# ECEN 5823-001
# Internet of Things Embedded Firmware

Lecture #27

04 December 2018

Be Boulder.

University of Colorado Boulder

# Agenda

- Class Announcements
- Remaining lecture periods
- FCQs
- Low power RF co-existence

# Course Project questions/discussions

# Remaining Lecture periods

- Today, Lecture
- Thursday, Final review
- Tuesday the 11th, Lab day
  - Will make myself available in the ESE lab unless a student team signs up for course project demo
- Thursday the 13th, Demo party!
  - What refreshments would you like?

# FCQs

- You can access the FCQ for this course at:
  - colorado.campuslabs.com/courseeval
- I will be back in 15-minutes

# Class Announcements

- Final Exam is on Monday, December 17th
  - On-campus students will take it at 4:30pm in ECCS 1B14
  - Distant students the exam will be open at 4:30pm and must be completed by 11:59pm on the 17th

- Course demo signup has started!
  - https://docs.google.com/spreadsheets/d/16ptNNX_VnZ24nZUCIAx9v0wLgThQoEv4PflUBVypAbM/edit#gid=0
  - You must use your @Colorado.edu email address for access

# Driving Wi-Fi, ZigBee, and Thread Co-existence

- On World predicts that in 2020, of the projected 2 billion wireless sensor nodes that will ship, one in seven will contain a Wi-Fi radio
  - Why would these sensor nodes contain a Wi-Fi radio?

- The growth in IoT is closely linked to the inclusion of Wi-Fi and the convergence of home controllers with home gateways
  - Can you name a wireless gateway other than an access point?

# Driving Wi-Fi, ZigBee, and Thread Co-existence



# Driving Wi-Fi, ZigBee, and Thread Co-existence

- ABI Research predicts that the ratio of end wireless devices to a controller, containing a WiFi, will rise from less than 7 to 1 in 2017 to 10 to 1 in 2020
  - What does this increase in end devices to controller ratio mean to the end controller?

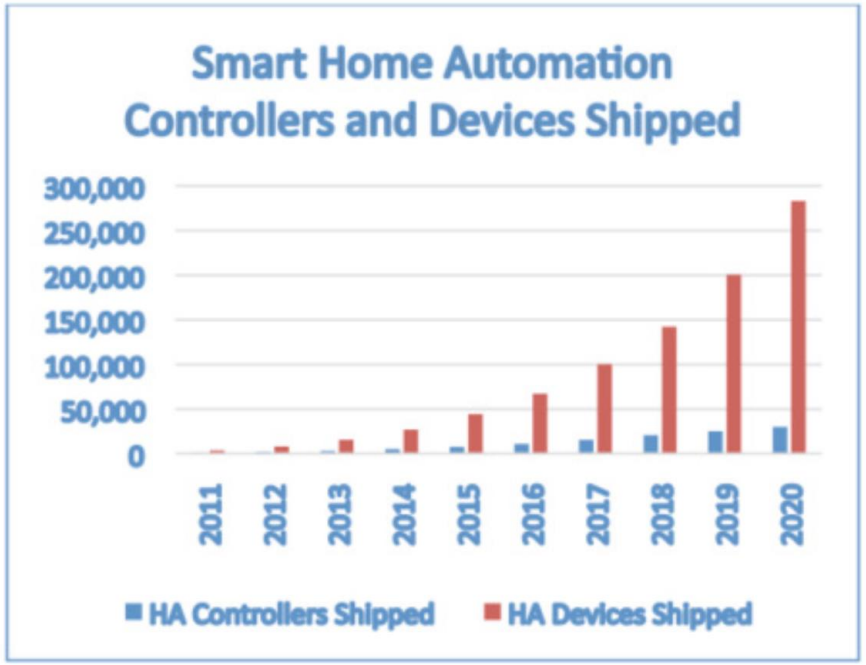



Figure 1 | Relationship between Smart Home Controllers and Smart Home Devices shipped over time[1].]



