IEEE 802.15.2 ENABLING COEXISTENCE OF WPANS WITH WLANS

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IEEE 802.15.2

- The core purpose of the IEEE 802.15.2 standard is to facilitate coexistence of IEEE 802.15 wireless personal area network (WPAN) devices with other wireless appliances operating in unlicensed frequency bands
  - For example, WLANs that can operate at 2.4 GHz
- IEEE 802.15.2 defines several coexistence mechanisms that can be deployed to make the coexistence of WLAN and WPAN networks possible
- These mechanisms are categorized into two distinct classes: *collaborative* and *non-collaborative*
- Coexistence mechanisms are typically implemented on Bluetooth devices because Bluetooth is more vulnerable to cochannel interference due to its low power

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Characteristics of CoChannel Interference

- The effect of cochannel interference (CCI) depends on several factors
  - Distance between the mutually interfering networks
  - The traffic generated by each of the wireless networks
  - Power level of the devices in each network
    - More resilient “victim” but also more powerful “aggressor”
  - Data rates of the WLAN
  - Type of data transferred between the networks

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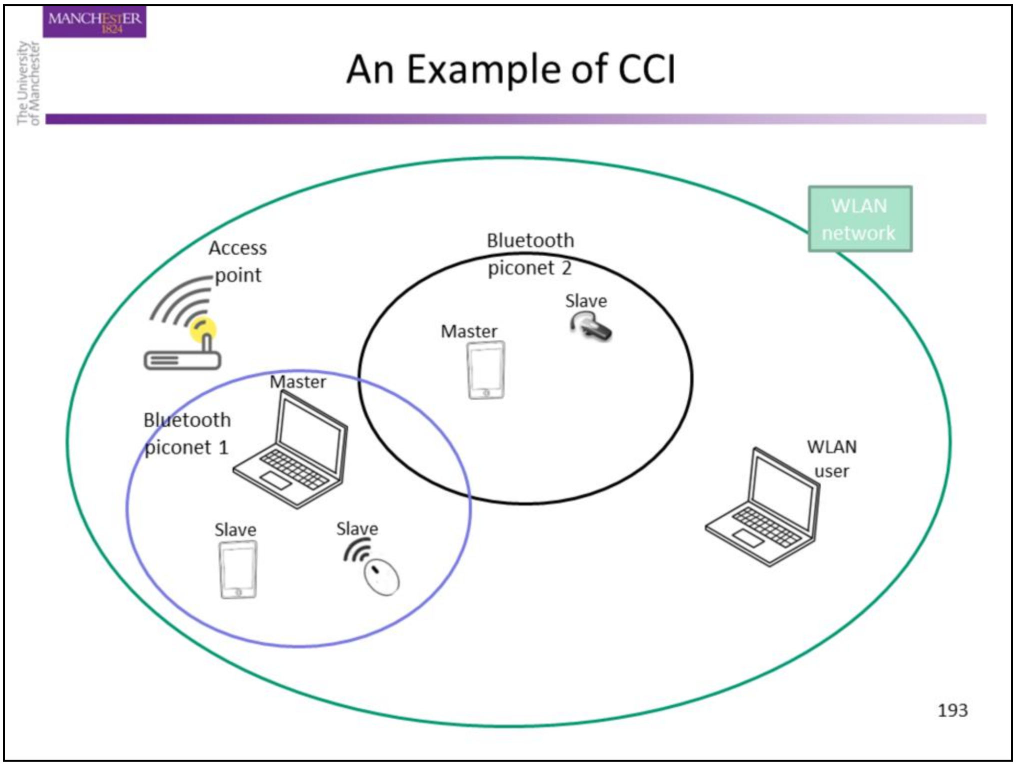
- The scope of 802.15.2 is limited to DCF implementations of IEEE 802.11 and does not include the point coordination function (PCF) access scheme.
- Initially, 802.11 included both a 1 and 2 Mbps frequency hopping spread spectrum (FHSS) PHY layer as well as a 1 and 2 Mbps direct sequence spread spectrum (DSSS) PHY layer. The FHSS PHY layer uses 1 MHz channel separation and hops pseudo randomly over 79 channels.
- The DSSS PHY layer uses a 22 MHz channel and may support up to three non-overlapping channels in the unlicensed band.
- Thus, the IEEE 802.11 DSSS PHY layer was extended to include both 5.5 and 11 Mbps data rates using complementary code keying (CCK). This high rate PHY layer is standardized to be named IEEE 802.11b. This high rate version includes four data rates: 1, 2, 5.5, and 11 Mbps. The channel bandwidth of the IEEE 802.11b PHY layer is 22 MHz.
- The IEEE 802.15.1 PHY layer uses the same seventy-nine 1 MHz-wide channels that are utilized by the FHSS version of IEEE 802.11. IEEE 802.15.1 hops pseudo-randomly at a nominal rate of 1600 hops/s.



