Bluetooth and Wi-Fi Coexistence

**A White Paper from
Laird Technologies**

Bluetooth and Wi-Fi transmit in different ways using differing protocols. When Wi-Fi operates in the 2.4 GHz band, Wi-Fi transmissions can interfere with Bluetooth transmissions, and Bluetooth transmissions can interfere with Wi-Fi transmissions. Because Bluetooth and Wi-Fi radios often operate in the same physical area and many times in the same device, interference between Bluetooth and Wi-Fi can impact the performance and reliability of both wireless interfaces.

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OVERVIEW

Bluetooth is a wireless technology designed for short-range wireless connections between devices in a wireless personal area network (WPAN). Bluetooth is compliant with the IEEE 802.15 standard and operates in the 2.4 GHz band, or the 2.4 GHz portion of the radio frequency spectrum. Wi-Fi is a wireless technology designed to connect devices and an infrastructure in a wireless local area network (WLAN). Wi-Fi is compliant with various IEEE 802.11 standards such as 802.11a, 802.11b, 802.11g, and 802.11n. 802.11b and 802.11g operate in the 2.4 GHz band, 802.11a operates in the 5 GHz band, and 802.11n can operate in both bands.

Several methods of interference mitigation through temporal, special, and frequency isolation have been developed and are described in this document. While each is effective, all reduce performance. Migrating Wi-Fi operation to the 5 GHz band eliminates Bluetooth/Wi-Fi mutual interference while providing increased network capacity.

SPREAD SPECTRUM

Both Wi-Fi and Bluetooth are based on spread spectrum signal structuring. With this radio transmission technique, a narrowband signal such as a stream of zeros and ones is expanded (or spread across a given portion of the radio frequency spectrum) to result in a broader or wideband signal. Spread spectrum signaling was originally developed for military applications and offers two main benefits. First, a wideband signal is far less susceptible to intentional blocking (jamming) and unintentional blocking (noise or interference) than a narrowband signal. Second, a wideband signal sometimes can be perceived as a part of the noise floor (static interference) and thereby remain undetected.

The two most popular spread spectrum signal structuring techniques are Frequency Hopping Spread Spectrum (FHSS) and Direct Sequence Spread Spectrum (DSSS). Bluetooth, cordless telephones, and other consumer electronics use FHSS; Wi-Fi uses DSSS. Given that both technologies operate in the same frequency band, this use of differing techniques is the heart of Wi-Fi/Bluetooth coexistence issues. FHSS devices and DSSS devices perceive each other as noise—Wi-Fi and Bluetooth are mutual interferers.

Frequency Hopping Spread Spectrum

FHSS spreads a narrowband signal by "hopping" across a given frequency band. With Bluetooth, the narrow band is 1 MHz wide. Bluetooth transmits on any one of 79 1-MHz channels, or frequencies, in the 2.4 GHz band. FHSS changes channels at set intervals; in the case of Bluetooth, this is 1,600 times per second. The transmitter and the receiver adhere to a common hopping pattern or sequence of channels during a given session so that the receiver is able to anticipate the frequency of the next transmission. Because of this, Bluetooth makes full use of the 2.4 GHz band.
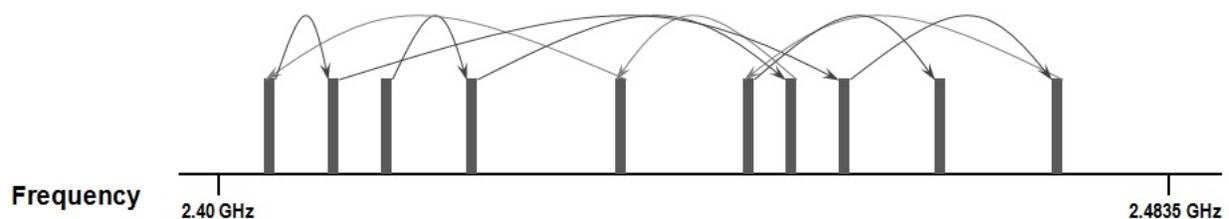

Figure 1: With Frequency Hopping Spread Spectrum, the signal is transmitted on different frequencies at intervals to spread the signal across a relatively wide operating band.

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Direct Sequence Spread Spectrum

DSSS starts with the same sort of narrowband signal as does FHSS but spreads that signal across a spectrum in a very different way. With DSSS, the narrowband signal is divided and then combined with a sequence called a chipping code. The chipping code spreads multiple copies of the original signal across a wider portion of the operating band to form a channel. In the case of 802.11b and 802.11g, which both operate in the same 2.4 GHz band as Bluetooth, the channels are 22 MHz wide. Because the 2.4 GHz band is 83 MHz wide, three non-overlapping Wi-Fi channels are available for 802.11b and 802.11g operation. Upon receiving a wideband signal, the receiving station decodes the original narrowband signal by using the same chipping code as the transmitting station.
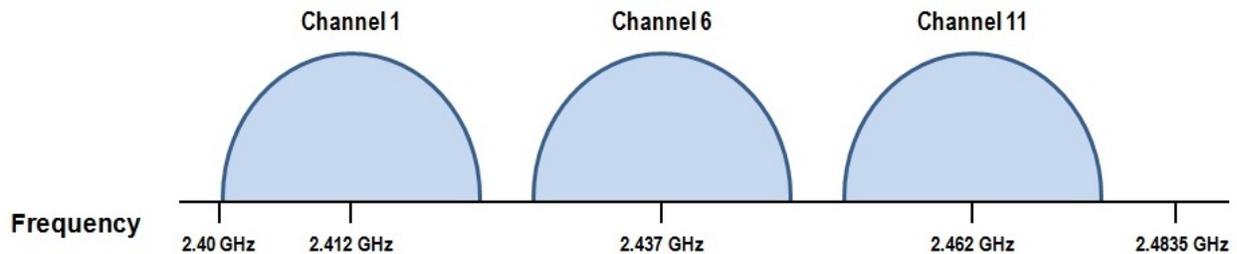

