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EFFECT OF INTERFERENCE DUE TO WI-FI CO-EXISTENCE IN BLUETOOTH TRANSMISSION

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ABSTRACT – The advancements in the wireless networks provide realistic distant communication of different areas of the world. New generations of wireless communication will rely on intergraded networks consisting of multiple wireless technologies. Hybrid networks based, for instance, on cellular system such as Bluetooth and Wi-Fi technologies can combine their respective advantages on coverage and data rates. Both Wi-Fi and Bluetooth operate on ISM (Industrial, Scientific and Medical) unlicensed radio frequency (RF) spread spectrum from 2.4GHz to 2.4835GHz. Early Bluetooth devices interfered with 802.11b because both techniques use same channel for an extended period of time which causes interference, data lost, and eventually loss of services of both technologies. But this interference greatly effects SCO voice link which is main issue of interference due to collision. This paper presents the effect of interference due to Wi-Fi co-existence in Bluetooth transmission and how much Bluetooth transmission is effected during Wi-Fi interference. In addition, this paper presents a new Bluetooth voice packet Synchronous Connection Oriented with Repeated Transmission scheme to minimizing the interference between Bluetooth and 802.11 wireless networks. For the sake of experimental verifications, we provide a comprehensive simulation results using MATLAB Simulink.

KEY WORDS – WPAN, Bluetooth, Wi-Fi, interference, SCO etc.

1. INTRODUCTION

The proliferation of mobile computing devices such as PDA (Personal Digital Assistants), laptops are used as WPANs and the most popular application in Bluetooth or IEEE802.15, wireless personal area network (WPAN) is currently used for voice transmissions. It allows closely located devices to share data. In modern era, Radio technologies are considered by WPAN and WLAN. Both technologies operated on popular and unlicensed 2.4 GHz ISM (Industrial, Scientific and Medical) frequency band. WLAN devices operating in proximity to WPAN devices have significant impact of the interference on the performance of WPAN and vice versa. As in band adjacent WLAN networks can almost make the voice quality of a Bluetooth SCO link unacceptable to users.

As the changes occurred in wireless world, voice transmission becomes most popular like music, voice files etc. Due to the co-existence of various technologies on same frequency band, the interference increases in the performance of the system and degrades the value of SNR. But there is one point should be noted that as Bluetooth and Wi-Fi both operated on same frequency band 2.4 GHz but they adopt different operating methods. Such as Bluetooth uses FHSS (Frequency Hopping Spread Spectrum) scheme while Wi-Fi adopts DSSS (Direct Sequence Spread Spectrum) technique as shown in figure 1.