- A Bluetooth receiver may experience up to 27% packet loss for data traffic and 25% packet loss for voice applications in the presence of IEEE 802.11–based WLAN interference. Results reported in N. Golmie and F. Mouveaux, ‘‘Interference in the 2.4GHz ISM band: impact on the Bluetooth access control performance,’’ in Proc. IEEE Int. Conf. on Communications, Vol. 8, Helsinki, Finland, June 2001, pp. 2540–2545.
- Theoretically, the performance degradation for a Bluetooth piconet in the presence of a WLAN is about 28%. Can you guess why?

Recent Devices for IoT Supporting WiFi/Bluetooth

- Manufacturer: Qualcomm
- Application: IoT, Smart Assistant/Speaker
- Technology: WiFi + Bluetooth
- Frequency: 2.4 / 5 GHz
- Bluetooth Standard: Bluetooth V5 + BLE
- WiFi Standard: 802.11ac
- WiFi Band: 2.4 / 5 GHz

- Manufacturer: Murata
- Application: Industrial and IoT Applications
- Technology: LoRa
- Frequency: 860 to 930 MHz
- Modulation: FSK, OOK

- Manufacturer: Digi
- Application: IoT, Point-to-Point, Point-to-Multipoint
- Frequency: 2.4 GHz
- Technology: ZigBee
- Other Standards: 802.15.4
- Data Rate: RF 250 Kbps, Serial Up to 1 Mbps

- Manufacturer: California Eastern Laboratories
- Technology: WiFi + Bluetooth
- Application: IoT, Connected Home, Safety, Building Automation
- Bluetooth Standards: Bluetooth v5
- WiFi Standards: 802.11 b/g/n
- Mesh Networking: Yes
- Output Power: 15 dBm (BLE), 18 dBm (Wi-Fi)

- Manufacturer: u-blox AG
- Description: Dual-band Wi-Fi 4 and Bluetooth 5 Combo
- Technology: WiFi + Bluetooth
- Application: Industrial Automation, Smart Manufacturing, Building automation
- Frequency: 2.4 to 5 GHz
- Bluetooth Standards: Bluetooth v5
- WiFi Standards: 802.11a/b/g/n/ac
- Data Rate: 150 Mbps

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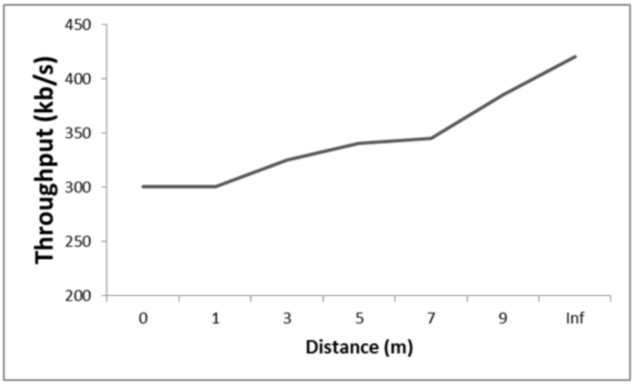
Some Measurements of CCI

- The distance between the WLAN transmitter and receiver is 4 meters
- Bluetooth throughput versus distance between the Bluetooth slave and WLAN/BT master device



