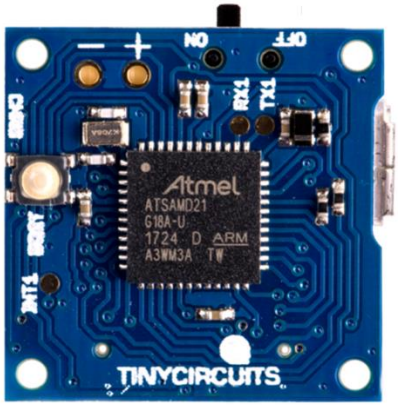
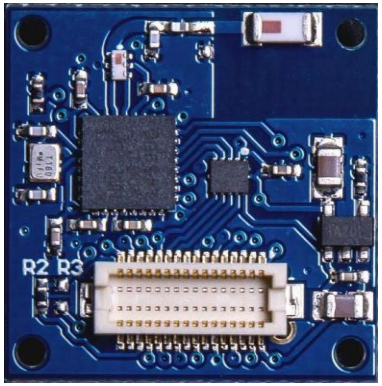
CSE190 Winter 2025



Lecture 20

Wireless



Wireless Embedded Systems

Aaron Schulman

Wireless Protocol Characteristics

- Why so many protocols for indoor and outdoor applications?
- All radios have to make tradeoffs
  - Short vs. long distance
  - High vs. low power/energy
  - High vs. low speeds
  - Large vs. small number of devices
  - Device-to-device, device-to-infrastructure
  - Indoor vs. outdoor usages

Common Radio Protocols

Radios for indoor IoT applications

- Design requirements
  - Short range
  - High data rate
  - Small number of devices
- Common protocols
  - Bluetooth/Low Energy
  - ZigBee
  - Ant
  - WiFi

Radios for outdoor IoT applications

- Design requirements
  - Long range
  - Low data rate
  - Large number of devices
  - Low energy consumption
- Common protocols
  - GSM/GPRS
  - LTE
- Emerging protocols
  - Sigfox/LoRA
  - 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 transmit power
- Frequency hopping communication

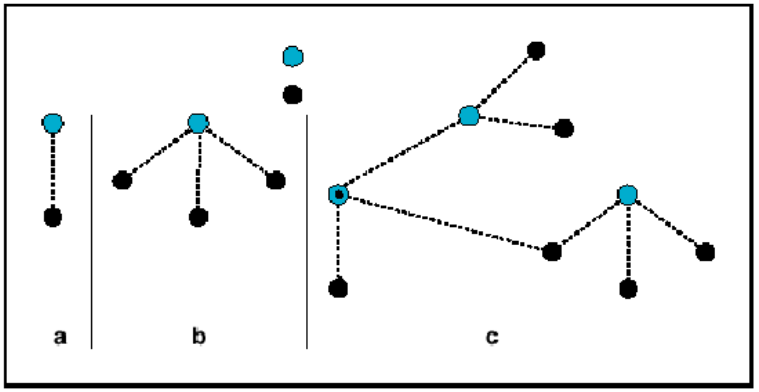


Figure 1.2: Piconets with a single slave operation (a), a multi-slave operation (b) and a scatternet operation (c).

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

Frequency hopping communication was invented by actress Hedy Lamar

UNITED STATES PATENT OFFICE

2,292,387

SECRET COMMUNICATION SYSTEM

Hedy Kiesler Markey, Los Angeles, and George Antheil, Manhattan Beach, Calif.

Application June 10, 1941, Serial No. 397,412

6 Claims. (Cl. 250—2)

This invention relates broadly to secret communication systems involving the use of carrier waves of different frequencies, and is especially useful in the remote control of dirigible craft.

Fig. 2 is a schematic diagram of the apparatus at a receiving station;

Fig. 3 is a schematic diagram illustrating a starting circuit for starting the motors at the

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!

