IEEE 802.11 & Bluetooth Interference: Simulation and Coexistence

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***Abstract*-IEEE 802.11 and Bluetooth, these two operating in the unlicensed 2.4Ghz frequency band are becoming more and more popular in the mobile computing world. The number of devices equipped with IEEE 802.11 and Bluetooth is growing drastically. Result is the number of co-located devices , say within 10meters, grown to a limit, so that it may cause interference issues in the 2.4Ghz radio frequency spectrum. Bluetooth supports both voice(SCO) and data(ACL) packets. In this paper we investigate these interference issues and use a new Bluetooth voice packet named synchronous connection-oriented with Repeated Transmission (SCORT) to study the improvement in performance. For the sake of simulation results, we provide a comprehensive simulation results using MATLAB Simulink.**

***Index Terms*—ACL, Bluetooth, SCO, SCORT**

I. INTRODUCTION

The growth of wireless networks has transformed our daily life into such a situation that we can't think of a life without devices like computers, mobile phones like that. The wireless networks interconnecting these devices are adding up more and more nodes into it each minute. These devices communicate with each other using many popular standards developed by IEEE and such other groups.

The most popular among these communication standards are IEEE 802.11 or Wi-Fi and the Bluetooth. Almost 75% of the devices in the mobile computing world are equipped with either one of these or both of them. These technologies use the radio frequency for communication. The Bluetooth operates in 2.4GHz ISM band. Unfortunately IEEE 802.11 also operates in the same 2.4GHz ISM band. There are different versions of IEEE 802.11 like 802.11a, 802.11b, 802.11g, and 802.11n to name a few. Some of them operate in a different frequency range. However, in this paper we consider 802.11b which operates in the 2.4GHz ISM band as shown in Fig. 1.

When IEEE 802.11b tries to send a packet through the network, it will check whether the medium or the channel is already occupied or is there any transmission already going on through the channel. If it is not detecting any transmission, or

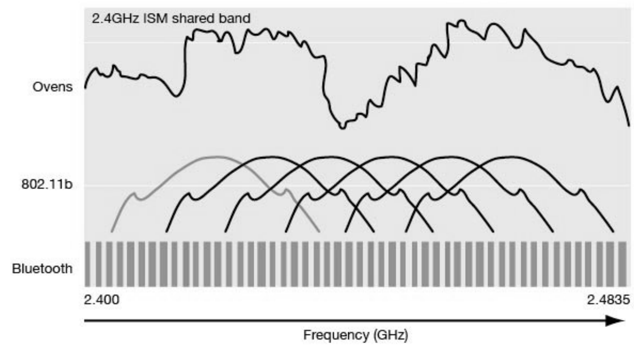

Figure 1: 2.4 GHz ISM Spectrum

not sensing any RF energy in the channel, it will issue a CTS or Clear To Send. That is the wireless network adapter will now start transmitting the packet. Using the same technique, while another co located IEEE 802.11b network tries to send the packet, it will postpone the transmission.

This technique provides a good resolution for mutual interference between co located IEEE 802.11 networks. But when it comes to a co-located Bluetooth and IEEE 802.11 network they just don't communicate each other. So there is no way they will identify each other. There is a definite chance of collision when they use the same channel at a particular time.

A Bluetooth device may haphazardly begin transmitting packets while an IEEE 802.11 device is sending a frame. This may result in interference, which forces the IEEE 802.11 station to retransmit the frame when it realizes that the destination station is not going to send back an acknowledgment. This lack of coordination is the basis for interference between Bluetooth and 802.11.

The objective of this paper is to build a simulation model and study the impact of interference between IEEE 802.11b and Bluetooth. We also study about a new Bluetooth voice packet to reduce interference, which is proposed by IEEE working group on co-existence.

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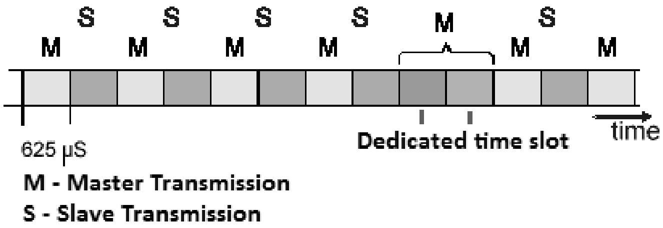

