The Effect of Interference on Bluetooth Data Exchange over WLAN

M. ABU SHATTAL* and ABDEL-RAHMAN AL-QAWASMI**
*Computer Department
Al-Hussein Bin Talal University
Ma'an
JORDAN
engmas5@gmail.com http://masdiamond.webs.com
**Electrical Department
Al-Majmaah University
Al-Majmaah City
KINGDOM OF SAUDI ARABIA
a.alqawasmi@mu.edu.sa http://www.alqawasmi.org

Abstract: - The paper focuses on studying Bluetooth Wireless Personal Area Network (WPAN) and Wireless Local Area Network (WLAN) technologies to make Bluetooth data exchange over WLAN applicable. In particular, it addresses the problem of using WLAN coverage area to exchange data between two Bluetooth devices connected to different piconets. To achieve this goal, we propose a new approach of Bluetooth-WLAN integration taking in account the effect of Interference.

Problem arising from this integration can be solved using two approaches. Hardware solution when an electronic design for a hardware chip can be offered to support WLAN and the Bluetooth data exchange technologies between two wireless networks. Such chip would be good enough to work as fast as possible but it will suffer from incompatibility with the current technologies such as Mobile phones, PCs, and laptops. The second approach is the software solution when software development for WLAN-WPAN integration can maintain the capabilities of current devices for both technologies.

The work proposes different simulation Models developed to simulate the integration process, to study the effect of interference in different locations in Bluetooth-WLAN Integrated Network (BWIN). Simulation results show the ability of data exchange over WLAN considering architecture and interfering aspects.

Key-Words: - Bluetooth, WLAN, Integrated network, interference, data exchange.

1 Introduction

A WLAN is an on-premise data communication system that reduces the need for wired connections and makes new applications possible, thereby adding new flexibility to networking. Mobile WLAN users can access information and network resources as they attend meetings, collaborate with other users, or move to other campus locations.

Bluetooth WPAN Standard technology emphasizes constructing reliable links over low-power radius, but often at the cost of a reduced data rate compared to Wi-Fi. Bluetooth has already been widely deployed in hundreds of devices. Typical Bluetooth devices offers data rates of up to 1 Mb/s and ranges of 10 m, with far lower power consumption than IEEE 802.11 standard. The low power consumption and interoperability guarantee have encouraged acceptance of Bluetooth in the WPANs.

1.1 Wireless Local Area Networks

The IEEE 802.11 standard, variants and alternatives had made rapid progress and the Unlicensed National Information Infrastructure (U-NII) bands also presented new opportunities [1]. Mainly, the Industrial, Scientific and Medical (ISM) bands have a wide usage in WLAN.

In this paper, a main attention is given to IEEE.802.11.b WLAN standard. It has wide applications in universities, internet café and other public services.

Wireless Networks use the principle of cellular system to benefit more of the system main resource which is frequency and that what is called “frequency reusability” and it also suffers from all interference issues (e.g. co-channel interference and adjacent channel interference) which found in any mobile cellular system. WLAN Adapters, Wireless

Access Point (AP) and WLAN Bridges are the Main equipments used in WLAN system [2].

In this work, simulation and hardware test are developed at the bit level for laptop or Personal Computer (PC) with Bluetooth and WLAN devices installed. This simulation can help a developer to develop software for integration between Bluetooth and WLAN networks. This software with the installed hardware creates the needed Access point for integration between Bluetooth and WLAN. Modified joined wireless system will be called Bluetooth-to-WLAN Access Point (B2WAP)

Power control has been an area subject to extensive research in recent years. A simplified radio link model is typically adopted to emphasize the network dynamics of power control. The transmitter is using the power $p(t)$ to transmit data scrambled by a user-specific code.

The channel is characterized by the equation:

$$G(t) = 10\log_{10} g(t) \quad \text{dB}, \tag{1}$$

Where $g(t)(<1)$ is the power gain in linear scale

Correlating the received signal with the code, the receiver extracts the desired signal, which has the power $c(t)=p(t)g(t)$ and is also subject to an interfering power from other connections. The perceived quality is related to the signal-to-interference ratio (SIR) [3]

$$\gamma(t) = \frac{p(t)g(t)}{i(t)} \tag{2}$$

For error-free transmission (and if the interference can be assumed Gaussian), the achievable data rate $R(t)$ (bits/s) is limited from above by (Shannon, 1956) [3]:

$$R(t) = W\log_2(1+\gamma(t)), \tag{3}$$

Where W is the bandwidth in Hz.