Figure 2: With Direct Sequence Spread Spectrum, the signal is transmitted on a continual basis across a range of frequencies referred to as a channel.

MUTUAL INTERFERENCE

A FHSS receiver cannot decode a DSSS transmission and vice versa; a transmission using one spread spectrum technique is nothing but interference to a receiver using another spread spectrum technique. In the case of Bluetooth and Wi-Fi, interference between two co-located or nearby devices will occur approximately one quarter of the time, such as when a Bluetooth device hops to a frequency occupied by an active Wi-Fi channel.

$$\frac{22 \text{ MHz wide Wi-Fi channel}}{79 \text{ available Bluetooth frequencies}} = \text{collisions approximately 28\% of the time}$$

If this interference is sufficiently strong such that the Bluetooth or Wi-Fi receiver cannot decode a transmission, the transmission must be resent, resulting in a decrease in performance. Under the most extreme of circumstances, the Bluetooth or Wi-Fi device may completely lose connectivity.
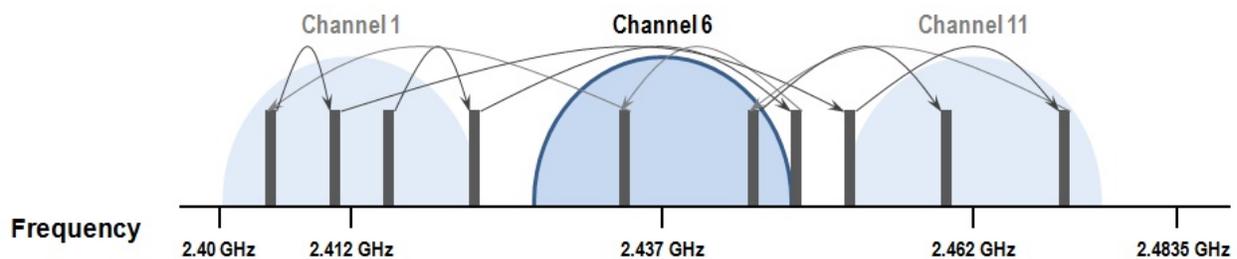

Figure 3: FHSS and DSSS transmissions will collide when the FHSS transmitted hops to a portion of the operating band occupied by the DSSS transmitter.

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Interference may be addressed by isolating radios. Isolation may be achieved by using one domain or a combination of domains: time, space, and frequency. Bluetooth and Wi-Fi coexistence schemes use one of these three domains and, when properly implemented, allow for acceptable performance and reliability for collocated Bluetooth and Wi-Fi radios.

TEMPORAL ISOLATION: TIME DIVISION MULTIPLEXING

Time Division Multiplexing (TDM) is a coexistence method where Bluetooth and Wi-Fi radios (that are embedded in the same device) take turns transmitting. The devices are linked together with input/output signaling pins or "wires". An output wire is asserted by a radio when transmitting; this indicates to the other device on the corresponding input wire that it should refrain from transmitting during this time. TDM can be implemented between separate Bluetooth and Wi-Fi chips by linking them together via a printed circuit board. With increasingly popular combination Bluetooth/Wi-Fi chips, TDM is implemented within the same chip and therefore arbitrates between the two interfaces quickly. Because TDM requires a physical link between the Bluetooth and Wi-Fi radios, it is referred to as a collaborative means of coexistence.

TDM can be implemented through the use of two or three wires, or signaling pins. With two-wire coexistence, two signaling pins are used to arbitrate between the Bluetooth and Wi-Fi radios:

- *WLAN_ACTIVE* – An output pin on the Wi-Fi (WLAN) radio that, when asserted (held high), signals to the Bluetooth radio that it should not transmit because the Wi-Fi radio is transmitting.
- *BT_ACTIVE* – An output pin on the Bluetooth radio that, when asserted (held high), signals to the Wi-Fi radio that it should not transmit because the Bluetooth radio is transmitting.

