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Bluetooth and Wi-Fi Interference: Simulations and Solutions

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Abstract: Bluetooth and IEEE 802.11b or Wi-Fi, both use the same unlicensed Industrial, Scientific and Medical (ISM) band in the frequency range of 2.4 GHz. As the demand and utility of Bluetooth and Wi-Fi devices has increased, the number of co-located devices has also increased in number, so there can be interference issues related to these devices. This review paper investigates interference of Wi-Fi signal in Bluetooth data or voice link with the help of simulations from MATLAB Simulink Bluetooth full duplex communication model. This review paper also discusses the techniques to improve the performance of Bluetooth and Wi-Fi co-located systems.

Keywords: Bluetooth, IEEE 802.11b, ACL, SCO, SCORT, Adaptive Frequency Hopping.

I. INTRODUCTION

Bluetooth is the short range wireless technology standard which is among the latest trend in wireless technology. It is usually compared with the IEEE 802.11b technology as both share the same spectrum and will often be located in close proximity to one another. So, there is concern for how they may interfere with one another even though both use different spread spectrum techniques.

A Bluetooth device uses the Wireless Personal Area Network (WPAN) and operates from 2.4 GHz to 2.4835 GHz frequency range. The whole Bluetooth spectrum is divided into 79 channels each of 1 MHz .On the other hand, IEEE 802.11 is a set of Media Access Control (MAC) and Physical Layer (PHY) specifications for implementing wireless local area network (WLAN) computer communication in the 2.4, 3.6, 5 and 60 GHz frequency bands. In case of Wi-Fi, the same spectrum is divided into 3 wide channels. Bluetooth supports both data and voice channels. Radio link for data transmission is Asynchronous Connection Less (ACL) link and for voice transmission, Synchronous Connected Oriented (SCO) link is used.

This paper is for analyzing the interference caused due to Wi-Fi signal transmitted at same frequency as that of the Bluetooth signal when a Bluetooth master device is sending a data signal or voice signal to another receiver device also known as Slave Device. This paper also considers the use of a different type of voice packet i.e. Synchronous Connection Oriented with Repeated Transmission (SCORT) to reduce the effect of interference in Bluetooth SCO voice links.

II. SPREAD SPECTRUM TECHNIQUES IN BLUETOOTH AND WI-FI

The two most popular spread spectrum signal structuring techniques are Frequency Hopping Spread Spectrum (FHSS, used by Bluetooth devices) and Direct Sequence Spread Spectrum (DSSS, used by Wi-Fi devices).The use of these differing techniques is the heart of Wi-Fi/Bluetooth coexistence issues when both technologies operate in the same frequency band [8].

The Bluetooth signal, when transmitted from master device takes fast acknowledgement from receiver or slave device and if it experiences any kind of interference in channel, it hops to a different frequency channel among 79 channels at a rate of 1600 hops/s according to the pseudo random code sequence with a time slot of 625μs in every frequency channel as shown in Figure 1 [6]. Bluetooth uses Gaussian Frequency Phase Shift Keying (GFSK) modulation technique.

IEEE 802.11b picked DSSS technique using 22 MHz of bandwidth to transmit data at speeds of up to 11 Mbps. A Wi-Fi system can utilize any of 11 22MHz wide sub-channels across the acceptable 83.5 MHz of the 2.4 GHz frequency band, thus there can be overlapping of channels. A maximum of three Wi-Fi channels can coexist without overlapping as shown in Figure 1.

Wi-Fi signal is spread along the frequency band with the help of bit sequence known as chipping code. This sequence spreads multiple copies of the original signal across a wider portion of the operating band to form a channel. Now there is a chance of interference when Bluetooth signal hops to a channel which coincides with the Wi-Fi operating channel.

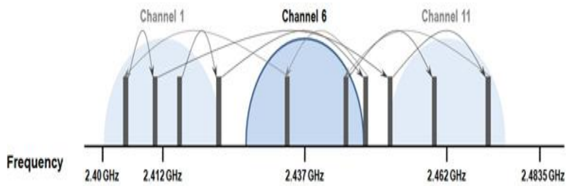

Figure 1: FHSS and DSSS transmissions together.

III. MATLAB SIMULINK MODEL FOR BLUETOOTH COMMUNICATION

To provide a wide understanding of coexistence issues, Simulations from MATLAB Bluetooth full duplex communication model as shown in Figure 2, are taken. This model supports DM1 data packet and HV1, HV2, HV3 and SCORT voice packets. There are two similar

Bluetooth devices, each with a Transmitter and Receiver. One of them is set as master and the other as the slave. Other than two Bluetooth devices, there is also an 802.11b packet generating block as an interference source, error reading meters and instrumentation. This model includes CVSD speech coding, HEC, payload CRC for DM1, FEC, framing, GFSK Modulation, frequency hopping, hop sequence generation, an 802.11b interferer, wave file I/O, BER meters, spectrum, timing, and spectrogram plot [3].