From a link perspective, the objective with power control can use constant power, variable coding and modulation to benefit from times of a favorable channel. Also, Power control can maintain constant Signal-to-Interference Ratio (SIR) and thereby constant data rate according to equation (2).

Quadrature Phase Shift Keying (QPSK) is used in WLAN 802.11b providing more data rate.

Differential modulation uses standard PSK constellations, but encodes the information in the phase transitions between successive symbols rather than in the absolute phase of one symbol. This allows recovery of the information even when there is no absolute phase reference [4].

In WLAN IEEE 802.11.b standard, the Spread Spectrum (SS) technique used is Direct Sequence (DS). In Bluetooth networking, Frequency Hop (FH) is used as a multiple access technique in a piconet with other techniques used such as Time Division Multiple Access (TDMA) and Time Division Duplex (TDD).

A DS signal is an SS signal generated by the direct mixing of the data with a spreading waveform before the final carrier modulation [5].

Ethernet LANs use Carrier Sense Multiple Access/Collision Detection (CSMA/CD) technique to transmit data between stations through wired medium. This technique cannot be used for wireless local area network simply because there is no previous information about users or stations that share the wireless medium. Also, due to the nature of the wireless medium that may be shared among all types of wireless devices; the medium access technique Carrier Sense Multiple Access/Collision Avoidance (CSMA/CA) (also known as Distribution Coordination Function (DCF)) is used instead of CSMA/CD which found to be beneficial choice to be implemented as multiple access technique for WLAN.

The following table contains the time durations for DCF Interframe Space (DIFS), Short Interframe Space (SIFS) and Point Coordination Function (PCF) Interframe Space (PIFS) for 802.11.b standard

Table 1: DIFS, SIFS and PIFS durations

IEEE standard	Time slot (μs)	DIFS duration (μs)	SIFS duration (μs)	PIFS duration (μs)
802.11.b	20	50	10	30

IEEE 802.11 standards cover the data link and physical layers of the International Organization for Standardization (ISO) Open System Interconnection (OSI) seven layer reference models [6]. The data link layer is concerned with the reliable transfer of data frames over the physical channel. It implements various forms of error control, flow control and synchronization. In the 802 reference model, the data link layer comprises two sub-layers, the Logical Link Control (LLC) sub-layer and Medium Access Control (MAC) sub-layer.

Logical Link Control is defined in the IEEE 802.11 standard. Its primary function is to provide an interface between the MAC layer and the higher layers (network layer).It performs multiplexing functions in order to support multiple upper layer protocols. Furthermore, it is responsible for flow control and error control. Both connectionless and connection-orientated frame delivery schemes are supported. LLC is unconcerned with the specific details of the LAN medium itself.

The responsibility of the MAC sub-layers is to manage access to the physical channel. The physical layer of 802.11 is responsible for the transmission and the reception of bits, encoding and decoding of signals and synchronization (preamble processing). The physical layer hides the specifics of the medium from the MAC sub-layer.

WLANs are used in three distinguished areas: Private: home, government and enterprise. Public: coffee shops and airports. Semi-Public: Universities and hospitals.

In every mentioned above area, WLAN needs to define different performances and security settings to meet different usages or applications.

1.2 Bluetooth Technology

The name "Bluetooth" and its logo are trademarked by the privately held trade association named the Bluetooth Special Interest Group (SIG).The name Bluetooth was a code name used by developers of this wireless technology. But as the time past name Bluetooth Stuck [7].

Second Bluetooth technical specification 1.0B released in 2000. Bluetooth 2.0 was introduced late in 2005; Bluetooth 2.1 with enhanced data rate in 2007 and latest version of Bluetooth is 3.0 released in April 2009. Alternate MAC/PHY (AMP) is the main new feature of the Bluetooth version 3.0. In this version, addition of high rate data transport with 802.11 is accomplished.