[1] https://www.embedded-computing.com/embedded-computing-design/driving-wi-fi-zigbee-and-thread-coexistence-ghz-band-part-1-unmanaged-coexistence#

# Driving Wi-Fi, ZigBee, and Thread Co-existence

- What would be some ideas on how to enable the co-existence of Wi-Fi and Low Power Wireless sensor nodes when the controller must have both in the same device?

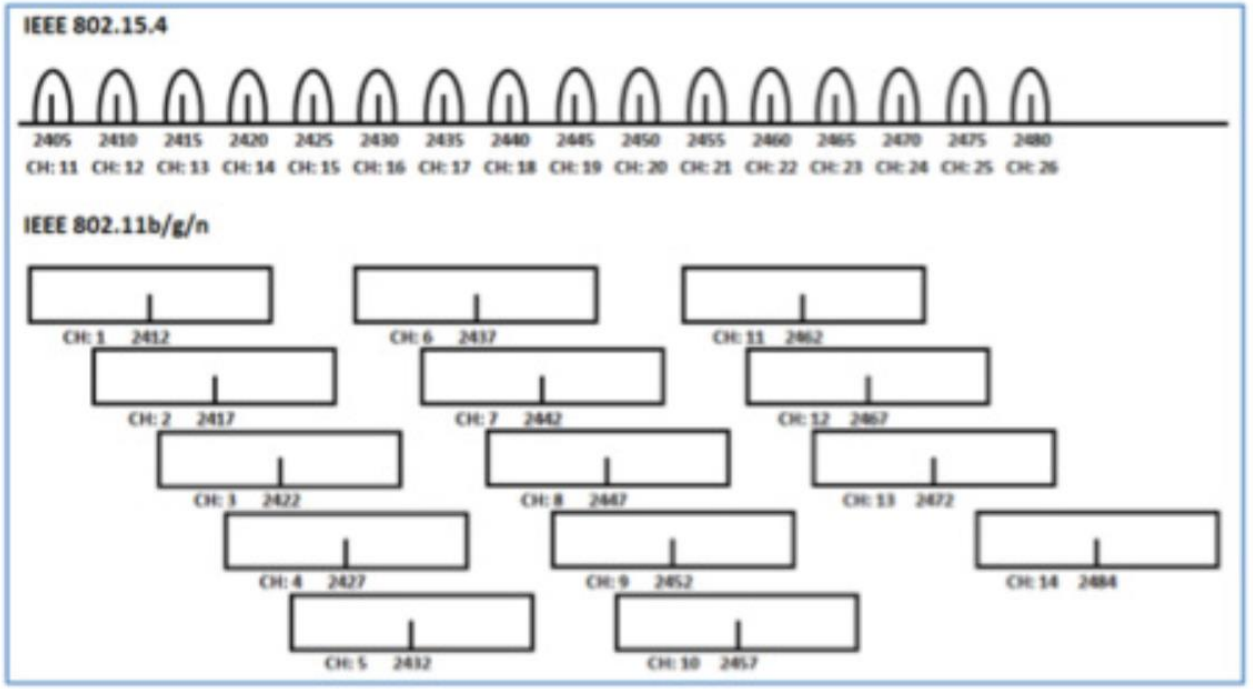
- Stop transmissions on one radio when another is transmitting is sufficient when:
  - There is one low-power radio in the design with Wi-Fi
  - The number per household is low
  - The transmit power of the radios is relatively low

# Driving Wi-Fi, ZigBee, and Thread Co-existence

- These recent trends are making co-existence more difficult:
  - Increased Wi-Fi transmit power level for “extended range”
    - +30dBm are now common
  - Increased Wi-Fi throughput
  - Increase Wi-Fi duty-cycle support for high throughput applications such as large files and video streaming
  - Integrating Wi-Fi, ZigBee, Thread, and Bluetooth into the same gateway