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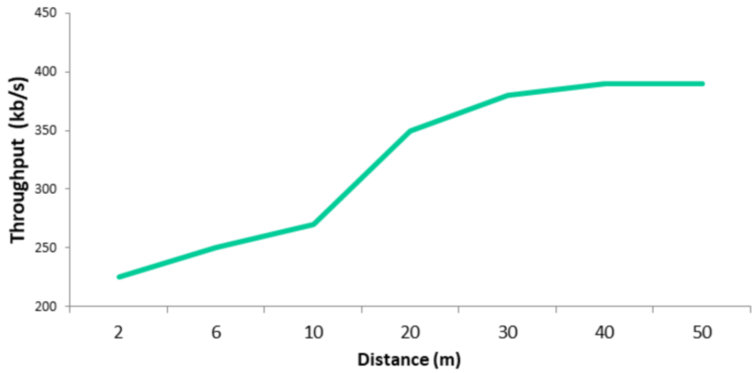
- Data taken from O. Karjalainen, S. Rantala, and M. Kivikoski, ‘‘The performance of Bluetooth system in the presence of WLAN interference in an office environment,’’ in Proc. 8th IEEE Int. Conf. on Communication Systems, Vol. 2, Singapore, Nov. 2002, pp. 628–631.

CCI Between WLAN and Bluetooth

- Throughput for Bluetooth versus the distance between WLAN terminal and AP
- If multiple Bluetooth piconets coexist with a WLAN, the performance degradation will be worse



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- Data taken from J. Lansford, A. Stephens, and R. Nevo, ‘‘Wi-Fi (802.11b) and Bluetooth: Enabling coexistence,’’ IEEE Network 15(5), 20–27 (2001).
- Bluetooth master/slave distance for this experiment is 1 m.

Definition of Collaborative Mechanisms

- Collaborative coexistence mechanisms are utilized if there is a communication link between the WLAN and WPAN networks
- This is best implemented when both WLAN and WPAN devices are embedded into the same piece of equipment (e.g., an IEEE 802.11b card and an IEEE 802.15.1 module embedded in the same laptop computer)
- Or more broadly there is direct communication between the co-existing networks

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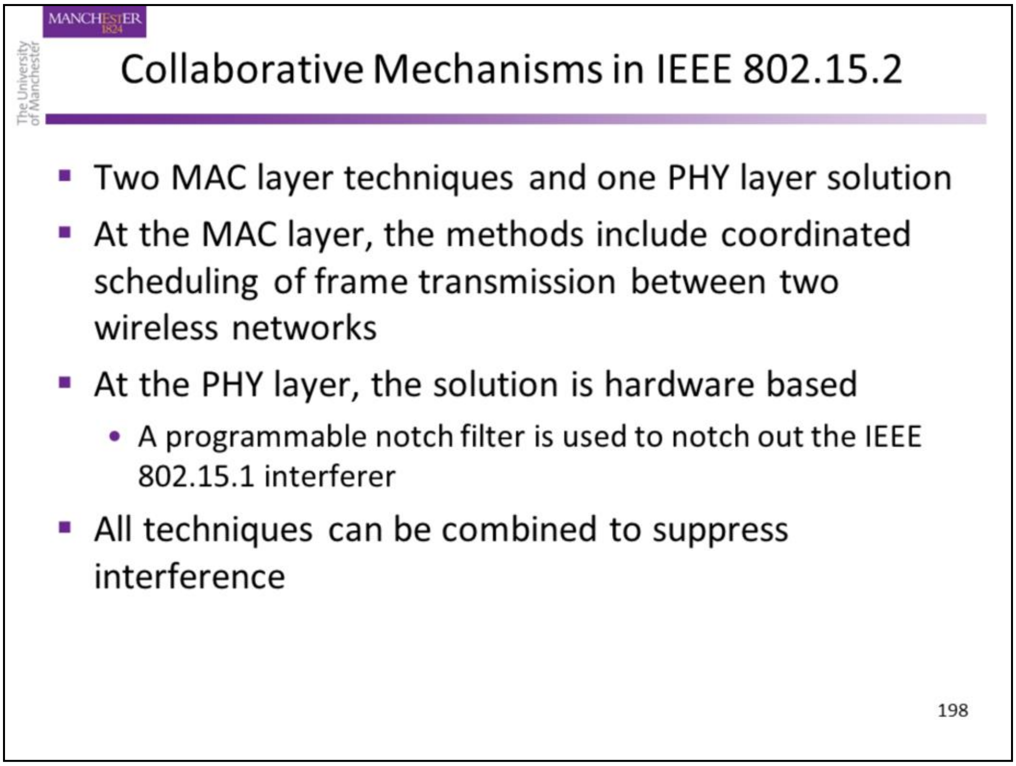
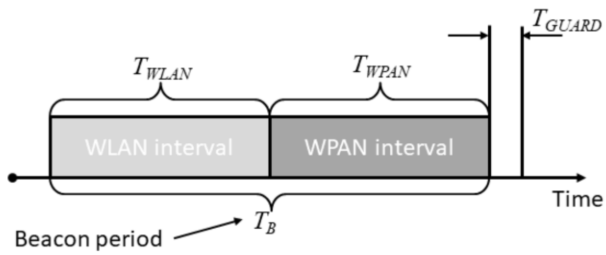