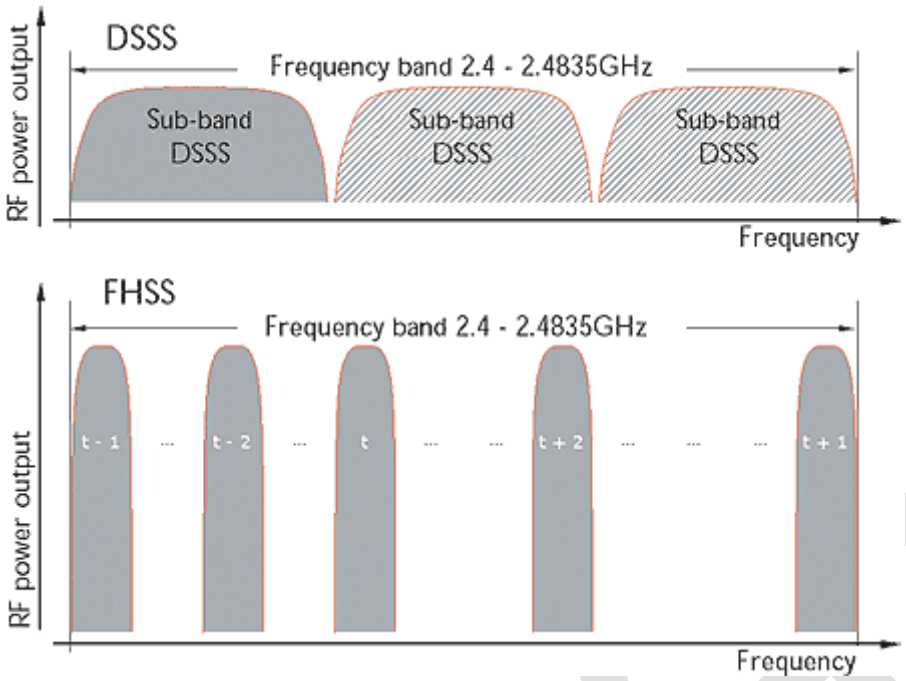

Fig:1 FHSS and DSSS operated on 2.4 GHz frequency band

As a reminder about radio transmission, a carrier frequency is modulated either in amplitude, phase and/or frequency shift (or a combination) to impress the data information onto the carrier wave. If one can transmit the data over many carrier waves in parallel, it becomes possible increase the data throughput. This hallmarks the advantage of the spread spectrum technologies. The data signals are diffused over many carriers instead of impressing the data within the sidebands of a single carrier wave. Such DSSS (Direct Signal Spread Spectrum) technologies use relatively wide bandwidths.

In contrast frequency-hopping technologies use narrower bandwidths and 'hop' (or 'jump') from one discrete frequency to another. These are the FHSS technologies (Frequency Hopping Spread Spectrum). DSSS and FHSS appeared many years ago for military applications where FHSS signals showed themselves to be more difficult to intercept or jam than DSSS ones. DSSS technologies (Direct Signal Spread Spectrum) work in 22MHz- wide bands (IEEE 802.11b).This provides three non-overlapping 22MHz channels over the band 2.400 to 2.483 GHz.
FHSS technologies (Frequency Hopping Spread Spectrum) use narrow bands (less than 1 MHz), and hop successively from one to the other at regular time intervals (...t-2, t-1, t, t+1, t+2...) in pseudo-random sequences synchronized at both ends of the link.

The transmission range of Bluetooth is 10 meters and 802.11b have 100 meters. The wider ranges of WLAN also cover up the Bluetooth range and interfere with Bluetooth transmission. If two or more WLAN devices using different channels exist in same area then the 2.4 GHz ISM band is fully occupied , making the Bluetooth FHSS system infeasible and increases BER in data output.

The main objective of this paper is to show the effect of interference on BER due to presence and absence of Wi-Fi. We also use HV1 voice packet for voice transmission using SCORT technique to reduce BER including Wi-Fi and without Wi-Fi which is purposed by IEEE working group on co-existence.

This paper differentiates into following parts: Section II presents overview of Bluetooth technology with ARQ and frame format. Section III describes the Bluetooth simulation model including Wi-Fi interfere model and without Wi-Fi. Section IV explains the purposed mechanism Synchronized Connection Oriented Repeated Transmission. Simulation results are represented in Section V and at last Section VI describes the conclusion of the purposed work.

II. OVERVIEW OF BLUETOOTH TECHNOLOGY

The Bluetooth system provides a point-to point connection (only two Bluetooth units involved), or a point-to-multipoint connection. In the point-to-multipoint connection, the channel is shared among several Bluetooth units. Two or more units sharing the same channel form a piconet.

One Bluetooth unit acts as the master of the piconet, whereas the other unit acts as slave. Bluetooth is a frequency-hopped spread-spectrum technology aimed at cable replacement and personal networking. It operates in the 2.4 GHz ISM band which may be used unlicensed in most countries. This band is divided into 79 distinct frequencies of 1 MHz bandwidth each. Bluetooth specifies two basic link types. Synchronous Connection Oriented (SCO) links (typically used for voice) are handled by reserving predetermined slots. Asynchronous Connectionless links (ACL), which are typically used for elastic data traffic, access the medium by a time division duplex scheme.

A. PACKET FORMAT

The Bluetooth packets have a fixed format as shows in figure 2. A 72-bit access code comes first in the packet that are coded with a so-called 1/3 rate FEC (forward error correction) which essentially means that every bit is transmitted three times. The access code is based on the master's identity and the master's system clock; for example, it provides the means for synchronization. These general form of the packet format of Bluetooth baseband packets which consist of a header of 126 bits and a payload section that may be 0 to 2745 bits in length.