A three-wire coexistence scheme adds a third wire (BT_PRIORITY) to the two-wire scheme for an additional signal:

- *BT_PRIORITY* – An output pin on the Bluetooth radio that, when asserted (held high), signals to the Wi-Fi radio that it should not transmit and should discontinue any transmissions in progress because the Bluetooth radio is transmitting latency-sensitive (high-priority) packets such as SCO voice packets.
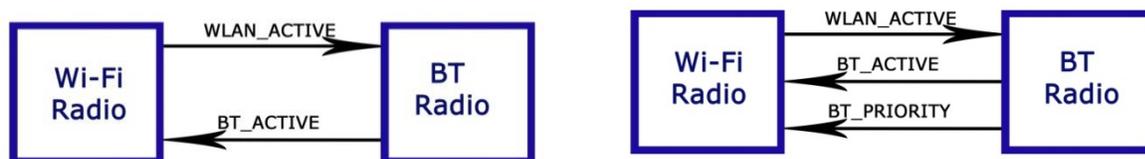

Figure 4: With two-wire coexistence (left), the radios are aware of the transmit status of the coexistent radio and can thereby refrain from transmitting simultaneously. Three-wire coexistence (right) adds an indication of the priority of the Bluetooth transmission.

SPATIAL ISOLATION

Spatial isolation involves placing collocated Bluetooth and Wi-Fi radios (and their associated antennas) as far apart from each other as possible and, when possible, placing insulating material between them. Spatial isolation alone is rarely sufficient to achieve acceptable Bluetooth and Wi-Fi performance and is commonly employed in conjunction with other coexistence schemes. Because spatial isolation requires no physical link between the Bluetooth and Wi-Fi radios, it is referred to as a non-collaborative means of coexistence. Unlike collaborative coexistence methods like TDM, spatial isolation may be employed by Bluetooth radios that are located both in the same device and in the same general area. Spatial isolation is impossible with the latest generation of combination Bluetooth/Wi-Fi chips and modules because these combination designs typically share a common transmitter, receiver, and antenna.

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FREQUENCY ISOLATION: ADAPTIVE FREQUENCY HOPPING

In 2003, the U.S. Federal Communications Commission (FCC) made changes to the rules associated with FHSS operation so that Adaptive Frequency Hopping (AFH) could be introduced as part of version 1.2 of the Bluetooth specification, which later was ratified as IEEE 802.15.2-2003. AFH is a built-in coexistence feature that is found in almost every Bluetooth device in operation today.

With AFH, a Bluetooth radio scans the operating band for interference on all 79 operating channels and compiles a report of clear and noisy channels. This report is then sent to all other Bluetooth radios to which the scanning radio is paired. The notifying and notified radios adapt their frequency hopping patterns to avoid the noisy channels, operating only on the channels identified as clear. The radios periodically rescan, update the report, and resend it. While the identified noise is typically interference from Wi-Fi radios, AFH identifies noise coming from all sources (such as microwave ovens).

Because AFH requires no physical link between the Bluetooth and Wi-Fi radios, it is referred to as a non-collaborative means of coexistence. Unlike collaborative coexistence methods like TDM, AFH may be employed by Bluetooth radios that are located both in the same device and in the same general area. By using AFH, both Bluetooth and Wi-Fi radios can operate in the same frequency band and physical location with a decreased level of interference, along with acceptable performance and reliability. AFH is often employed in conjunction with spatial isolation.
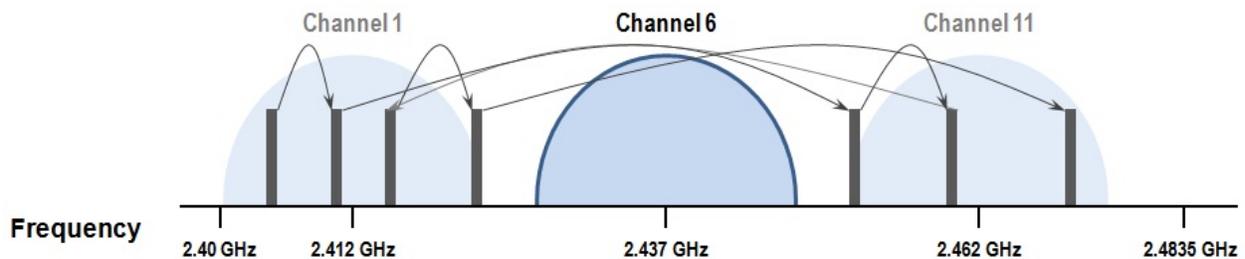

Figure 5: With AFH, FHSS devices avoid DSSS channels to allow for improved performance for both Bluetooth and Wi-Fi devices.

FREQUENCY ISOLATION: WI-FI OPERATION IN THE 5 GHZ BAND

Although the above methods of isolation are effective at mitigating Bluetooth and Wi-Fi operation in the same frequency band, each of these methods causes decreased performance. The most effective means of addressing Bluetooth and Wi-Fi mutual interference is to move Wi-Fi operation to the 5 GHz band. The newer IEEE 802.11n standard allows for improved operation in the 5 GHz band when compared to the earlier 802.11a standard. In addition to eliminating (rather than mitigating) Bluetooth/Wi-Fi mutual interference, Wi-Fi operation in the 5 GHz band provides for seven times the network capacity when compared to Wi-Fi operation in the 2.4 GHz band.

Please check the white papers section of the Summit website to learn more about IEEE 802.11n and operation in the 5 GHz band.

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