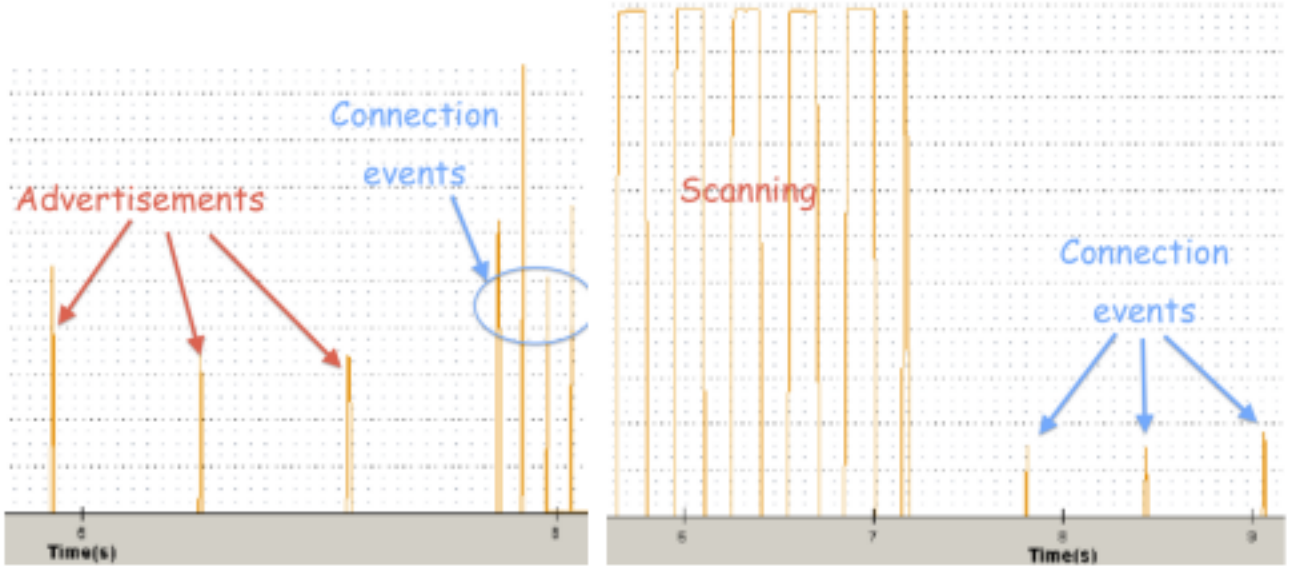
1. Advertise on only one of three channels (less freq. hopping)
2. Transmit quickly at 1 Mbit/s
3. Make the minimum time to send data only 3 msec
4. Make a very predictable time when the device accepts connections
5. Limit the max transmit power to 10 mW
6. However, don't sacrifice security: AES 128-bit

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

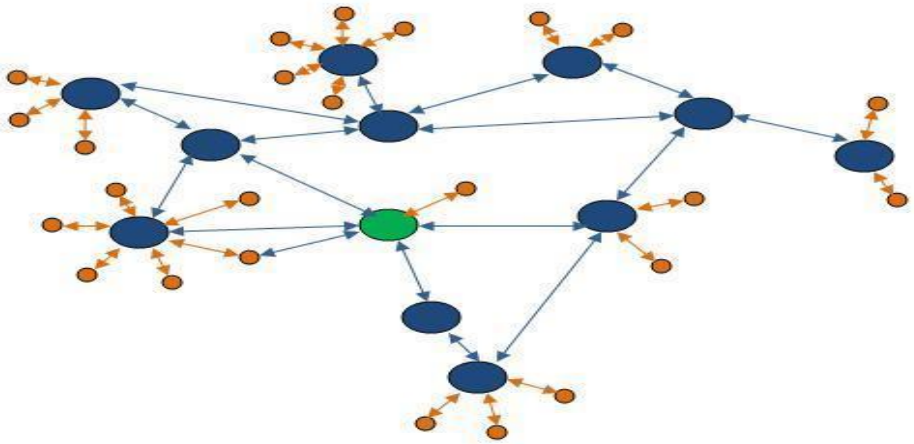
(Plots are power over time)



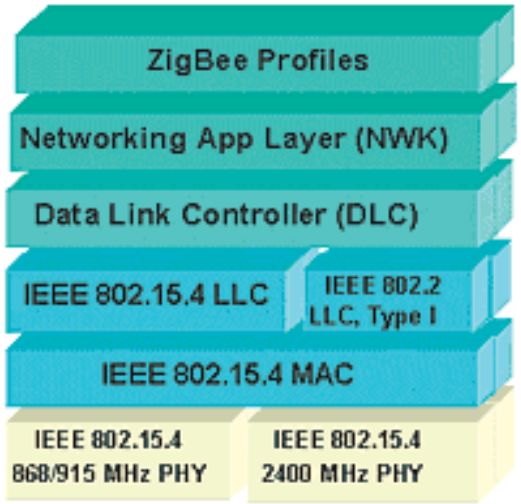
From: How Low Energy is Bluetooth Low Energy - Siekkinen et al.