IV. BLUETOOTH DATA TRANSMISSION/ ACL LINK

Bluetooth uses ACL (Asynchronous Connection Less) link for data transmission which is a packet oriented link and does not need a common clock to synchronize the data bit transfer. This radio link has efficient error correction capabilities as the data packet is repeatedly transmitted by the Master device till there is an acknowledgement from Slave device or the receiver. The successful reception of the data packet is decided by the ARQN number which is the Automatic Repeat Request Number. It is present in the Header of Data packet. The general data packet format is shown in Figure 4. If the ARQN=1, the reception is successful and transmitter can now send the new data packet. If the ARQN=0, the reception is unsuccessful and transmitter should retransmit the data packet.

This process is represented in Simulink model with the help of Stateflow chart as shown in Figure 3. Here payload bits or data bits in data packet are also passed through Cyclic Redundancy Check (CRC) generator for Forward Error Correction (FEC) [1]. FEC is the technique used in data transmission for correcting errors in noisy communication channels. FEC involves appending additional bits to the data information based on a certain algorithm and these additional bits would reveal if there was any error in data information bits.

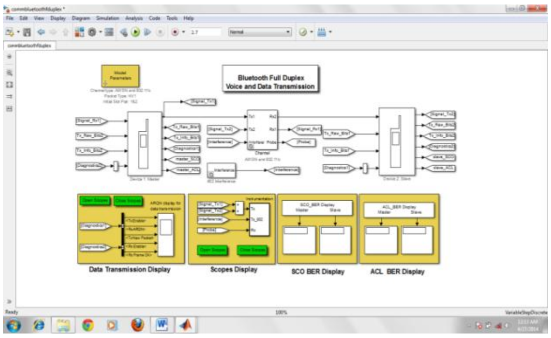

Figure 2: Bluetooth Full Duplex Communication Model in Simulink

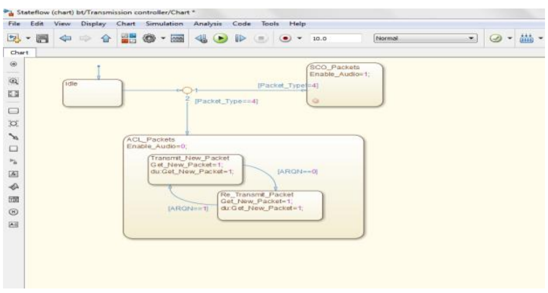

Figure 3: Stateflow Diagram for controlling data transmission

Thus there is a very little chance of interference in ACL link.

Figure 4: Data Packet Format

V. BLUETOOTH VOICE TRANSMISSION / SCO LINK

Bluetooth uses SCO link for voice transmission. SCO link is circuit-switched with restricted bandwidth and supports symmetrical point to point transfers at regular intervals of time i.e. data rate is same for sending and receiving voice packets. Bluetooth supports maximum of three SCO links at a same time and this time slot is of 3.75ms.Three types of voice packets are known denoted as HV1, HV2, and HV3, each with data transfer rate of 64kbps [1]. There is no acknowledgement of voice packet in receiver side, so voice transmission is more prone to interference by Wi-Fi signal. There is even no mechanism of FEC for HV3 packet. Correct SCO reception is determined by checking the packet's Access Code and Header Error Check (HEC) which is a CRC in Header. While developing a voice link in Bluetooth, there is also a need of speech encoding which is done with the Pulse Code Modulation (PCM) technique and Continuous Variable Slope Delta (CVSD) Modulation technique [4].

VI. SCORT VOICE PACKET TO AVOID INTERFERENCE

Since there is no acknowledgement of voice packet in receiver side and even there is no FEC in HV3 packet, thus interference can destroy the transmission and the received packet can be a degraded one. Thus, IEEE 802.15 working group on coexistence has proposed a new type of voice packet known as Synchronous Connection Oriented with Repeated Transmission (SCORT). Figure 5 shows the State flow diagram for SCORT packet as in receiver algorithm, used in MATLAB Simulation. From the State flow chart it is clear that the same voice packet is transmitted three times in an interval.