Bluetooth is an industry standard, later adopted by the IEEE 802.15 work group as the Wireless Personal Area Network Standard [7].

A Personal Area Network can be defined as a network of devices in close range to a person, which can communicate with each other. A typical PAN could consist of a Laptop, a Mobile Phone and a Printer. The user can transmit images from the mobile phone equipped with a camera to his computer which can then send it to the printer.

Bluetooth is a wireless technology and hence it must deal with impairments, noise and interference faced by other wireless technologies, For Bluetooth to work effectively many technologies cooperated together such as Frequency Hopping Spread Spectrum, digital modulation [4].

Frequency Shift Keying (FSK) has until recent years been the most widely used form of digital modulation, being simple both to generate and to detect, and also being insensitive to amplitude fluctuations in the channel. A binary Gaussian shaped frequency- shift-keying (GFSK) modulation scheme is applied in order to reduce cost and device complexity [9]. A symbol rate of 1 Mb/s can be achieved for an occupied bandwidth of about 1MHz. Bluetooth devices can create both point-to-point and point-to-multipoint connections. A connection with two or several (maximum 8 devices) devices is a Piconet where all devices follow the same frequency-hop scheme [11]. To avoid interference between devices, one of the devices automatically becomes a master of the piconet. In each slot, a packet can be exchanged between the master (M) and one of the slaves (S).

A Bluetooth packet format is based on one packet per hop and a basic 1-slotpacket of 625 μs that can be extended to 3-slot (1875 μs) and 5-slot (3125 μs) [12].A frame format allows the master to poll multiple slaves. Each packet begins with a 72-bit access code that is derived from the master identity and is unique for the channel. Every packet exchanged on the channel is preceded by this access code. Recipients on the piconet compare incoming signals with the access code.

If the two do not match, the received packet is not considered valid on the channel and the rest of its contents are ignored. Besides packet identification, the access code is also used for synchronization and compensating for offset. The access code is robust and resistant to interference. Two or several piconets can communicate with each other and are then called a scatternet.

The Bluetooth protocol stack allows devices to locate, connect, and exchange data with each other and to execute interoperable, interactive applications against each other. The Bluetooth protocol stack can be placed into three groups: transport protocol group, middleware protocol group, and application group.

Bluetooth has a number of applications such as Personal Networks: PC to PC, Cable Replacement: PC to Peripherals, Bluetooth in the Small Office or Home Office, Bluetooth for Voice Applications and Bluetooth for Wireless Gaming [8]

1.3 Wireless Local Area Network versus Bluetooth

Wi-Fi and Bluetooth are intended to coexist in the network, and although they certainly have overlapping applications, each has its distinct zones of advantage. The main differences between Wi-Fi and Bluetooth are as follow:

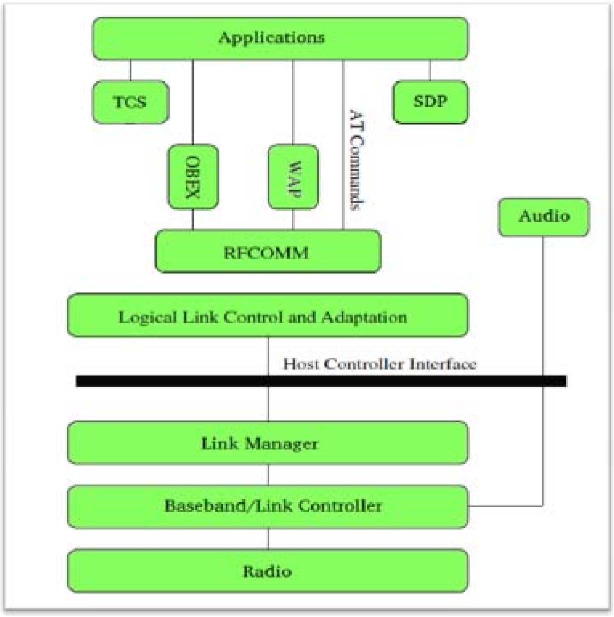

Fig.1 Bluetooth Protocol Stack

Distance: Bluetooth is lower powered device, which means its signal can only go short distances (up to 30 feet). 802.11 technologies can cover own home, and even more sometimes, depending on the antenna.