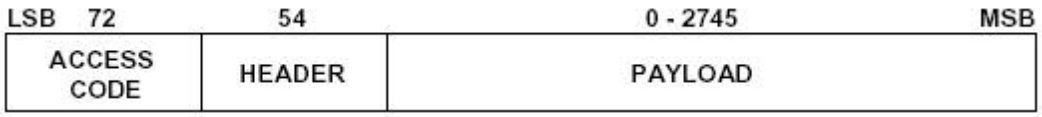

Fig: 2 Bluetooth packet format with LSB and MSB

Packets are assigned a 1 bit sequence number (SeqN) and are protected by a so-called fast automatic repeat request (FARQ), which essentially is an alternating bit protocol and explained in upcoming sub section. Positive or negative acknowledgments are piggy-backed in regular data packets (or NULL packets) in the ArqN_eld. The header_elds are protected by an 8 bit checksum.

AUTOMATIC REPEAT REQUEST

The co-existence of Bluetooth and Wi-Fi technologies is the main reason of interference due to which the packet loss and connection loss happens many times and degrade the performance of the systems and increases the BER. To complete the transmission of packets the ARQ (Automatic Repeat Request) is used. Bluetooth uni-cast packets are protected by an automatic repeat request mechanism (ARQ) on baseband level.

The so-called fast ARQ scheme retransmits each packet until it has been received and acknowledged successfully by the receiver. Packet header and payload are protected by separate checksums and thus the validity of the header may be con_rmed even if the payload of the packet has to be rejected.

If the header or the payload is corrupted, the payload will be rejected and the ArqN _eld in the packet header will be set to negative acknowledgment (NAK) in the next return packet sent by the receiver. In case the packet (header and data) is OK, its sequence number (SeqN) will be saved and the packet is accepted. The next return packet will carry a (piggy-backed) ACK. Note however that between the check for the header and the check for the payload the old sequence number is compared to the current one. Thus, if the packet has been successfully received before, the payload is ignored and an ACK is sent in the next return packet regardless of the status of the payload. Interestingly, this ACK acknowledges data received in a previous frame.