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



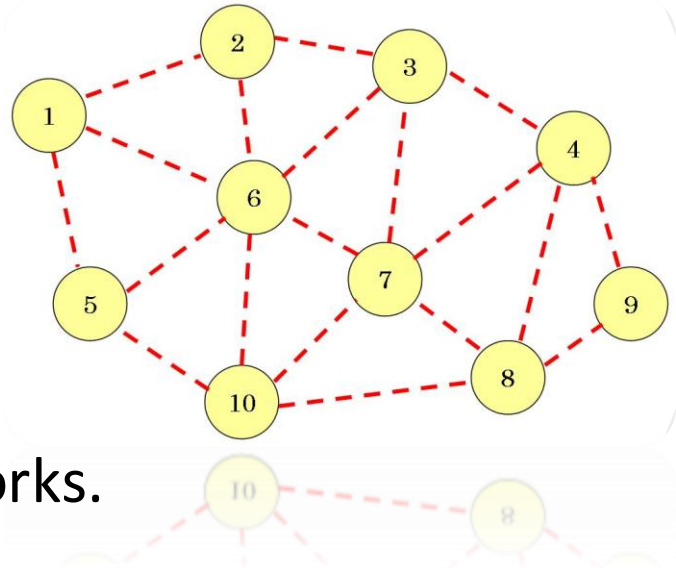
Zigbee/802.15.4 mesh network and device types



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.

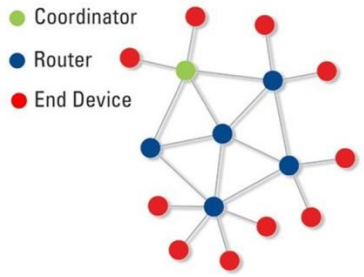


- ZigBee devices often form Mesh Networks.

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

Image Source: <http://kf5czo.blogspot.com/2012/03/ham-radio-and-mesh-networks.html>

Mesh Networking



- 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.

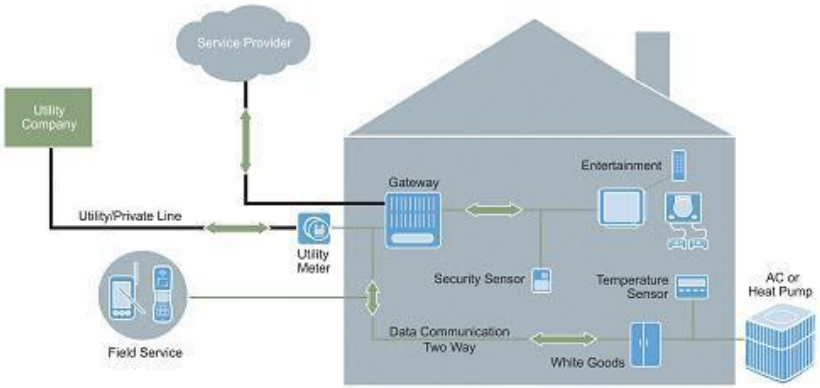
- Mesh Characteristics:
  - *Self-forming* – ZigBee devices can establish communication pathways when new devices appear.
  - *Self-healing* – If a node is removed from the network (either intentionally or not) the remaining network will look to establish alternate routes of communication.

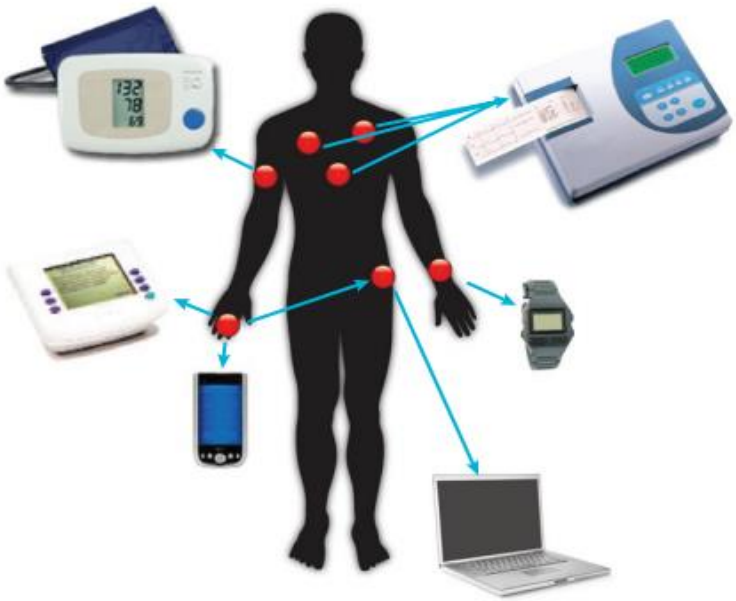
Why ZigBee?