# Driving Wi-Fi, ZigBee, and Thread Co-existence

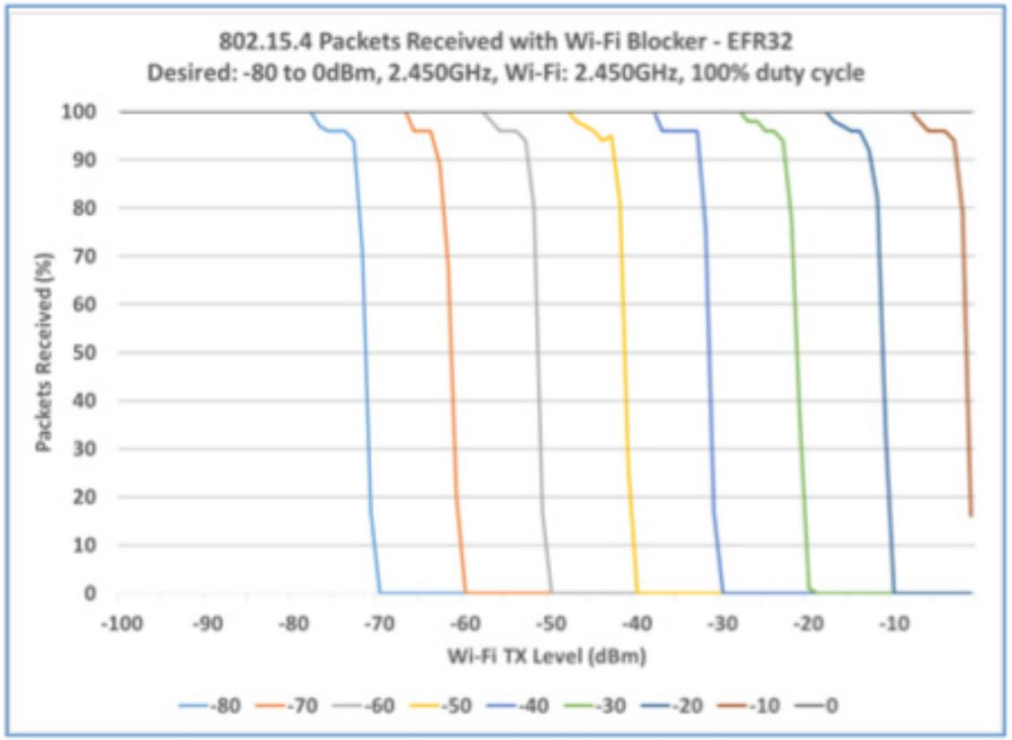
- From the frequency chart, what type of frequency co-existence must be taken into account?
  - Co-channel
  - Adjacent channel
  - Far-way channel




[Figure 2 | 802.15.4 and 802.11b/g/n Channel Mapping (Worldwide).]