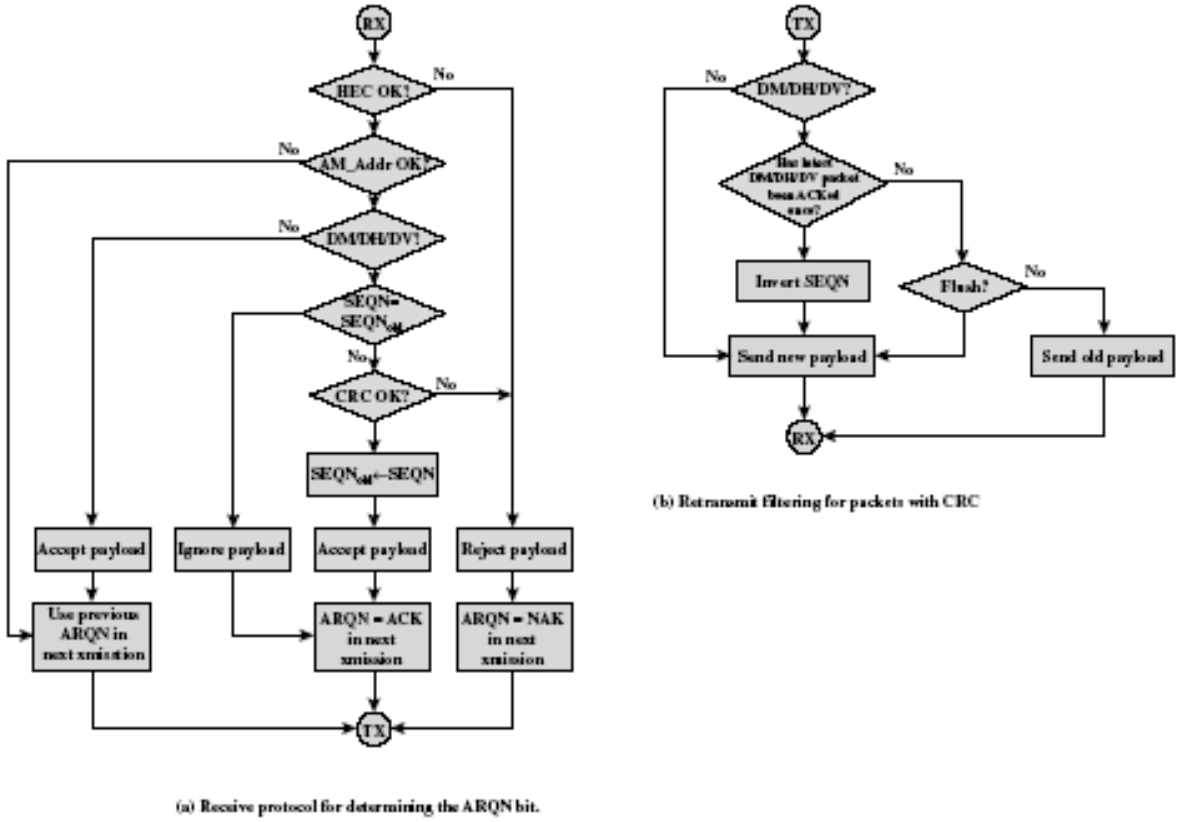

Fig: 3 Automatic Repeat Request Procedure

Furthermore, a master that sends a data packet to one of its slaves and does not receive a response in the slot following the packet just assumes a negative acknowledgment from the slave (*implicit NAK*). Slaves only send a NAK to their master in case they have data to send. If there is no data ready to send, they leave it to the implicit NAK mechanism to trigger retransmission. This feature is meant to save power and reduce interference.

C. BLUETOOTH LINK TYPES FOR COMMUNICATION

The Bluetooth specification defines two link types, Asynchronous Connectionless (ACL) and Synchronous Connection Oriented (SCO). Different master-slave pairs in the same piconet can use different link types. The link type may be changed during a session. The SCO links are primarily used for voice traffic and their data rate is 64 kbps. ACL links are used mainly for data traffic and support broadcast messages (i.e. from the master to all slaves to the piconet). Multiport packets use the ACL link type and can reach the maximum data rate of 721 kbps in one direction and 57.6 kbps in the other direction if no error correction is used.