Figure 2: Bluetooth time Slot

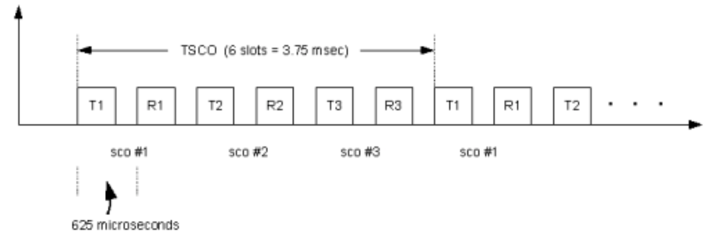

Figure 4: Bluetooth SCO voice slot

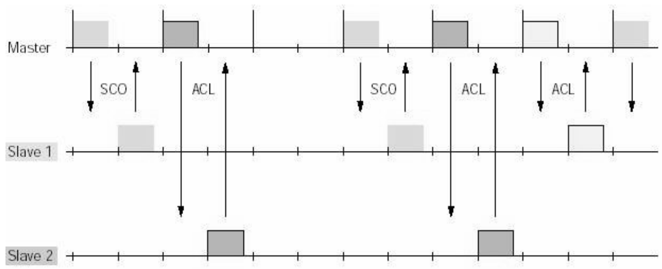

Figure 3: Bluetooth SCO & ACL

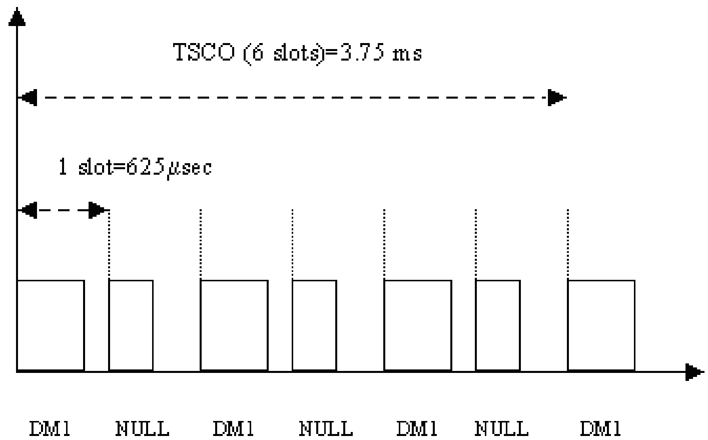

Figure 5: Asynchronous Connection Less (ACL) link

This paper is arranged in different sections. In section II we explain about Bluetooth specifications for voice and data transmission. Section III presents the simulation model with a brief discussion. In Section IV, we present "SCORT" the new voice packet. Testing of the model and results are presented in Section V. Finally, Section VI presents the conclusion.

II. BLUETOOTH SPECIFICATIONS

Bluetooth device can send both voice and data packet through a radio channel with a data rate of 1Mbps. Bluetooth is a short range Personal area network (PAN). Its operating range is normally 10meters. Transmitting power of a Bluetooth Tx is very low. It's just 1mw. Bluetooth uses Gaussian Frequency Shift Keying (GFSK) modulation technique. Bluetooth also uses Frequency Hopping Spread Spectrum technique to reduce interference from other devices operating in the same frequency spectrum. Interference in Bluetooth system can be recovered or sometimes avoided using various coexistence techniques. Fig. 2 represents the utilization of time slot in Bluetooth. In this paper we consider synchronous connection-oriented with Repeated Transmission (SCORT) to reduce the effect of interference in Bluetooth SCO voice links.

A time division multiplexing technique divides the channel into slices of 625 μs slots as shown in Fig. 5. A new hop frequency is used for each slot. Bluetooth supports both voice and data transmission. Bluetooth voice transmission is called Synchronous Connection Oriented (SCO) and data transmission is called Asynchronous Connection Less (ACL). Bluetooth SCO link is established between a master device and a slave device in the Piconet as shown in Fig. 3. SCO link uses reserved slots to communicate. Bluetooth master device use these reserved slots to maintain the communication. Bluetooth establishes an ACL link to transmit data. Unlike SCO, ACL links can be established between one master device and up to seven slave devices. ACL packets are transmitted in the free slots after SCO transmission. An ACL packet can be occupy up to one, three or five slots. All ACL packets other than Broadcast from master are acknowledged.

A. *Synchronous Connection Oriented (SCO) Link*

Bluetooth voice transmission is done by SCO (Synchronous Connection Oriented). The SCO link is a symmetric point to point voice link for sending and receiving voice packets at regular intervals of time. The SCO packets are transmitted in only every sixth slot. This period of time is equal to 3.75ms. The return path of transmission from the slave to master takes place on the next slot. Bluetooth can support a maximum of up to three voice calls at the same time. In Fig. 4, T1, T2, and T3 are the transmit slots for each SCO master link. Slots (R1, R2, and R3) are the return path for the slaves.

A master device initializes and controls the SCO link. Up to a maximum of three SCO links can be maintained by a master device at the same time. When a master device sends a SCO a packet in a slot, the slave device sends back in the following slot. So it is symmetric. That is data rate is same in both direction. The length of Bluetooth-SCO packet is always one slot. There is no acknowledgement for SCO packets. SCO packet transmission happens always in reserved slots at regular time intervals, every two, four or six slots. There are different types of SCO voice packets like HV1, HV2, and HV3. HV1 carries 10 data bytes and is transmitted every 2 slots, HV2 carries 20 data bytes and is transmitted every 4 slots and HV3 carries 30 data bytes and is transmitted every 6 slots .The data rate of HV1, HV2, HV3 packets are 64Kbps. HV1 and HV2 uses 1/3 and 2/3 rate Forward error correcting (FEC) mechanisms respectively. There is no FEC in HV3.

B. Asynchronous Connection Less (ACL) Link

Bluetooth data transmission is called asynchronous connection-less (ACL), which is different from SCO transmission in many respects. In data transmission there is no margin for error allowed.