# Driving Wi-Fi, ZigBee, and Thread Co-existence

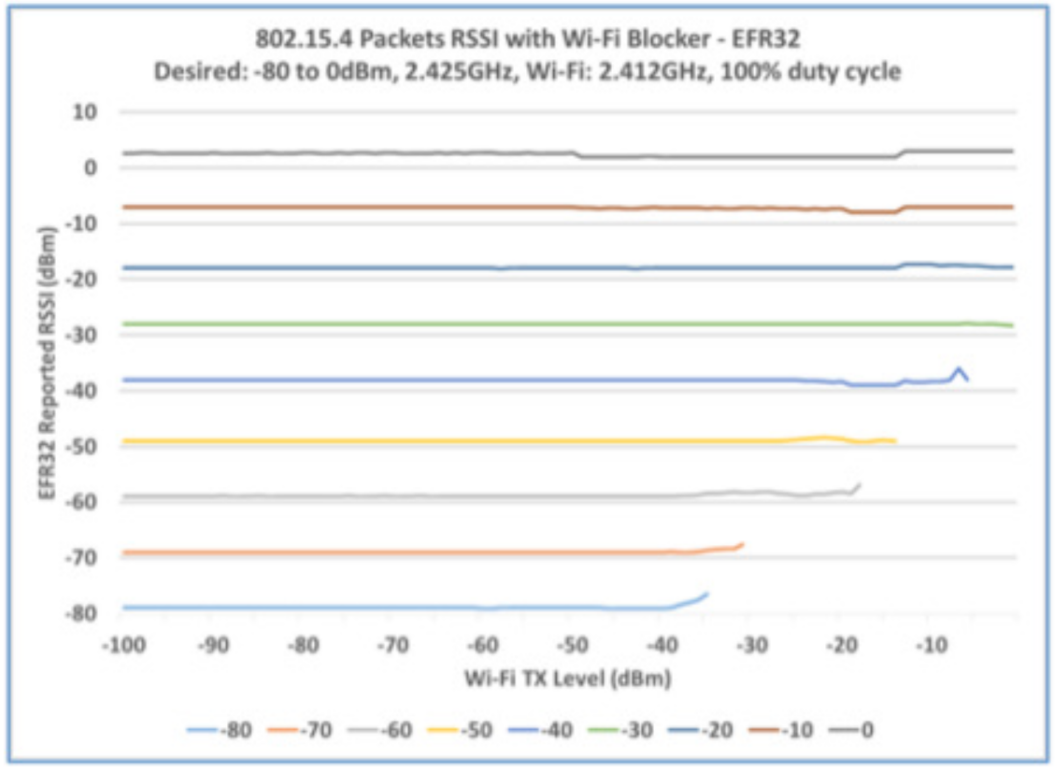
- From the co-channel Low-Power received chart on the right, what conclusion can you make?
- The EFR32MG1 can receive 802.15.4 packets down to 6 dBm weaker than the aggregate Wi-Fi transmit power




[Figure 3 | 100 percent Duty Cycled 802.11n Blocker with Desired 802.15.4 at Co-Channel.]

# Driving Wi-Fi, ZigBee, and Thread Co-existence

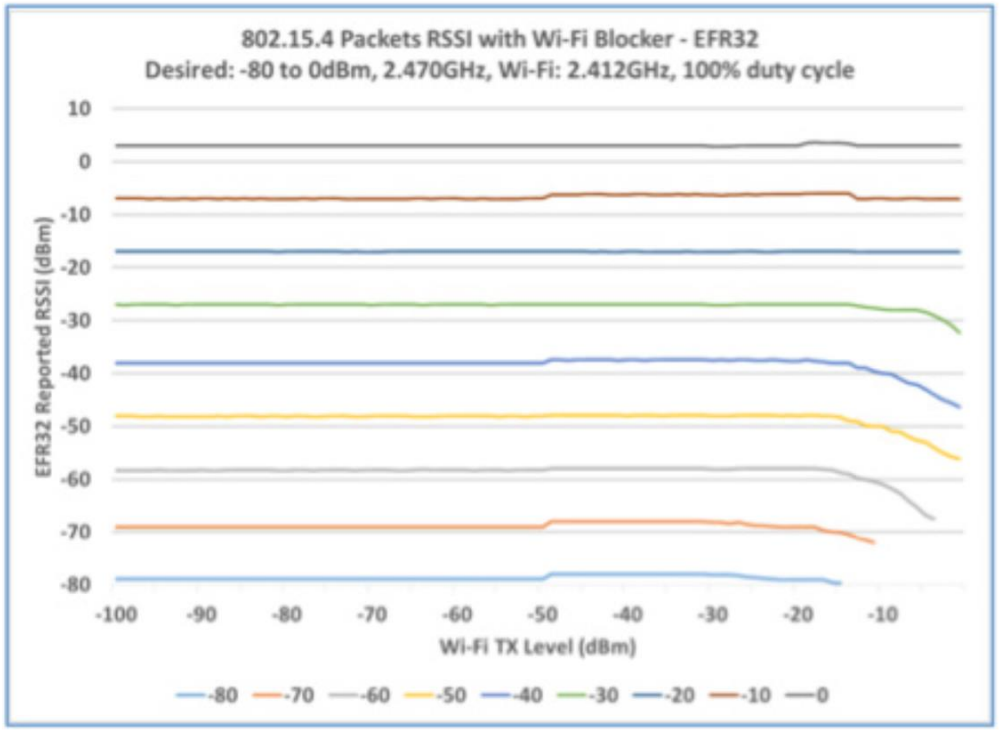
- From the adjacent-channel Low-Power received chart on the right, what conclusion can you make?
- The EFR32MG1 can receive a -80 dBm 802.15.4 signal with -35 dBm or weaker Wi-Fi signal