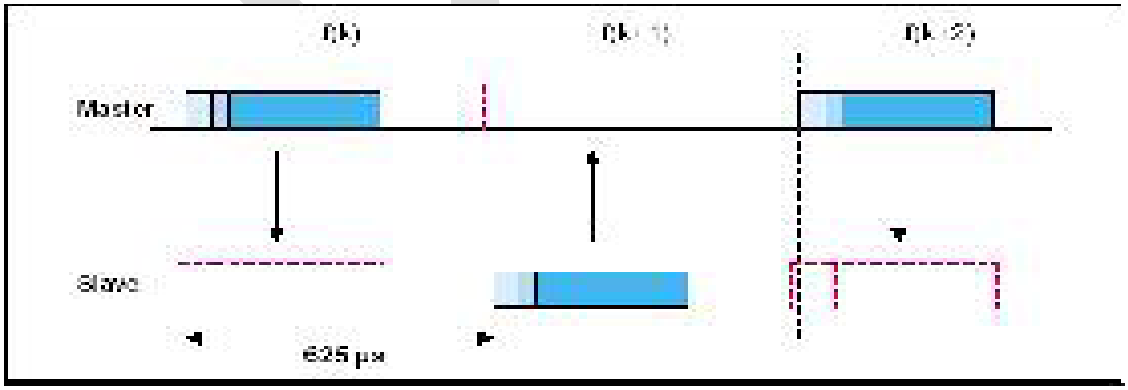

Fig: 4 Single slot packet and TDD and timing of slots

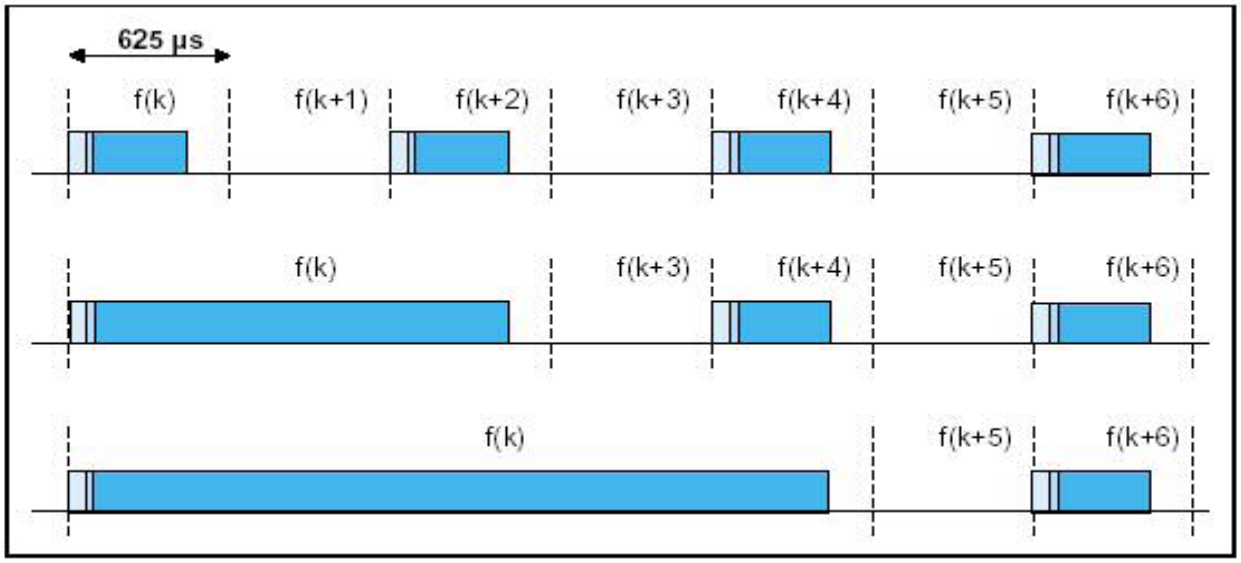

Fig: 5 Multi slot packets and TDD framing

D. PREVIOUS INTERFERENCE REDUCTION TECHNIQUES

Firstly, Frequency hopping and adaptive frequency hopping techniques are used to reduce the interference in the Bluetooth transmission for it link state state (LSH) using a counter. The counter continues count the connection state and on the bases of that the transmission of data happens.

There are two new coexistence mechanisms for Bluetooth SCO links, namely the Bluetooth SCO link Interference Mitigation (BSIM) scheme and Enhanced BSIM (E-BSIM). Both mechanisms are non-collaborative, meaning that they do not have to exchange information between two different wireless devices while the mechanism is in operation. The most famous collaborative coexistence mechanisms are alternating wireless medium access (AWMA) and packet traffic arbitration (PTA). Several other schemes, including overlap avoidance (OLA) , Bluetooth interference aware scheduling (BIAS) , Bluetooth carrier sense (BCS) and interference source oriented AFH (ISO AFH), have also been presented to reduce the impact of interference.

Moreover, many other techniques are used to minimize the interference due to co-existence of Bluetooth and Wi-Fi. But in this paper new mechanism Synchronized Connection Oriented RT is purposed. This mechanism reduces the BER (Bit Error Rate) in the received signal by passing through AWGN channel.

SECTION III BLUETOOTH SIMULATION MODEL WITHOUT WI-FI AND INCLUDING WI-FI

Figure 6 presents a Bluetooth simulation model made up in Matlab simulink. It consists of a Bluetooth transmitter, AWGN channel and a Bluetooth receiver. There is one important thing that the Wi-Fi interfere model is only used to verify the effect of interference on the Bluetooth transmissions.