As the SCO packet is transmitted three times repeatedly, there can be only one possible voice link instead of three in one time interval of 3.75ms. This technique ensures that if packet reception was failed due to interference in first time slot, there are still two other slots for successful reception. There is no method of FEC in SCORT packet but still it a very efficient way in robust communication to avoid interference as it replaces bit-level redundancy of FEC with packet-level redundancy. The receiver algorithm tracks two items of state, the slot pair and whether the packet is received correctly. If the first packet is received correctly, the machine changes to the state "Slot_pair_1" and sub state "Good" and payload will be accepted by state machine. If the first packet was not received correctly the sub state for "Slot_pair_1" would be "Bad". Then the state machine moves to next two slot pairs and check their sub states. At the last slot pair, if the sub state is "Bad", the state machine now would know that payload is to be rejected [12].

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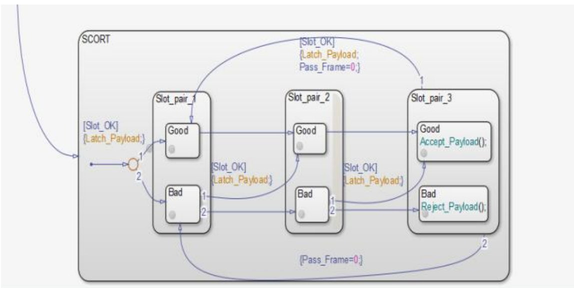

Figure 5: State flow chart of SCORT voice packet in receiver

VII. SIMULATIONS AND RESULTS

The effect of 802.11b interferer for the Simulink model of Figure 2 can be observed by the instrumentation block which is a masked block in Figure 2 and is designed to display the timing diagram, channel spectrogram and received signal spectrum. When the 802.11b transmitter is turned on, the timing diagram in Figure 6 shows the overlap of the Bluetooth and 802.11b transmissions. The spectrogram in Figure 7 clearly shows the interaction of transmissions from the two devices including which packets are colliding. The thin lines are the Bluetooth transmissions, while the larger, more colorful blocks are the interferer slots.

Most of the time, due to frequency hopping, there is not much overlap of these slots. In a few cases, the signals do collide, as the Spectrogram plot clearly shows. Figure 8 shows the channel spectrum of the received signal. It can be observed from the spectrum that large 22MHz bandwidth is generated by the 802.11b interferer and other peaks are for the Bluetooth slots. The peak of Bluetooth in the large spectrum where 802.11b is operating shows that some amount of interference is occurring whenever the time slots of both the devices match. Thus, the scopes displayed by Simulink model shows the effect of 802.11b interference on Bluetooth signal.

VIII. OTHER METHODS TO RESIST INTERFERENCE

From the above discussions it is clear that deterioration of quality of voice signal is more apparent as compared to data signal. For example, one is more likely to be aware of poor sound quality while using a Bluetooth headset than of the extent to which data packets must be retransmitted between two mobile phones. Thus following techniques other than using SCORT packet has been developed and are used by latest technologies nowadays.

A. Adaptive Frequency Hopping

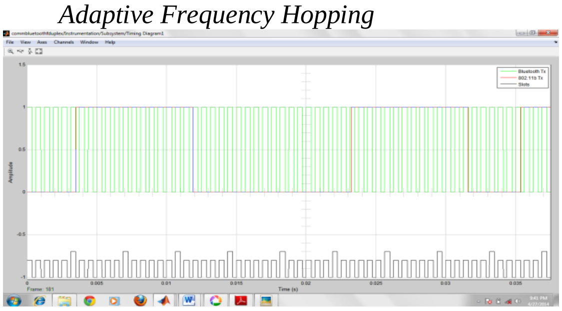

Figure 6: Timing diagram of the received signal showing overlapping of Bluetooth and 802.11b slots.