- Low Power, Cost, and Size
- Straightforward configuration
- Good support and documentation
  - Lots of products already on the market
- Mesh Networking
- Lends itself well to a variety of applications
- Very low wakeup time
  - 30mS (Zigbee) vs. up to 3S (Bluetooth)

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





Bluetooth, Zigbee, and WiFi contend

- Competes with Wi-Fi for bandwidth..
  - Only four usable bands in Wi-Fi intensive scenarios

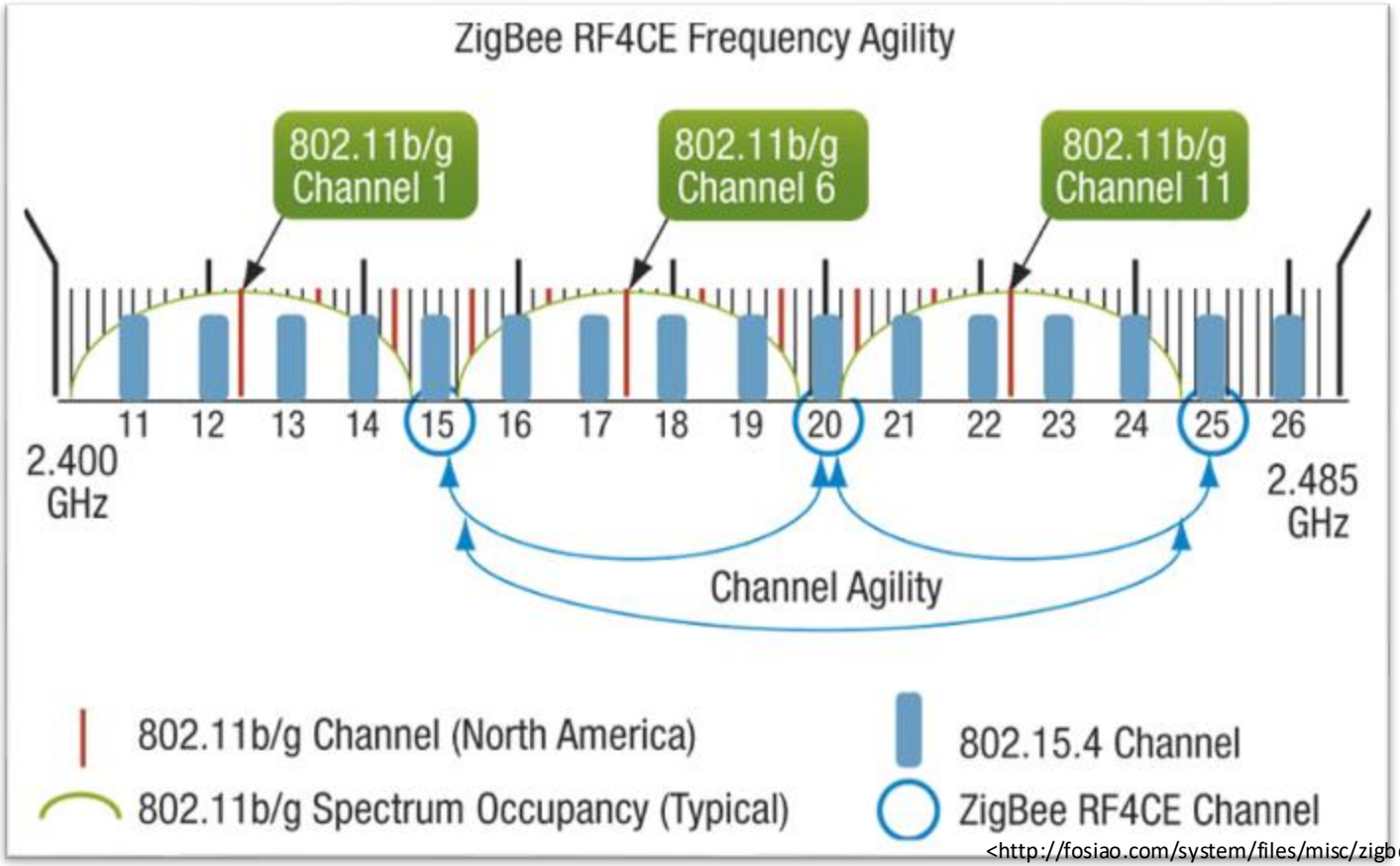
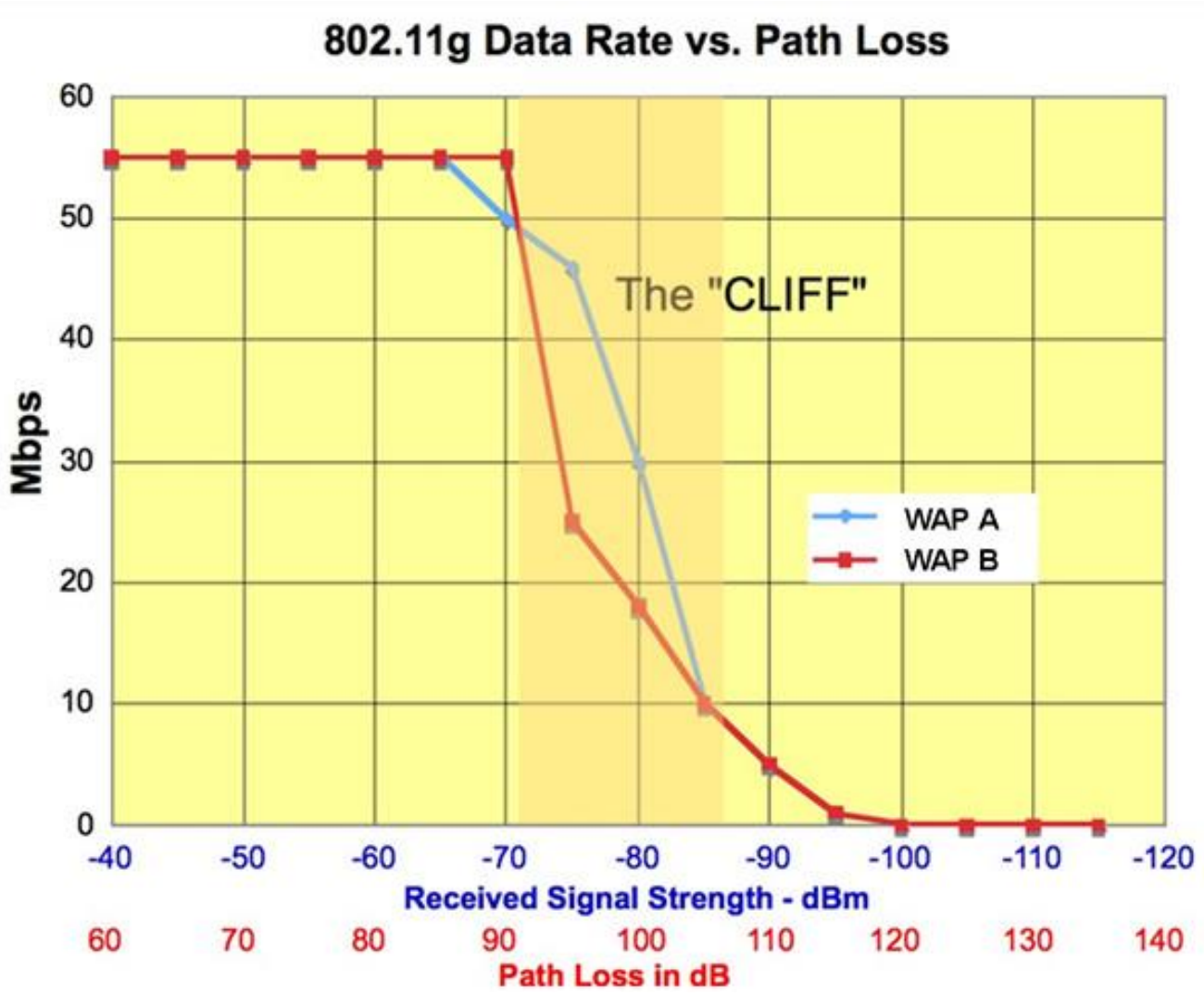


