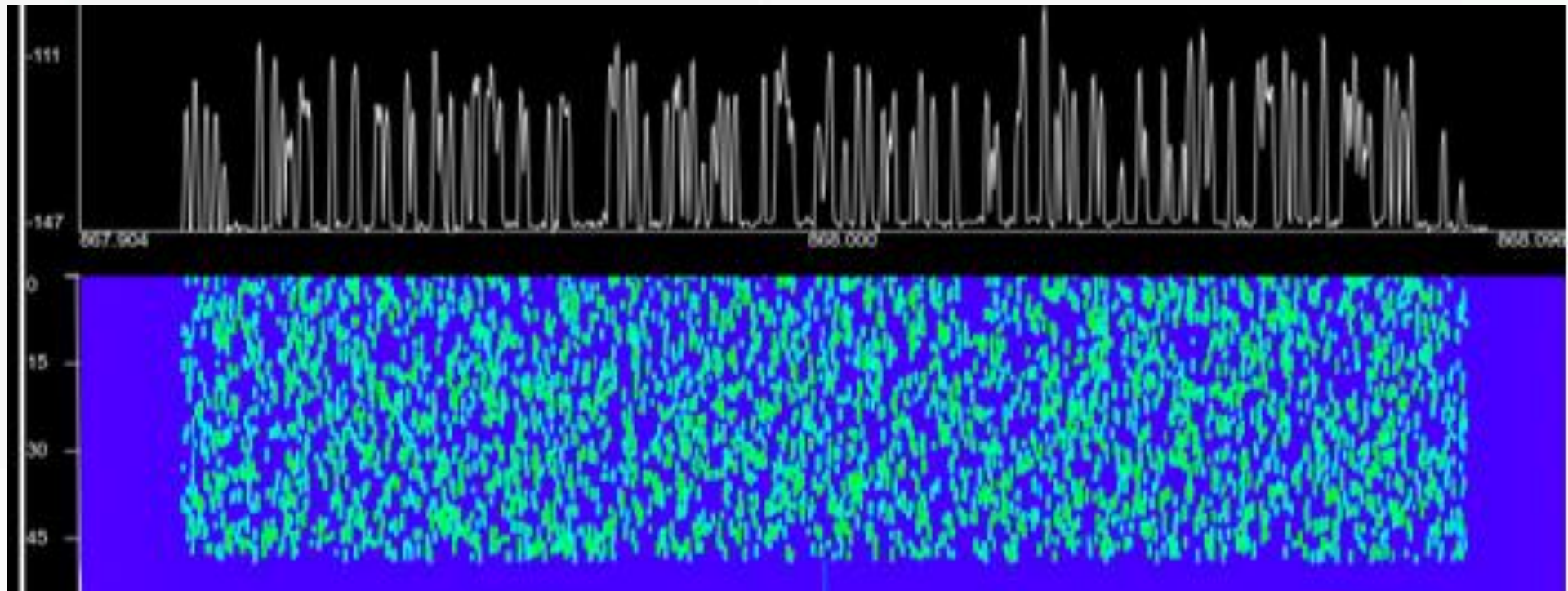
200 simultaneous messages within a 200kHz channel

NB-IoT LTE