If an error occurs, those packets must be transmitted again. Different techniques can be used to implement it. In the case of Bluetooth ACL transmission the system will wait for acknowledgement from the receiver. It will send the packets repeatedly till an acknowledgement is received. The receiver will check the packet and verify the CRC to make sure the packet is received correctly. In ACL Tx the through-put (in bps) must be checked. The Bit Error Rate doesn't matter much. The through-put will go down if a packet has to be transmitted again.

The receiver will set the ARQN bit in the header info. Then it will send it to transmitter in the return path packet. That is how receiver sends an ACK. By checking the ARQN, transmitter senses if the transmission was successful. If the value of ARQN is 1, it means a successful transmission, and if ARQN is 0 it means a failed transmission. In the case of a one way communication (master-to-slave) the slave sends back a dummy packet in the next slot. NULL packet or dummy packet does not have any payload. Fig. 3 shows the DM1 packet being transmitted in the first slot, and the slave replying with a NULL packet containing the ACK in the immediately following slot. The master then transmits again in the next slot.

III. BLUETOOTH SIMULATION MODEL

Fig. 6 shows the simulation model of the network in MATLAB Simulink. The above shown model simulates Bluetooth Full duplex communication. We have to two similar devices, each with a Transmitter and Receiver. One of them should be set as master and the other as the slave. Other than two Bluetooth devices, we also have an 802.11b packet generating block as an interference source, error reading meters and instrumentation.

A. Transmitter Design

The transmitter shown above performs data and voice input, processing. Framing is also done. It also performs HEC, FEC. Buffering and modulation is also done here. Frequency hopping is the transmission technique used Fig. 7 shows the state flow diagram of the data transmission. When the "ACL_packets" is entered the transition to "Transmit_blank_packet" will happen. The "Enable_Audio=0" & "Get_blank_Packet=1" actions activates to disable audio and

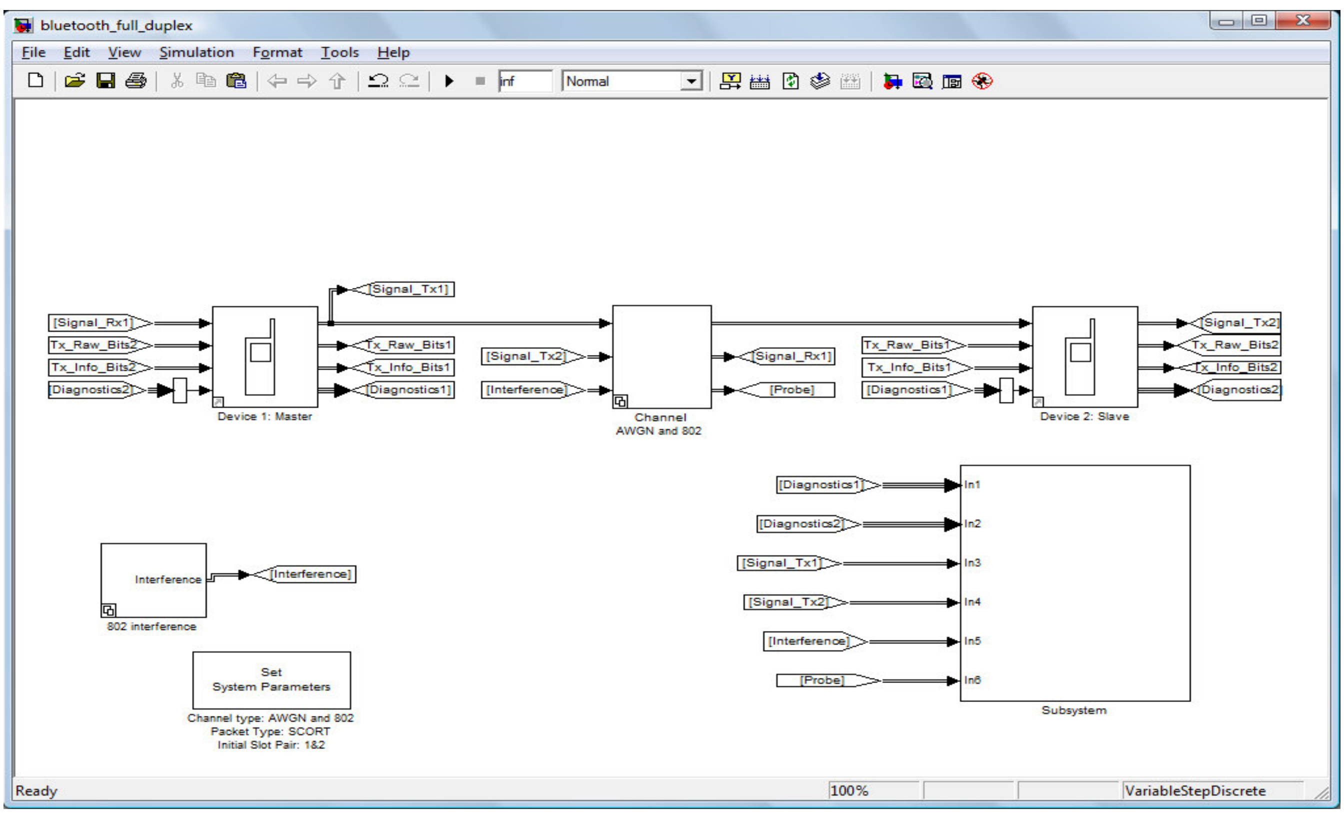

Figure 6: Bluetooth Interference Simulation Model.