Image & Data Source <http://fosiao.com/system/files/misc/zigbee.wifi_.channel.jpg>

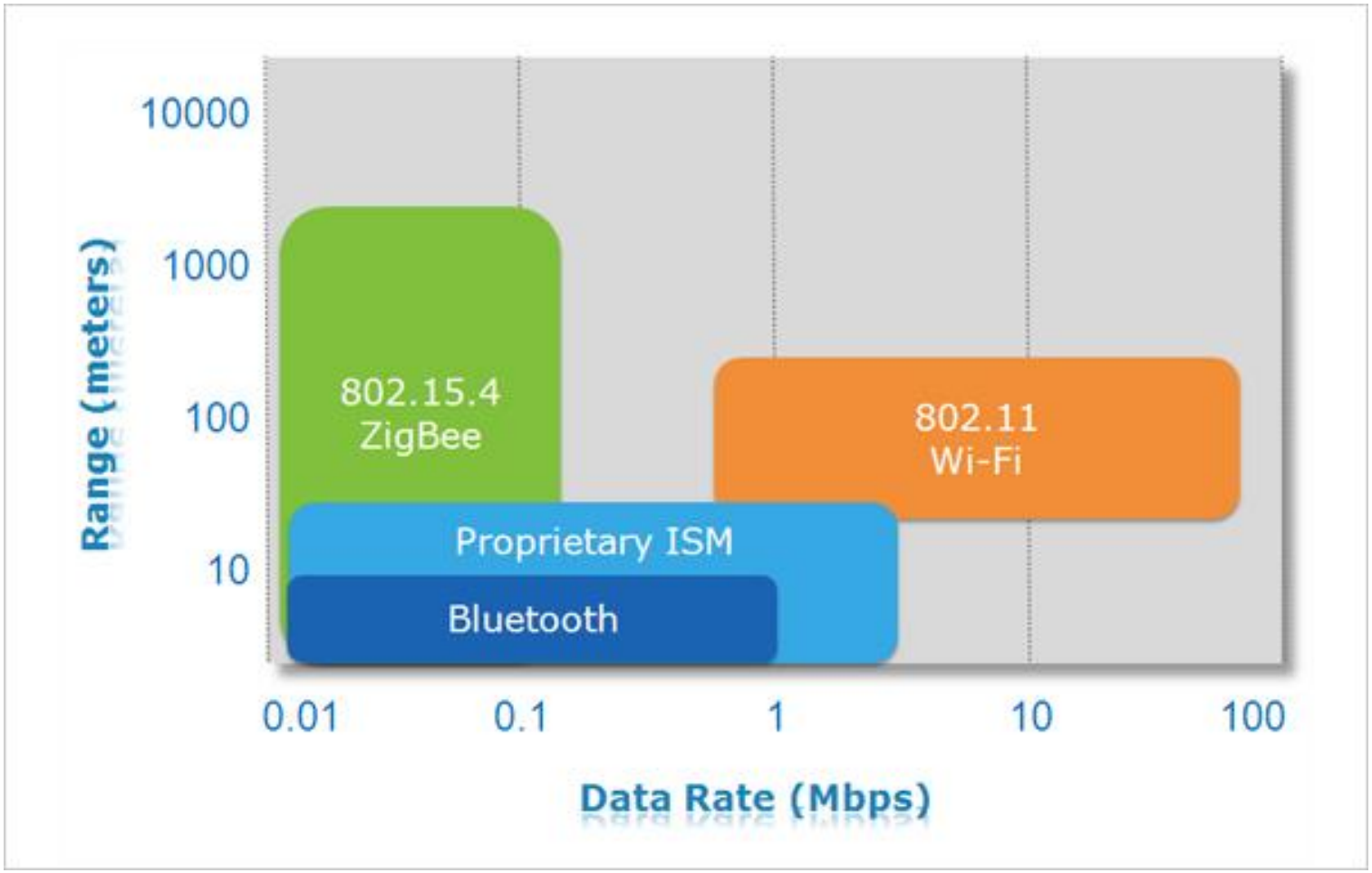
WiFi

- Dual Bands: 2.4GHz and 5GHz
- 802.11a/b/g/n
  - Cost vs Speed vs Interference (2.4/5.8 GHz) tradeoff
- Roaming
- Global standard
- High speed
  - Up to 300 Mbps
- High power consumption
  - Concern for mobile devices
- Range
  - Up to 100m