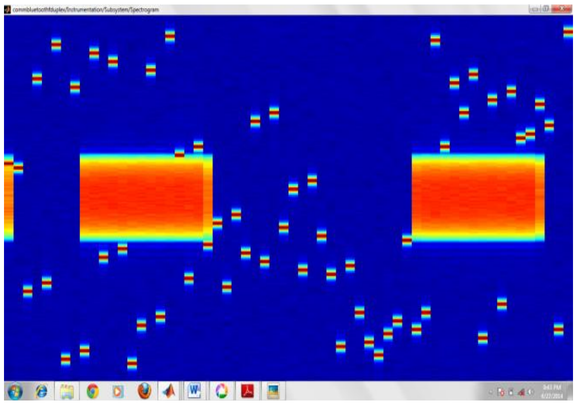

Figure 7: Channel Spectrogram

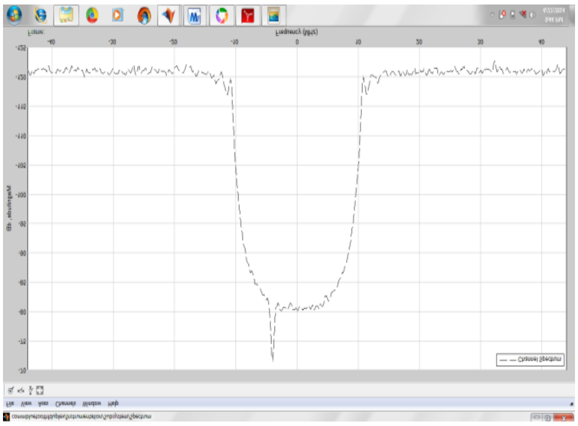

Figure 8: Channel Spectrum of received signal

The technique of Adaptive Frequency Hopping has been introduced by the Bluetooth Special Interest Group (SIG) in collaboration with IEEE 802.15 Working Group to reduce the effect of interference from a Wireless device. This technique allows Bluetooth channel to adapt to the environment by identifying the channels which are fixed sources of interference, so the signal can avoid that channel. The Bluetooth radio detects the RF energy in the channels, and once the radio energy is detected, it marks the channels as “Active” and start communicating through that channel.

The Bluetooth device can detect the channel which Wi-Fi signal is using to communicate with its Access Point and will remove that channel from its hop sequence. This process also reduces the number of channels used by Bluetooth, thus increasing the risk of collisions among Bluetooth channels. This Channel Assessment to identify the bad channel is done by two methods: RSSI (Received Signal Strength Indication) and PER (Packet Error Rate). RSSI is more accurate as compared to PER but consumes more power than PER.

In the normal case Slave device may use some other channel to communicate with the Master device, which is different from what Master device used, thus leading to series of retransmissions but with AFH both the devices use the same frequency channel. Figure 9 and Figure 10 shows the Bluetooth and Wi-Fi environment without and with Adaptive Frequency Hopping (AFH) respectively [10].

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B. Time Division Multiple Access (TDMA)

TDMA allows Bluetooth and Wi-Fi to make alternate transmissions. With this method Bluetooth can support piconets but cannot support SCO links. Thus this technique provides temporal isolation to both Bluetooth and Wi-Fi radios.

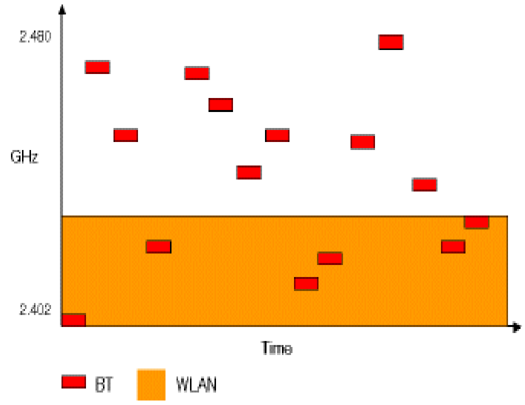

Figure 9: Collisions between Bluetooth and Wi-Fi signals without AFH

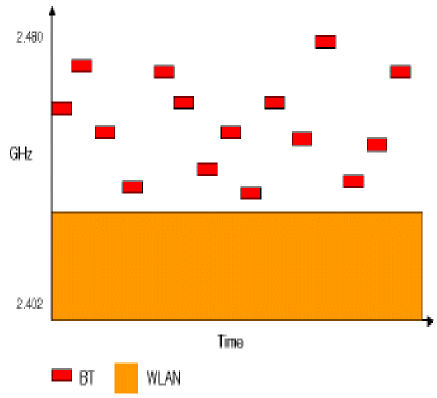

Figure 10: Bluetooth and Wi-Fi environment with AFH

C. Wi-Fi Migration to 5GHz Band

Coexistence problems have motivated the migration of WLAN standard to 5 GHz band as in IEEE 802.11ac. This method provides an additional advantage of seven times increase in network capacity of Wi-Fi [6].

D. RF Isolation and Gain Adjustment

Most Wi-Fi and Bluetooth devices have transmit power algorithms, where according to the link conditions, the transmitting device either increases or decreases transmit power. The higher the transmit power from the Wi-Fi device, the more Bluetooth channels one needs to mask in order to ensure low packet error rate (PER). So, there is a need to adjust maximum gain of the intermediate receiver stages of individual devices or adjust the transmitting power of the two devices so that it is low enough to sufficiently maintain the individual links [9].

IX. CONCLUSIONS

It is clear from the above discussions that IEEE 802.11 network can work efficiently when there is no hindrance from Bluetooth signal or vice-versa. There is a need to avoid congestion of channels and avoid collisions of transmitted signal from both the networks. Use of SCORT voice packet is a good solution to avoid hindrance in case of voice signals. Other techniques employed by latest technologies these days include Adaptive Frequency Hopping, TDMA Frequency division RF isolation, gain adjustment etc. The MATLAB Simulations from Simulink model provide an easy way to understand the concept of coexistence.

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BIOGRAPHY

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