Application: Bluetooth is considered as cables replacement. For instance in the situation where one has to get rid of huge tangle of cables linking for instance mouse, printer, monitor, scanner, as well as other devices on desk and around home. It is important to notice here that the first Bluetooth device was a Bluetooth headset, eliminating annoying cable to the telephone. Nowadays cars are also becoming fitted with Bluetooth so driver can use cell phone in car, with car's stereo speakers and an onboard microphone serving as hands-free capability.

Wi-Fi (IEEE 802.11a, 802.11b, and 802.11g) and Bluetooth are similar in certain conditions: for instance they both can make possible wireless communication between electronic devices but are more complementary than direct competitors. Wi-Fi technology is mostly used to make a wireless network of personal computers that could be situated anyplace in a home or business. Bluetooth devices usually on the other hand communicate with other Bluetooth devices in relatively close range. [8]

Although, there are differences between Bluetooth and WLAN, in this paper we attempt to exchange the Bluetooth data between piconets using the WLAN wider coverage area comparing to Bluetooth coverage area.

2 Bluetooth – WLAN Integrated Model in Interference Environment

Bluetooth and WLAN network system operates using the same ISM Frequency band (2.4GHz) which makes each one of them a great source of interference to the other; figure 2 shows a demonstration of this issue.

Transmitting its own packets, WLAN 802.11b occupies one of twelve channels allocated for Wireless networking in 2.4GHz band, while Bluetooth divide the same band into 79 channels. In this case a channel reserved for 802.11 devices can interfere with one or more Bluetooth devices working on the same channel.

In this section, a brief survey about interference issue between Bluetooth and WLAN is provided focusing on the Device and Service Discovery processes.

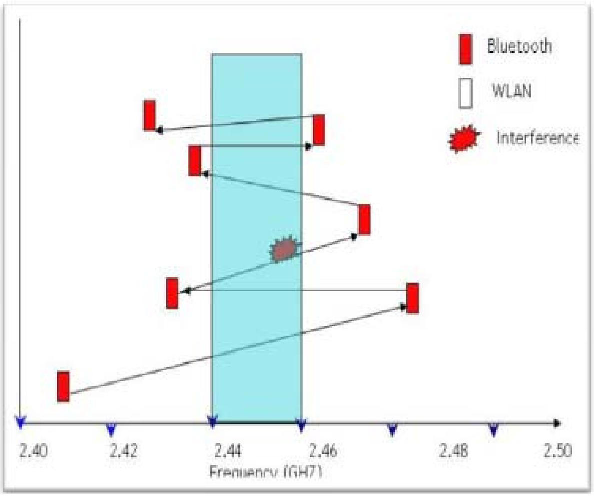

Fig. 2 Interference between Bluetooth and WLAN networks

The issue of interference have been extensively studied by a special group (TG2: Task group 2) of IEEE committee 802.15 which focuses on the coexistence of Bluetooth and other devices competing in the same ISM band, many solution have been proposed in two broad areas: collaborative and non collaborative mechanisms.

With collaborative mechanisms the mutual interference is reduced to make information exchange between Bluetooth and WLAN. Collaborative mechanisms can be implemented when interfering devices are co-located in the same terminal. With non-collaborative mechanisms there information exchange between the two network systems is not allowed and they operate independently.

Interference take place if both systems transmit data at the same time with the same frequency, figure 3 shows two interfered packets with a desired packet with three different values for Bit Error Rate (BER). BER will take three values depending on the length of interfered packet with the desired packet, as length of interfered signal goes up BER will increase.

If the desired signal is a WLAN packet data can be retransmitted again according to the mechanism of ARQ, but this will degrade the overall WLAN system performance. If the desired packet is a Bluetooth packet FEC will attempt to correct the packet, if couldn't the packet will be dropped.