WiFi adapts speed to signal (802.11g)



Protocol Comparisons



Protocol Comparisons

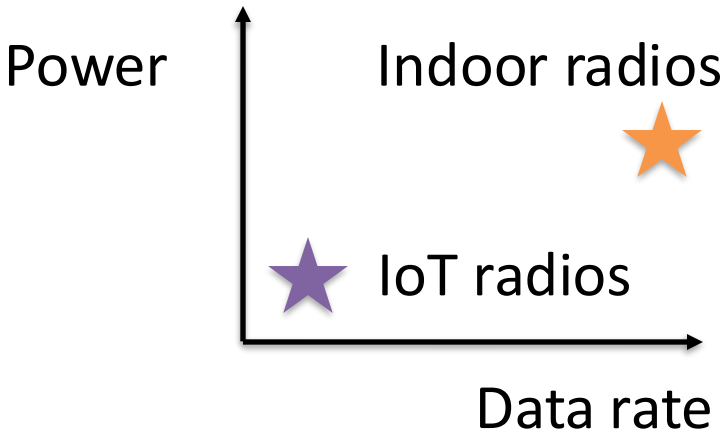
	Bluetooth	**Zigbee/802.15.4**	**WiFi**
Speed	Moderate	Low	High
Range	Moderate - High	High	High
Power Consumption	Low - Moderate	Low	High

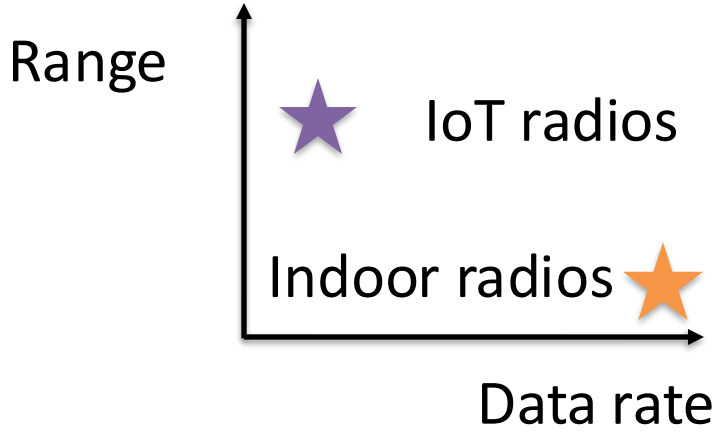
Design requirement of outdoor radios for IoT applications

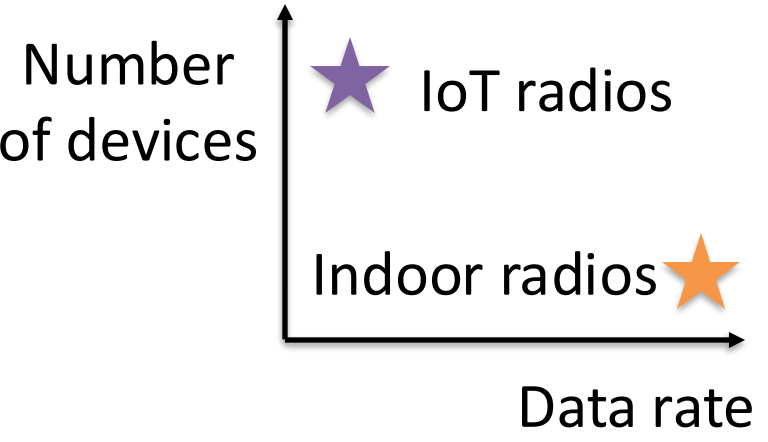
- Can we use WiFi/Bluetooth/ZigBee/Ant radios to support IoT applications deployed outdoor?
  - Can we achieve kilometer communication distance?
  - Can we support 3~5 years lifetime with a coin battery?
  - Can we support the communication with thousands of IoT devices with the coverage of a base station?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

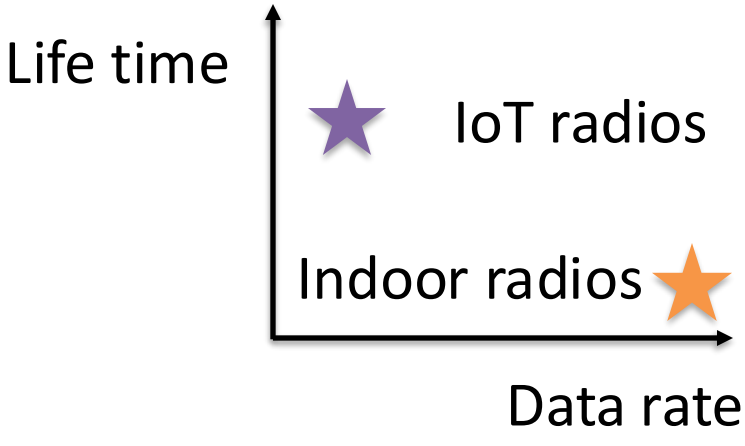
We are wiling to trade data rate for range, lifetime, and the number of devices supported.