[Figure 4 | 100 percent Duty Cycled 802.11n Blocker with Desired 802.15.4 at Adjacent Channel.]

# Driving Wi-Fi, ZigBee, and Thread Co-existence

- From the far-way-channel Low-Power received chart on the right, what conclusion can you make?
- The EFR32MG1 can receive a -80 dBm 802.15.4 signal with -15 dBm or weaker Wi-Fi signal




[Figure 5 | 100 percent Duty Cycled 802.11n Blocker with Desired 802.15.4 at "Far-Away" Channel.]

# Driving Wi-Fi, ZigBee, and Thread Co-existence

- If we are going to design for co-existence “unmanaged,” what do we need to design towards?
  - Implement frequency separation
    - For Wi-Fi networks, an access point establishes the initial channel, and in auto configuration, it is free to move the network to another channel using the Channel Switch Announcement to schedule a channel change
    - If the Wi-Fi and 802.15.4 radios are implemented with a common host, then the host should attempt to maximize frequency separation

# Driving Wi-Fi, ZigBee, and Thread Co-existence

What are two methods that could be used to increase frequency separation between a Wi-Fi and Bluetooth network?

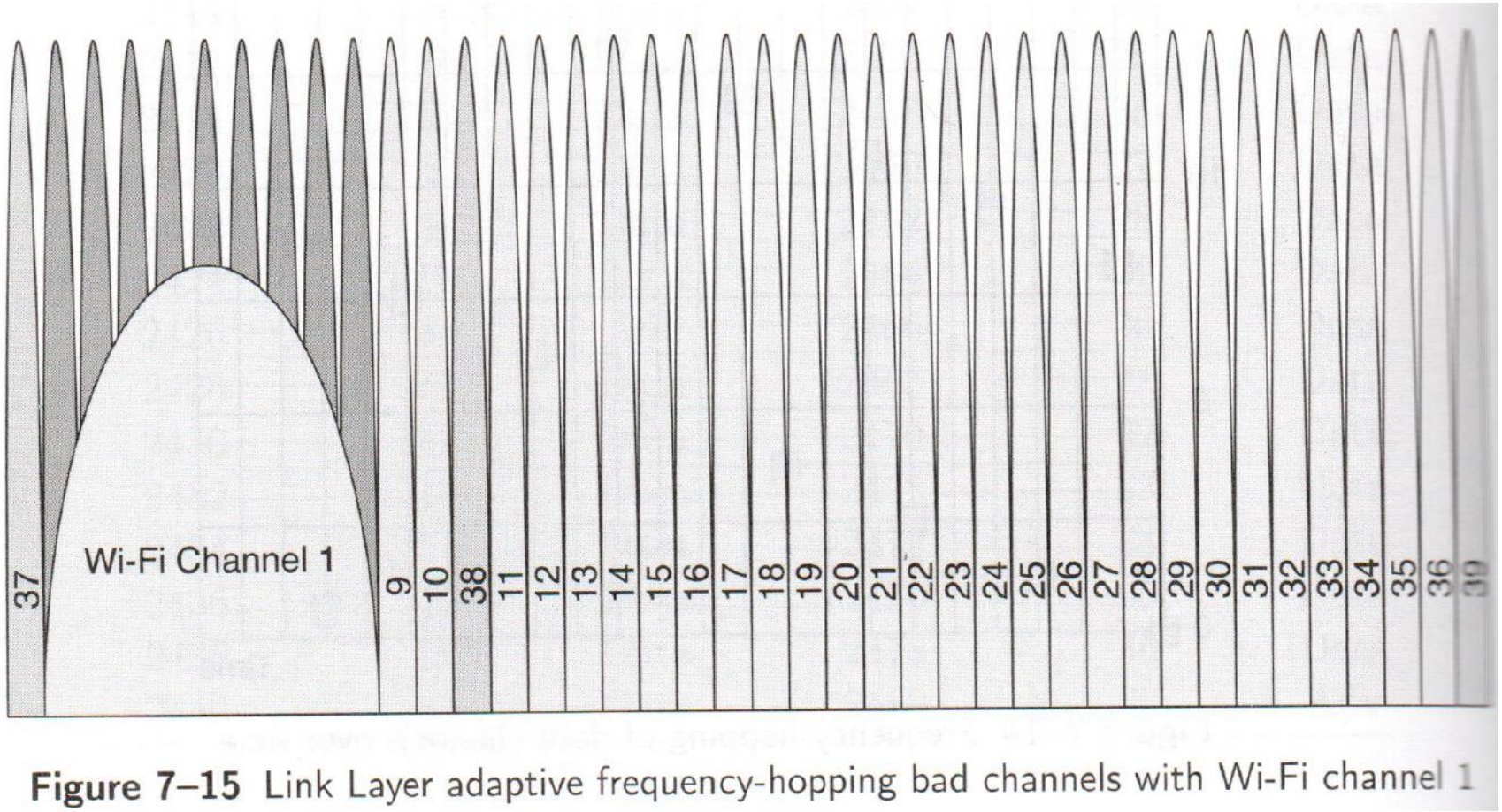



**Figure 7–15** Link Layer adaptive frequency-hopping bad channels with Wi-Fi channel 1

# Driving Wi-Fi, ZigBee, and Thread Co-existence

- Operate Wi-Fi with 20 MHz bandwidth
  - If operating in the Wi-Fi allowed 40 MHz mode, 40 MHz of the 80 MHz ISM band is consumed, leaving only half the ISM band for 802.15.4 devices
  - Any Wi-Fi station can set the “Forty MHz Intolerant” bit in the HT Capabilities Information informing the access point that other 2.4 GHz ISM devices are present and force the entire network to 20 MHz

# Driving Wi-Fi, ZigBee, and Thread Co-existence

- Increase antenna isolation
  - Increasing the distance between antennas
    - In open-air, far-field received is proportional 1/R2, where R is the distance between the antennas
  - Taking advantage of antenna directionality
    - A monopole antenna provides a null along the axis of the antenna, when can be directed towards the Wi-Fi antenna