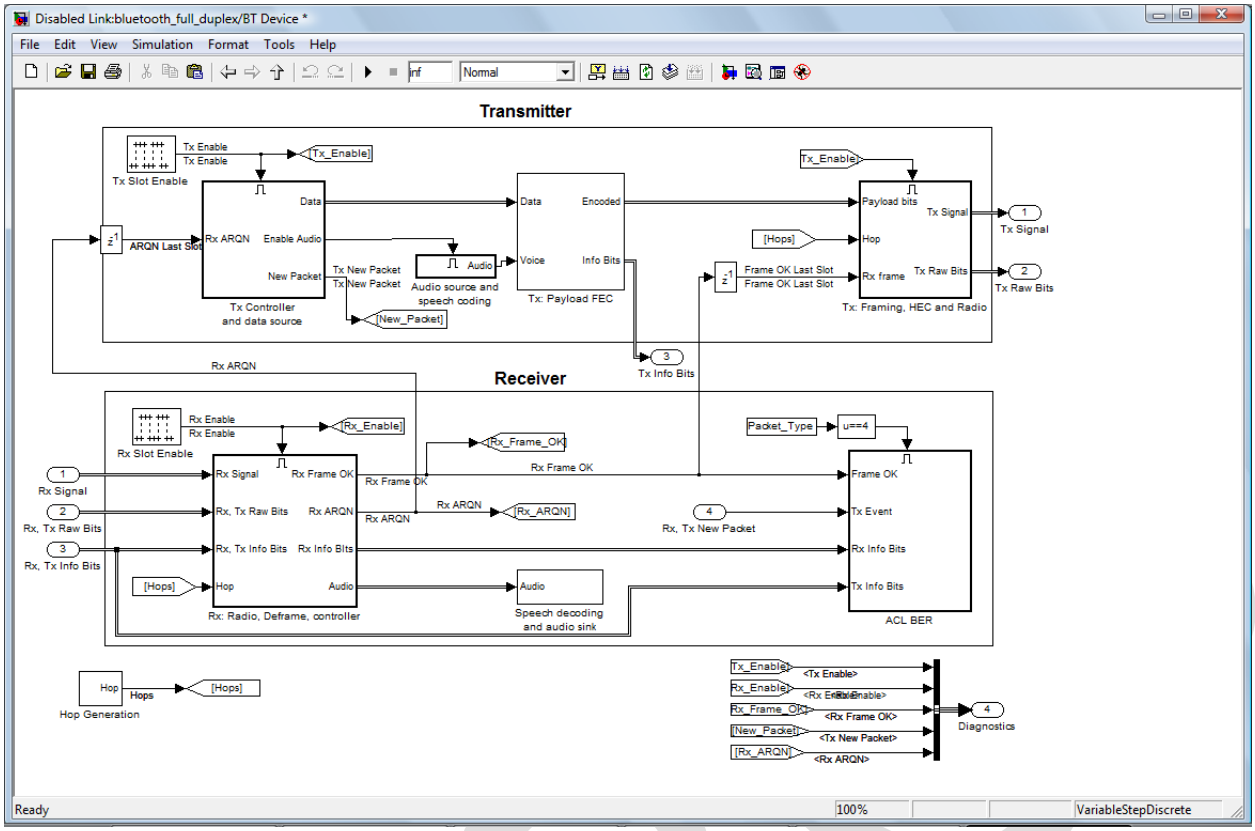

Fig: 6 Bluetooth simulation model

The various parts of Bluetooth simulation model are explained in detail following**:**

A. SIMULATION PARAMETERS

The simulation parameters which are mainly used to design the Bluetooth simulink model are given as below in table 1.

Table no.1 Simulation Parameters

S. No.	Simulation parameters	Range used in simulink model
1.	Speech signal	Input audio signal
2.	Length of speech signal	366bits
3.	Packet type	HV1,DM5
4.	Sampling time	8KHz
5.	Bluetooth clock	28 bits
6.	Bluetooth clock sampling time	(1/1600)/2
7.	FEC repetition count	3
8.	M-ary	2
9.	Integer routing mode	Floor
10.	Modulation index	0.32

B. BLUETOOTH TRANMITTER DESIGING

The Bluetooth transmitter is shown in figure 6. The transmitter block processes both the voice and data transmission. For voice transmission the HV1 packet is used for SCO link and the DM5 packet is used for data transmission for ACL link. The Bluetooth transmitter consists of transmitter controller, source, encoder, frequency hopping and GFSK modulation etc. Frequency hopping sequence generator is used to generate a frequency number from 0-79 channels. FEC repetition code is three used for HV1 packet. The security key is used for authentication process contains password or PIN number of slave to which the transmission have been done. The transmitter controller is responsible for the new packet as per it receives the acknowledgement from the receiver. If it

receives negative acknowledgement then the repeated transmission is happens and if positive acknowledgement then the new packet transmission is done. The buffering is done at the transmitter side to control the congestion in the network. Sampling of a voice signal is done at standard rate 8 KHz.

C. AWGN CHANNEL AND WI-FI INTERFER MODEL DESIGNING

The AWGN channel is used because of its importance that it contains all the colored frequencies. The free path loss of 40db is considered all the loss in the signal strength due refraction, diffraction and reflection etc. The 802.11b interfere is configured so that it can adjust in the 2.4GHz ISM band having mean packet rate, packet power and length of the transmitted signal. But only to show the internal and environmental interference without Wi-Fi transmission, the Wi-Fi interfere block does not included. This paper shows the effect and comparison between BER rate and SNR values.