- All collaborative coexistence mechanisms, described in the standard (and discussed in this part of the course) are meant to be deployed when at least one WLAN station and WPAN device are collocated within the same physical unit.
- If the aforementioned WLAN and WPAN equipment is collocated on the same device, there should be a dedicated communication link between them that can be either a wired connection or integrated on the same chip.
- The collaborative coexistence mechanism supports coexistence of a WLAN (in particular IEEE 802.11b) and a WPAN (in particular IEEE 802.15.1) by sharing information between the collocated IEEE 802.11b and IEEE 802.15.1 radios while locally controlling transmissions to avoid interference.

Alternating Wireless Medium Access (AWMA)

- Core idea: use some of time interval (T_B) between successive Beacon frames for WPAN transmission
  - In AWMA, the WLAN radio and the WPAN equipment are collocated in the same physical unit
- Devices connected to the same AP restrict their WLAN traffic and WPAN traffic to nonoverlapping time intervals
  - Eliminates interference for all connected devices to this AP



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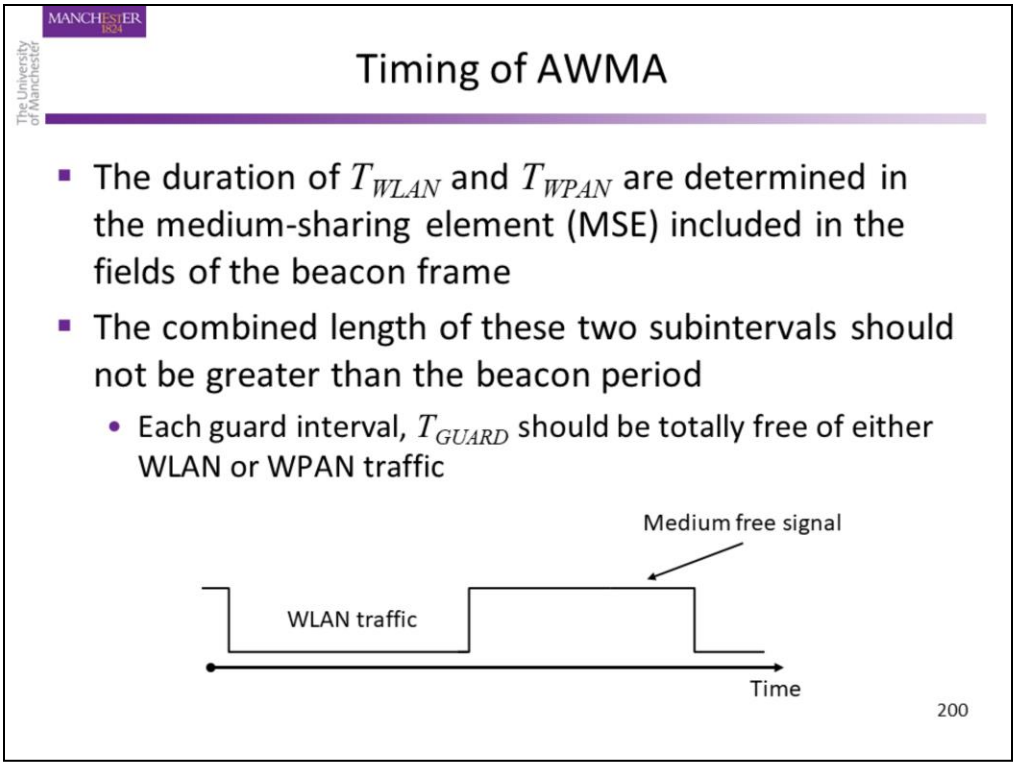
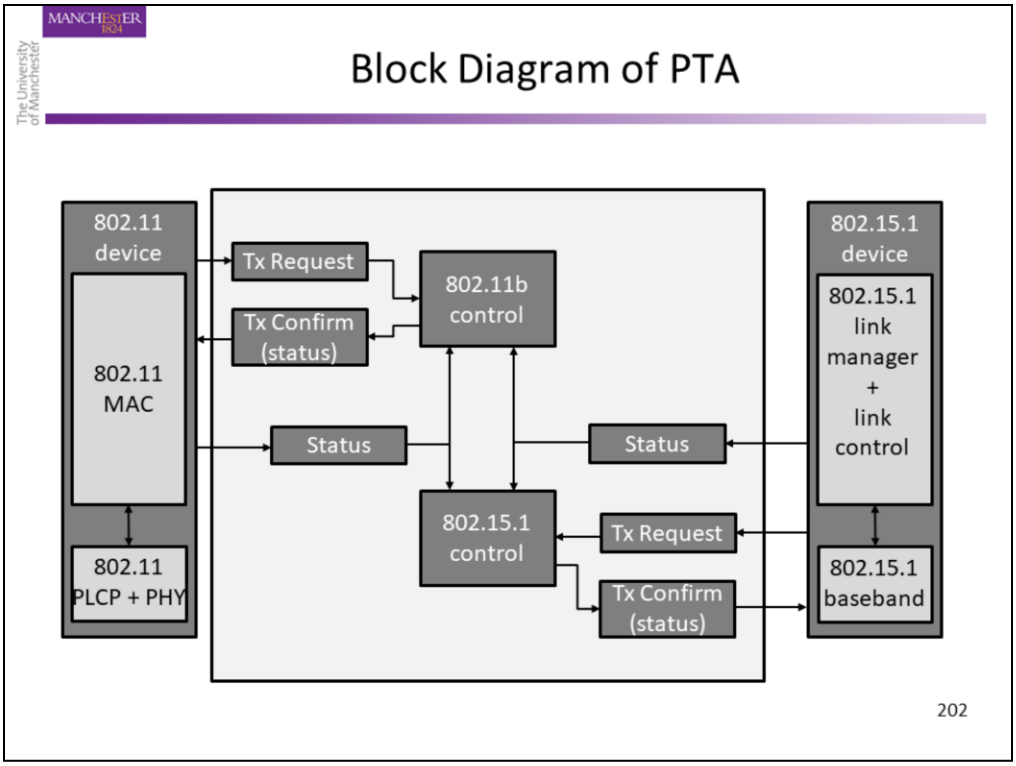
- The recommendation as to when to use AWMA states that this mechanism is more appropriate whenever there is a large density of devices (that is more or equal to 3 devices) that incorporate both WLAN and WPAN with a space defined by a circle of radius 10m and the SCO communication mode (audio) is not active.
- Alternatively, if the density of the devices supporting both WPAN and WLAN is less than three within the same area or if the WPAN SCO communication is active, the PTA (described on later slides) mechanism is recommended along with deterministic interference suppression mechanism.
- If there are more than one AP, typically the APs are not synchronized. In that scenario, some residual interference between WPAN devices synchronized with one WLAN AP and WLAN devices synchronized with another AP is unavoidable. However, if the APs are synchronized, the residual interference can also be easily eliminated.