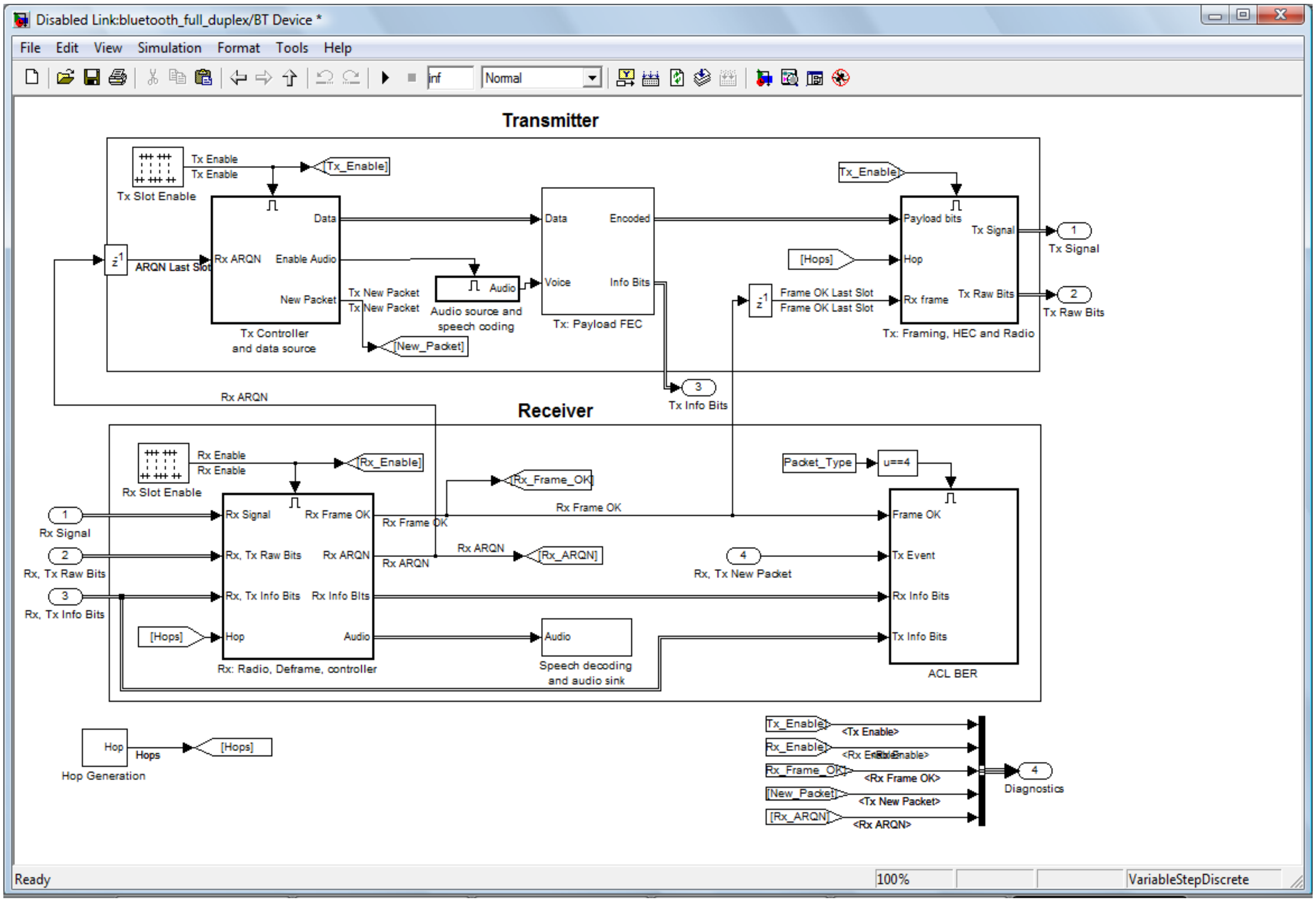

Figure 7: Bluetooth device having both Transmitter & Receiver.

to generate a new data packet. When the next slot is about to transmit, the transmitter will check the status of ARQN bit returned from the receiving device.

If it's in "Transmit_blank_Packet" ARQN is one, it stays in the state and transmits another new packet. If ARQN is zero, it shifts to the "Re_Transmit_Packet". This simulation model use frame based processing. It can transmit samples having high number of frames in each step of the simulation. This technique enables quick simulation of digital systems. In this particular model, a top sample rate of 100MHz is used.