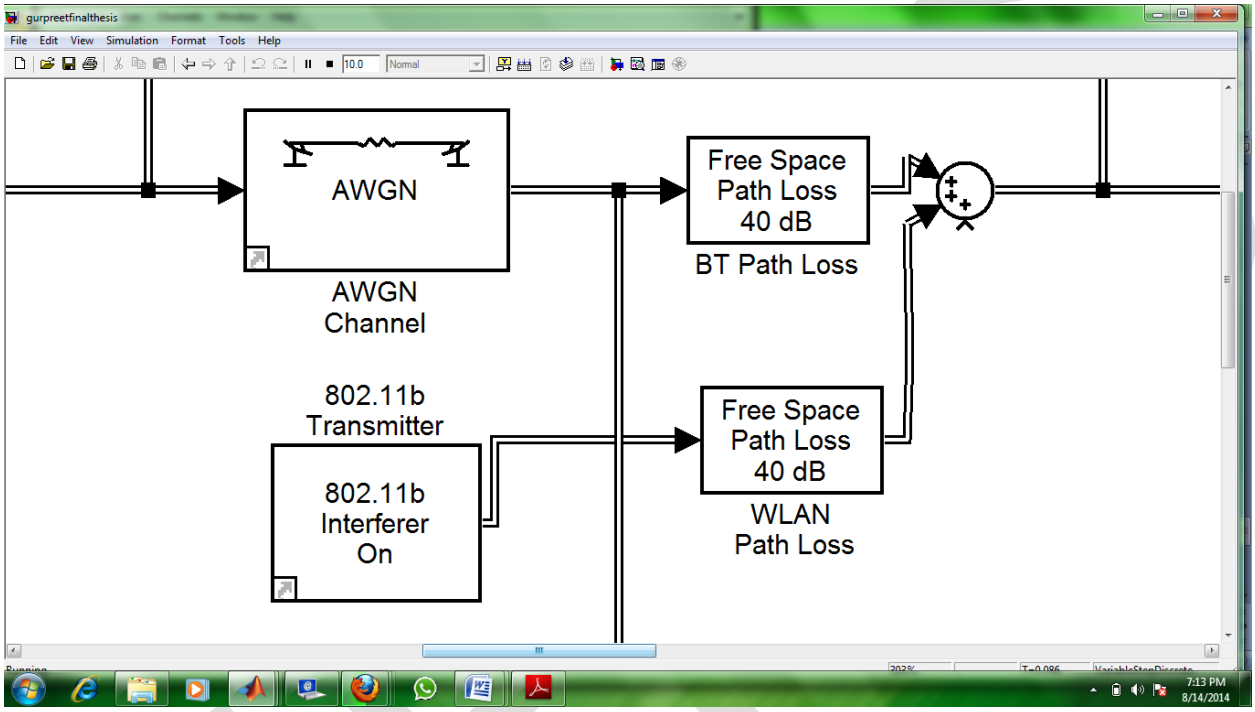

Fig: 7 AWGN channel and Wi-Fi interfere model including free path loss

D. BLUETOOTH RECEIVER DESIGNING

The Bluetooth receiver has a big responsibility for a better reception of the signal. It contains all the opposite parameters to the transmitter like decoder, down sampler, demodulation etc. There is a threshold value exists in the receiver side that evaluate that the received signal is correct or not. It also checks the HEC (Header Error Check) and CRC. If both are ok and the signal is above the threshold value then the signal is assumed to be correct and accepted and a positive acknowledgement is transmitter for new packet transmission. But if both are not ok and the signal value is less than threshold value the signal is rejected and negative acknowledgement is transmitted to transmitter and requested to the repeated transmission.

SECTION IV THE PERPOSED MECHANISM FOR CO-EXISTENCE INTERFERENCE

The Synchronized Connection Oriented Repeated Transmission algorithm is given by the co-existence working group. The synchronous connection-oriented with Repeated Transmission packet achieves more robust transmission by replacing bit-level redundancy with packet-level redundancy. The state flow diagram of Synchronized Connection Oriented Repeated Transmission is presented in Figure 8.