- AWMA requires the WLAN entity to control the timing of both WLAN and WPAN subintervals. All WLAN stations connected to the same AP are synchronized and hence have the same TBTT.
- The WLAN entity should send out a physical synchronization signal to the WPAN master, which is in the same physical unit as the WLAN equipment. That synchronization signal, shown on the figure of this slide, specifies both the WLAN interval and the WPAN interval.
- When the medium free signal is true, the medium is free of WLAN traffic.

Packet Traffic Arbitration (PTA)

- In PTA as in AWMA, both IEEE 802.11b and IEEE 802.15.1 nodes are supposed to be collocated in the same physical entity
- In contrast with AWMA, PTA supports SCO traffic
- PTA dynamically coordinates sharing of radio resources between two coexisting wireless systems
  - Whenever a collision is expected to occur, different transmissions requests are ordered based on a set of simple rules that depend on the priorities of the various packets



- There are two different priority comparison schemes: *fixed* and *randomized*.
- In a *fixed* priority assignment, an IEEE 802.15.1 SCO packet should have a higher priority than IEEE 802.11b data type MAC protocol data units (MPDUs) while an IEEE 802.11b acknowledgment (ACK) MPDU should have a higher priority than all IEEE 802.15.1 packets.
- In the *randomized* scheme, the priority of packets may be assigned in a randomized fashion. For this purpose, a random variable *r* uniformly distributed between [0, 1] and a threshold T ($0 \le T < 1$) are used.

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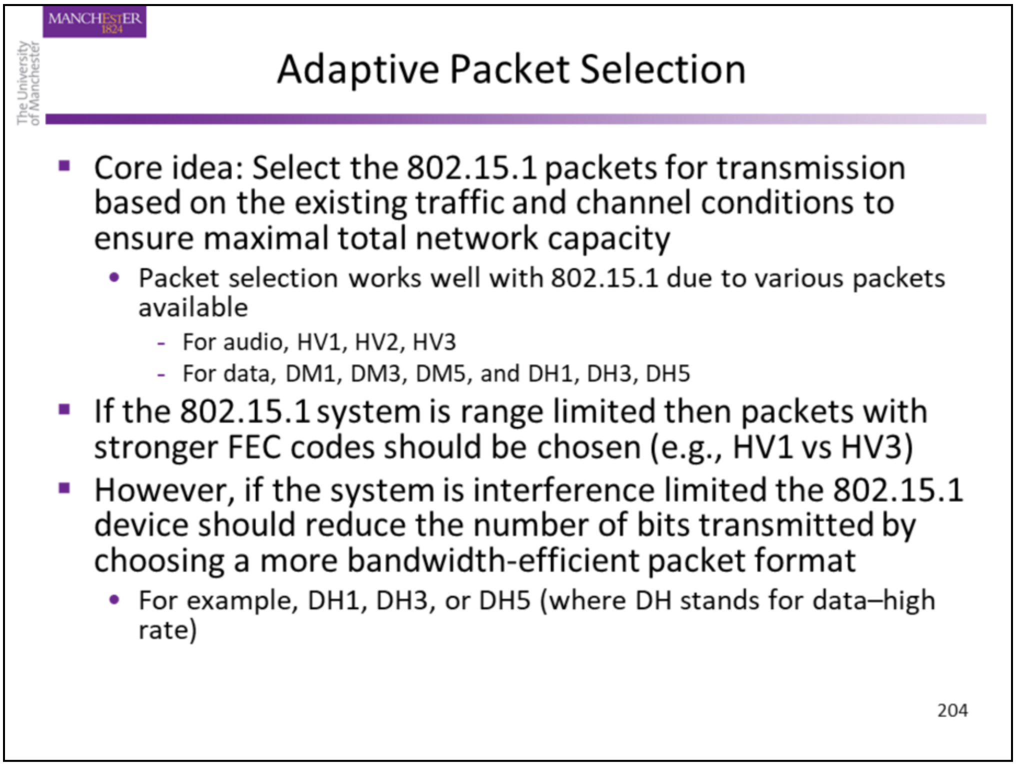
Definition of NonCollaborative Mechanisms