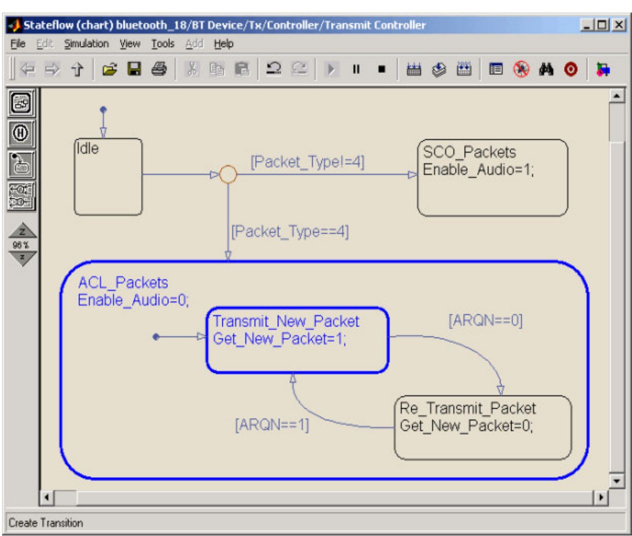

Figure 8: Transmitter state flow diagram

Fig. 8 shows the state flow diagram of the data transmission. When the "ACL_packets" is entered the transition to "Transmit_blank_packet" will happen. The "Enable_Audio=0" & "Get_blank_Packet=1" actions activates to disable audio and to generate a new data packet. When the next slot is about to transmit, the transmitter will check the status of ARQN bit returned from the receiving device. If it's in "Transmit_blank_Packet" ARQN is one, it stays in the state and transmits another new packet. If ARQN is zero, it shifts to the "Re_Transmit_Packet". If the transmitter is in "Re_Transmit_Packet", and ARQN is one, it shifts to "Transmit_blank_Packet". Else it will not shift and will stay in "Re_Transmit_Packet".

B. Receiver Design

The state flow diagram of receiver is shown in Fig. 9. It can be seen in Fig.9 that the receiver waits a new packet all the

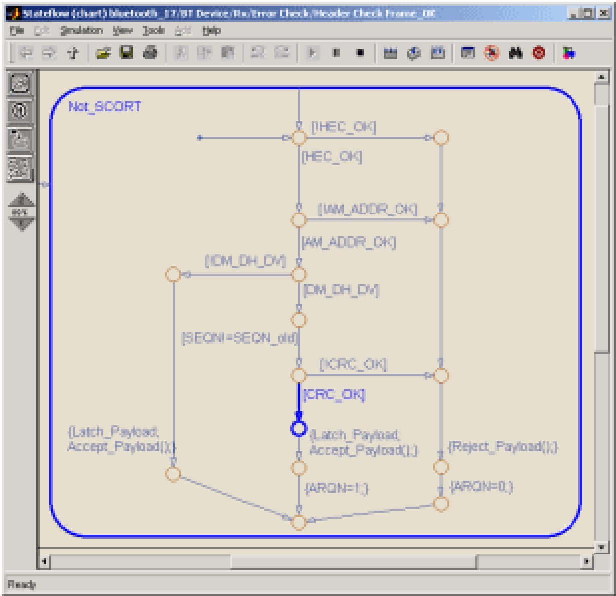

Figure 9: Receiver state flow diagram

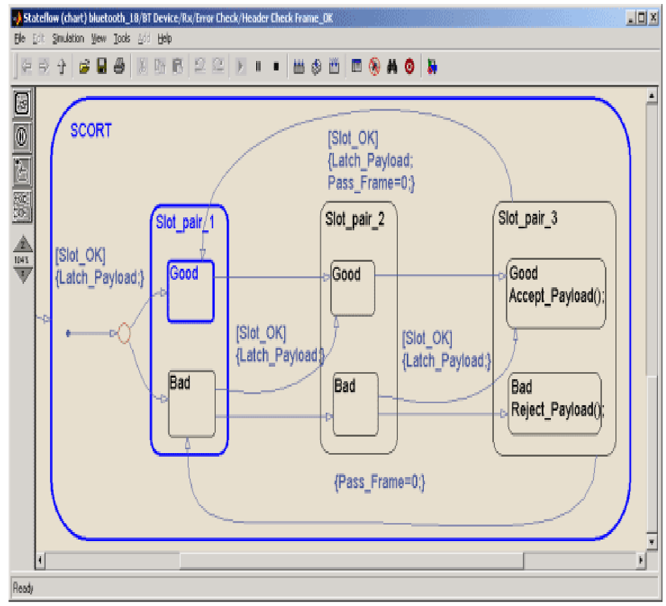

Figure 11: SCORT State Flow Diagram

time. When it senses the arrival of a packet it will register the arrival. It will also make sure the decoder is enabled. The above mentioned sequence of events is triggered because of the detection of an arriving packet. The receiver has to make a number of decisions to make sure whether the received packet is correct or incorrect.

A DM1 packet will be checked for integrity. The receiver performs a header error check (HEC).The address is also verified. The receiver makes sure the packet is new and is not a duplicate. It also checks the CRC.