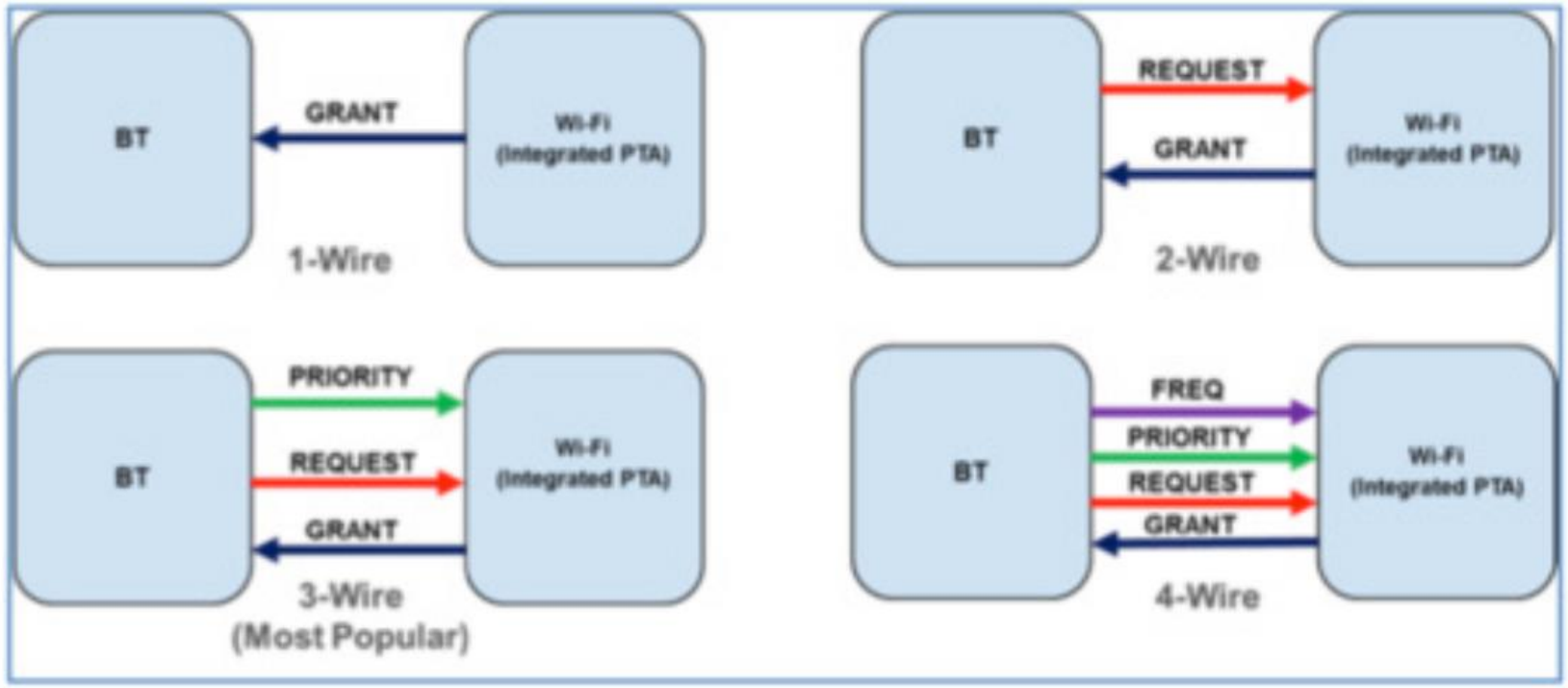
# Driving Wi-Fi, ZigBee, and Thread Co-existence

- Use the Low-Power RF retry mechanisms
  - 802.15.4 specifies retries at the MAC layer
  - Further improve message delivery robustness by implementing network retries
  - The user, or application, can also implement retries

# Driving Wi-Fi, ZigBee, and Thread Co-existence - Managed

- Market trends is implementing WiFi and Low-Power RF radios into the same device
- What advantages does this integration provide?
- What disadvantages this integration enable?
- What can be done to overcome these disadvantages?

# Driving Wi-Fi, ZigBee, and Thread Co-existence - Managed




[Figure 1 | Typical Wi-Fi/Bluetooth PTA implementations.]

# Driving Wi-Fi, ZigBee, and Thread Co-existence - Managed

- Silicon Labs' has a family of multi-protocol devices
  - https://www.silabs.com/products/wireless/multiprotocol-connectivity#multiradio
- Managed coexistence uses PTA, Packet Traffic Arbitration to manage when one radio can transmit/receive and the other is paused
  - TX REQUEST – to PTA from Low-Power RF requesting the radio
  - TX CONFIRM – to Low-Power RF confirming radio access
  - PRIORITY

# Driving Wi-Fi, ZigBee, and Thread Co-existence - Managed

- Managed Coexistence results:
  - Improved Low-Power RF network formation, but with formation occurring via broadcasting, it is still affected due to broadcast messages are not retried
  - How could you improve LP-RF formation with co-located radios?
    - Network formation can be improved by temporarily reducing WiFi traffic during joining of devices

# Driving Wi-Fi, ZigBee, and Thread Co-existence - Managed

- Managed Coexistence results:
  - Substantially reduced MAC retries
  - What other benefits does reducing MAC retries provides?
  - Substantially reduces message failures even during high WiFi duty cycles
- It is recommended and important to implement all of the non-managed coexistence design principles