- These mechanisms do not require any communication link between the WLAN and WPAN networks
- To determine the level of interference channel monitoring is required to estimate traffic
- Noncollaborative methods include
  - Adaptive interference suppression of IEEE 802.11b devices
  - Adaptive packet selection and scheduling
  - Adaptive frequency hopping (AFH) for IEEE 802.15.1
  - Packet scheduling for ACL links

- The philosophy of the adaptive packet selection and scheduling techniques is to frequently monitor the channel and adapt to the channel conditions.
- A useful metric to this end is the packet error rate (PER) instead of simply a bit error rate. PER is preferred as packets are dropped due to collisions between IEEE 802.15.1 and IEEE 802.11 systems rather than channel noise leading to bit errors within packets.
- The effectiveness of the different methods is determined by the capability of these methods to accurately evaluate the traffic and more broadly the condition of the channel.



- For SCO links in the coexistence scenarios, usually the dominant reason for packet drop is not noise or range but rather the strong interference produced by the collocated network such as an IEEE 802.11b network.
- In this scenario, increasing FEC protection will cause IEEE 802.15.1 devices to generate more packets (HV1 packets occupy the channel three times more than HV3 packets) and thus more interference to the IEEE 802.11b network.

Packet Scheduling

- Scheduling includes two basic components
  - Channel classification
  - Master delay policy
- Channel classification listens to the traffic on the channel(s) or frequency to determine the presence and severity of interference
  - A frequency is determined to be good if a device can correctly decode a packet received on it. Otherwise, it is marked as bad
- Based on this classification, the master applies a delay policy
  - The master determines in which slot and/or frequency, a packet (or segment of packet) will be transmitted

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- A channel classification table capturing the frequency status (good or bad) for each device in the piconet is kept at the master device.
- In the master delay policy, the master checks both the slave’s receiving frequency and its own receiving frequency before choosing to transmit a packet in a given frequency hop.
- This is because following each master transmission there is a slave transmission.

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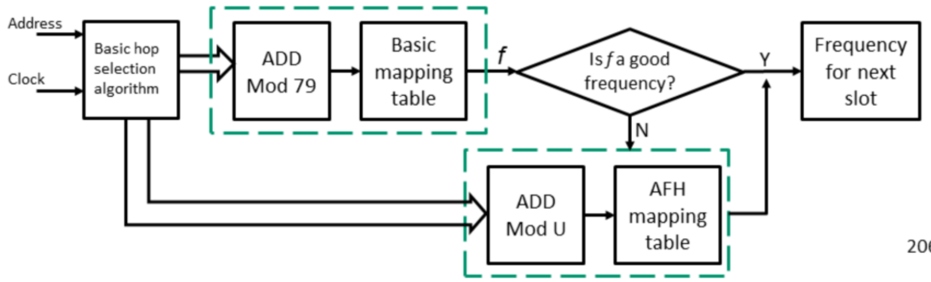
Adaptive Frequency Hopping (AFH)

- Core idea: Classify ‘‘good’’ and ‘‘bad’’ frequency channels, then modify their hop patterns to avoid frequency bands occupied by a WLAN
- How do you classify a frequency as good or bad?
  - Measure PER
  - SIR -> signal to noise interference
  - Packet loss or frame error rate in a Bluetooth receiver



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- If the packet error rate (PER) is the metric used for the quality of the channel, then if the PER on a certain carrier frequency is greater than the packet loss threshold of 0.5, this frequency is considered to be a “bad” frequency, otherwise, it is considered to be a “good” frequency.
- AFH has been shown to improve the throughput in FTP applications by 25%.