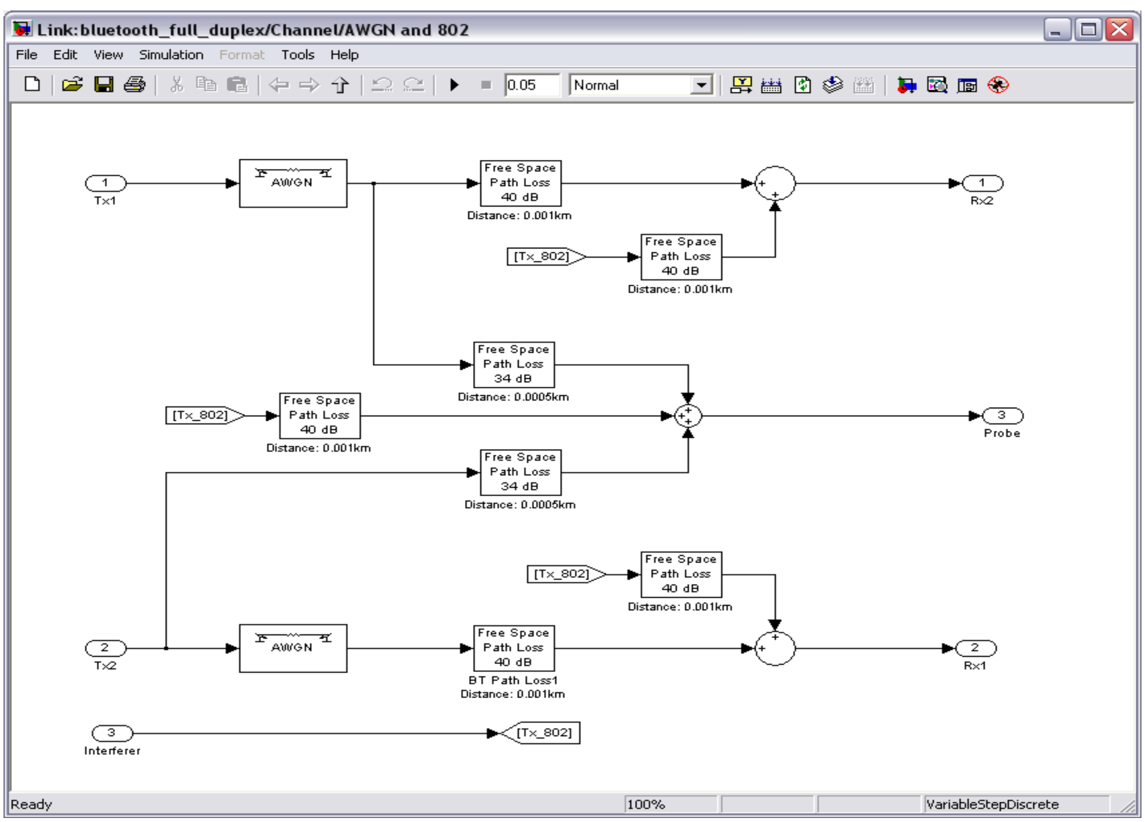

Figure 10: 802.11b Interference Source added to the channel

If all these checks are correct then the packet will be accepted. Else the packet will be rejected. This happens in the case of a repeated packet arriving or in the case of its CRC failing. This flow diagram is implemented in Stateflow semantics as shown in Fig. 8. This image, captured during a simulation, illustrates the animation provided with Stateflow, which highlights the decision path (in bold) through the flow chart.

C. Channel and Interferer Modeling

The 802.11b channel bandwidth is approximately 22MHz. The Simulation model has a block which produces signals in this bandwidth. This block can be configured to specify mean packet rate, packet length, power, and frequency location in the ISM band. This block is then connected to the channel where the distance between the interference source and Bluetooth system can be varied. Fig. 10 shows the addition of 802.11b interference into the channel. We use this model in our experimental verifications to determine the behavior of added interference.

IV. Coexistence Solution - SCORT Voice Transmission

The Coexistence task group working on co-existence has suggested the use of a special voice packet to fight interference. The synchronous connection-oriented with Repeated Transmission (SCORT) packet achieves more robust transmission by replacing bit-level redundancy with packet-level redundancy. The state flow diagram of SCORT is presented in Fig. 11. It works by repeating the transmission of the same packet three times in one SCO interval. SCORT does not have any error correction. SCORT is transmitted every second time slot. As the same packet is being transmitted three times in a row, only one voice link will be there, which is a full duplex link. If interference destroys the transmission during first slot, there are still three other slots, or opportunities to communicate the packet, thus very much improving frame-error rate (FER) in an interference scenario. It does not affect the BER of the payload.

V. Experiments And Results

Using the above model, we performed a series of tests to evaluate the performance of a Bluetooth system under interference. We used DM1 packet type to check the performance of ACL transmission. Packet types HV1, HV2 and HV3 are used to evaluate SCO performance. Finally we used SCORT packet type to compare its performance with HV1, HV2 and HV3.

Fig. 12 represents the Bluetooth system throughput has been evaluated by varying the distance between the device and the interference source. It should be noted in Fig. 2 that a consistent values of throughput is achieved with respect to a constant increase in the distance between the Bluetooth devices. From Fig. 12, we can see that the throughput of a Bluetooth system is about 128kbps without 802.11b interference source.