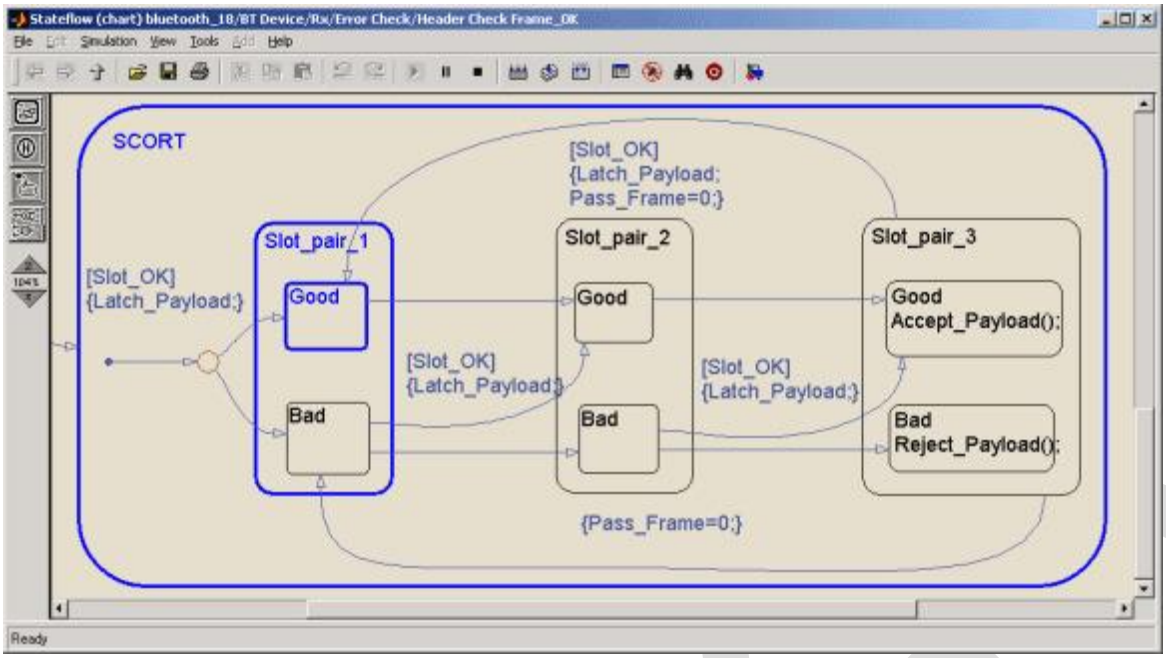

Fig : 8 Synchronized Connection Oriented Repeated Transmission for voice transmission state flow diagram

As the figure 8 depicts that the same packet is repeated three times in one SCO link interval.

There is no algorithm used for error correction in Synchronized Connection Oriented Repeated Transmission technique. In full duplex mode, the voice signal is repeated three times in a row. If the first packet is received correctly then the other two packets are rejected but if first row packet is lost and another packet is successfully received. In case of interference due to same packet transmission only one packet is received and another packet assumed as duplicate copies and are rejected by the receiver. It does not affect the BER of the payload. And it provides an improvement for frame error rate (FER).

SECTION V SIMULATION RESULTS

The Bluetooth simulation model creates two scenarios for testing the model. The first is only the Bluetooth transmission happens including its own and environmental interference without undertaking Wi-Fi interfere model. This first scenario is used to see the BER (Bit Error Rate) and SNR (Signal to Noise Ratio). The second scenario is created as that the Wi-Fi interference also worked i.e., the Wi-Fi transmission also carried on within the Bluetooth transmission and shows a great impact of interference on the Bluetooth transmission. In the whole Bluetooth transmission model, we have used the HV1 packet for voice transmission and DM5 for data transmission. The new voice packet Synchronized Connection Oriented Repeated Transmission (SCORT) is used to degrade the BER in the signal output for better performance and better communication.

Fig: 9 BER Vs Es/No using HV1 and DM5 packets with and without Wi-Fi interfere

It is predicted from fig 9 that the BER without Wi-Fi is in above green coated line and the Bluetooth model including Wi-Fi's BER is shown in below red colored line. The BER vs. SNR graph have its own specification that the BER decreases as the SNR increases as in figure 9 shown. And there is a great difference between the BER with and without Wi-Fi interference. There is a rapid reduction in BER using SCORT algorithm.

SECTION VI CONCLUSION OF THE WORK

The advancements in the wireless world provide comfort and relaxation to human being. This wireless world have reached our daily life at that level that we cannot imagine our daily life without Wi-Fi and Bluetooth devices. They both are unbreakable part of technical world. Our experiments show that the situation gets more and more the worse as the more devices come into play and try to communicate with each other and creates congestion in the 2.4 GHz frequency band. The SCORT (Synchronized Connection Oriented Repeated Transmission) are a big leap in the future for such networks and make the network congestion less and degrade the BER in the signal output. Hopefully, in future these techniques provide an error free performance to the users for better use. Finally, we can say that it is a great solution for devices to operate co-existence in the wireless world.

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