Design requirement of outdoor radios for IoT applications









LoRA

- Deploy your own indoor/outdoor base stations to support IoT applications
  - 10 Kilometer communication distance
  - Connect thousands of devices
  - 100 bits per second date rate
  - 5 years battery lifetime

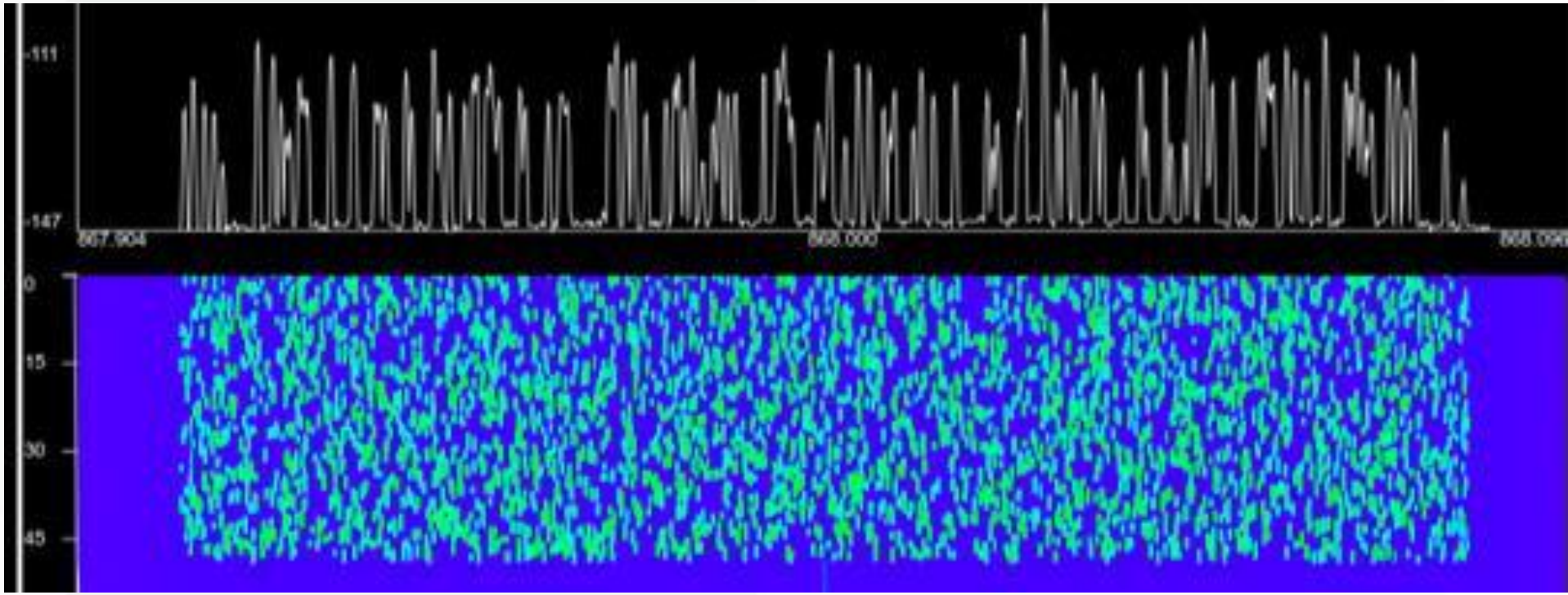
LoRA is Extremely Reliable

- Uses special modulation technique
  - Bits encoded as “chirps” that are robust to interference and can be received with low signal
- Built as a collaborative network
  - LoRAWAN allows multiple base stations to receive signal and whichever decodes properly forwards to the next hop
- Few collisions (Narrow band)
  - Many channels and base stations listen to all channels simultaneously

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 is also being built into LTE