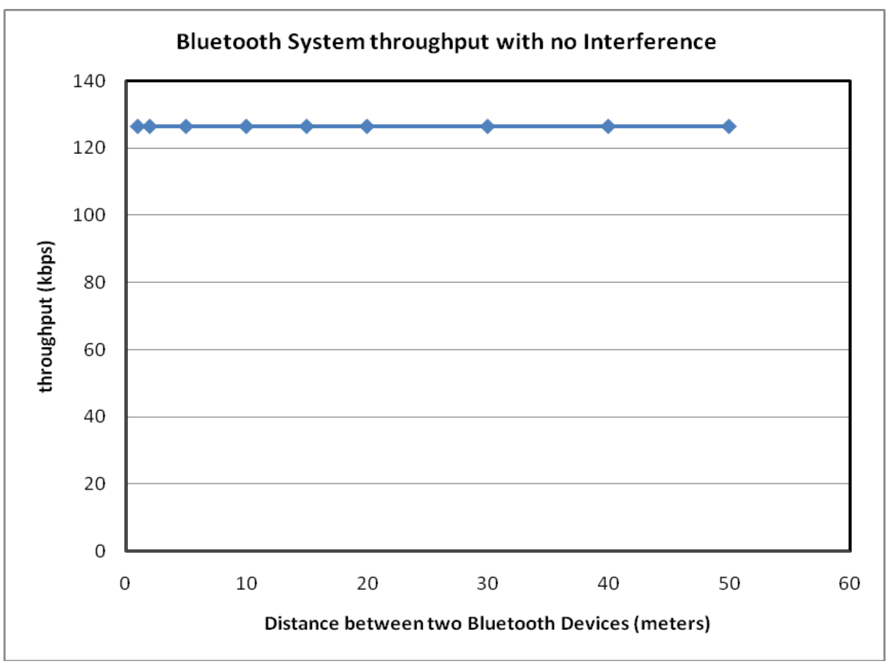

Figure 12: Bluetooth System throughput

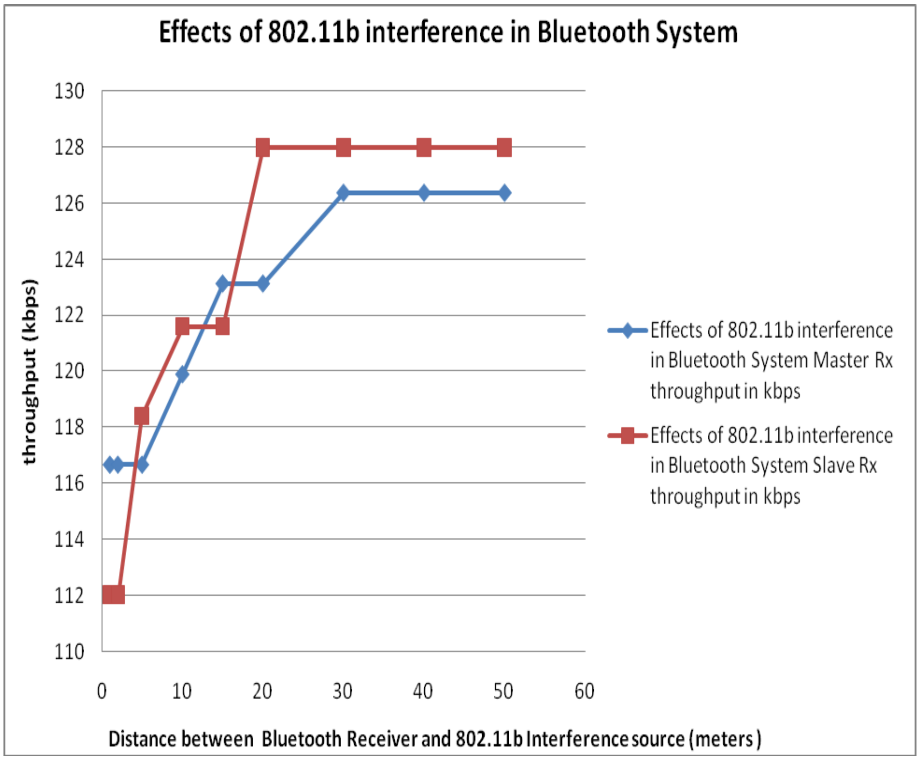

Figure 13: Bluetooth Master and Slave device throughput in the presence of 802.11b

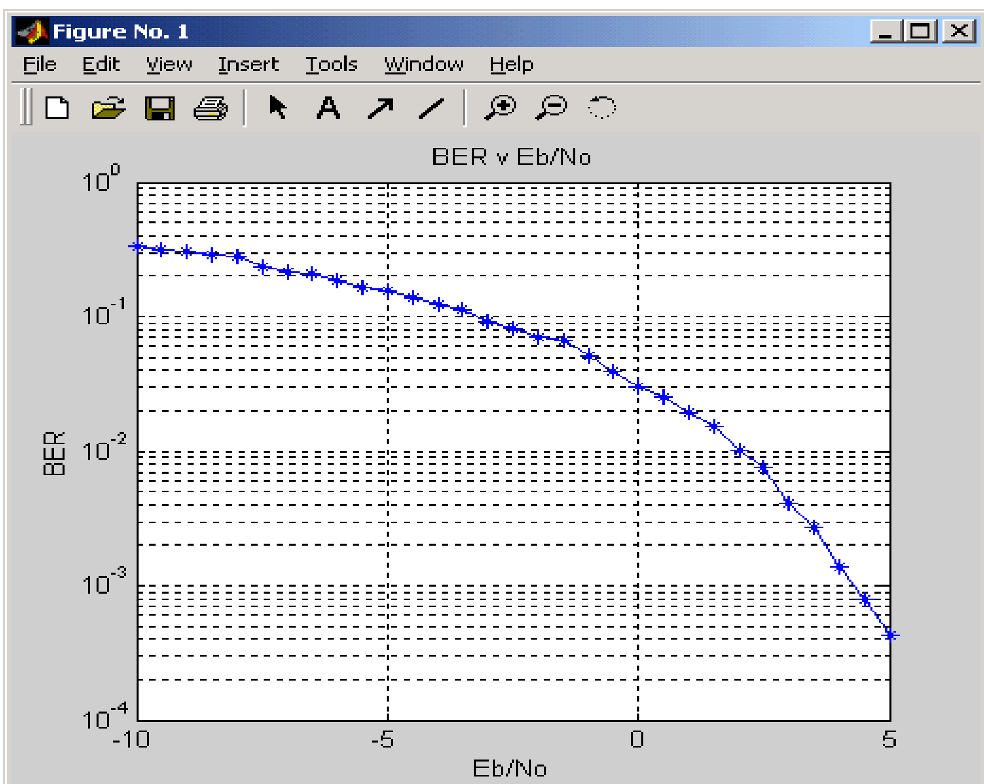

Figure 14: BER versus Eb/No

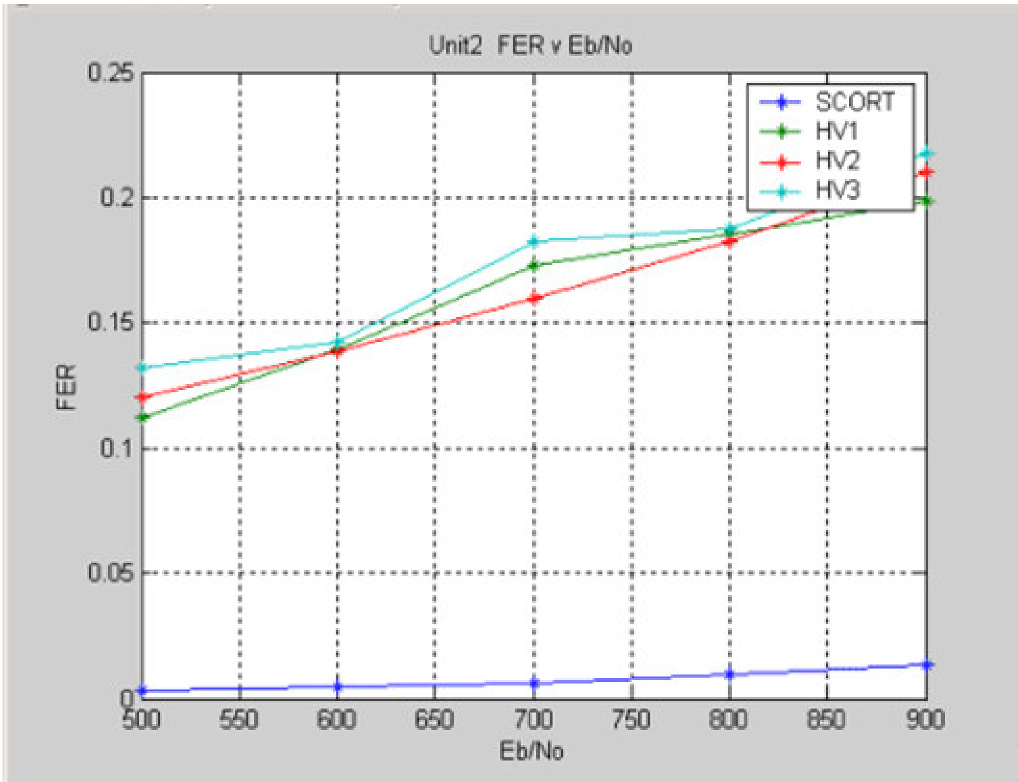

Figure 15: BER versus large values of Eb/No

interfering source come closer to the Bluetooth system. Fig. 14 demonstrates the BER performance with respect to Eb/No. It should be noted in Fig. 14 that the BER decreases linearly over the values of Eb/No. However, the BER divergence in Fig. 14 is very rapid and acceptable for a maximum value of Eb/No.

For Fig. 15, we measured the difference in Frame Error Rate, when using a SCORT voice packet, rather than the regular HV1, HV2 and HV3 packet. From Fig. 15, we can see that when using SCORT packets, there is a considerable reduction in the Frame Error rate.

VI. Conclusion

Today Bluetooth and 802.11 network devices are part of our daily life. This paper presented a model for the interference of these two standards. Our analysis shows that situation gets worse as more and more devices come into play. Such a situation calls for the urgency of congestion free network. Techniques such as SCORT are a big leap in the future for such networks. By using SCORT packets we can minimize the effect of interference. Hopefully in the future wireless industry will mature in such a way that smooth data and voice transmission will be achieved and finally a solution for Co-existence without compromise can be realized.

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