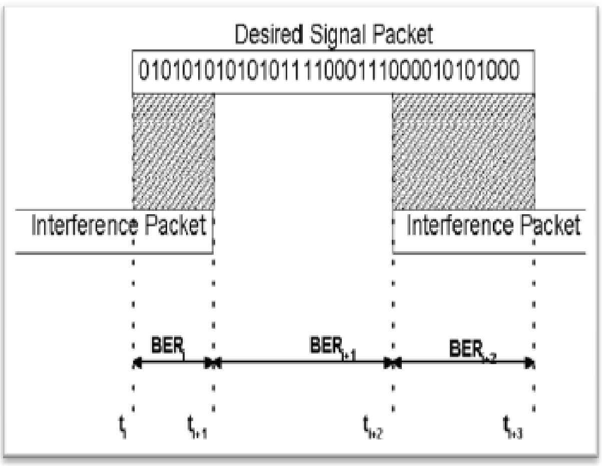

Fig. 3 Packet Collision and place of errors

WLAN 802.11b and Bluetooth systems can simultaneously operate in the same environment only if the target QoS, is guaranteed for both of them. QoS can be targeted by Packet Error Probability (PEP) or BER, depending on the level of study for coexistence issue [9].

In bit level simulation BER is more accurate to measure the quality of link between Bluetooth devices or with WLAN 802.11b devices or both if coexisted together.

While in analytical study PEP is preferred, since such study depends on the probability of existence of number of nodes of both systems in the same environment.

The number and location of bit errors in the desired packet depends on SIR, Signal-to-Noise Ratio (SNR) at the receiver, the type of modulation used by the transmitter and the interferer, and the channel model. [10]

The power control may have fewer benefits in the coexisted environment. Increasing the WLAN transmission power to even fifty times the power of Bluetooth is not sufficient to reduce the WLAN packet loss and in the same time it increase the interference on Bluetooth so , limiting the WLAN power may help avoid interference to Bluetooth.

Bluetooth voice represents the worst type of interference for WLAN. In addition, the WLAN performance seems to degrade as the Bluetooth offered load is increased. The use of error correcting block codes in the Bluetooth payload does not improve performance since errors caused by interference are often too many to correct. [10]

3 Proposed System Model for Bluetooth – Wireless LAN Integration

The main Idea of this paper is to suggest a wireless Access Point (AP) with Bluetooth (BT) interface connected to it; this access point receives data from Bluetooth master node in piconet The AP then processes the received data and then forwards it to a wireless interface. Then the wireless interface in the AP receives this data and then buffers it to the Bluetooth interface. According to this scenario a transparent connection between two Bluetooth devices over wireless LAN connection is made, taking the advantages of high throughput and long distance covered by WLAN Access Point.

The proposed AP (B2WAP) together with the software simulated in this paper will provide the intended functionality, however design for this access point will be a manufacturer concern and it will be out of the scope of this paper.

Instead of designing two Access points, we suggest to use a laptop or PC connected to two interfaces to integrate Bluetooth and WLAN network, WLAN Card and Bluetooth dongle, this laptop will act as the proposed Access point but with more advantages. First, it represents a real application where WLAN is integrated with Bluetooth device. Second, it allows us to measure the behavior of such an application in an Ad-Hoc WLAN topology as shown in figure 4. Third, we can also extend this system to be in infrastructure mode by connecting ordinary AP to this system, while maintain the proposed connectivity, as shown in figure 5.

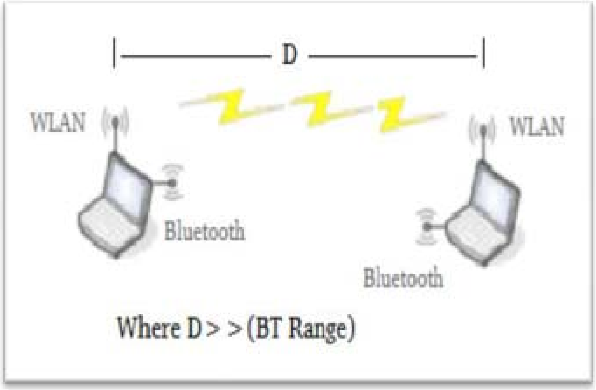

Fig. 4 Proposed Architecture

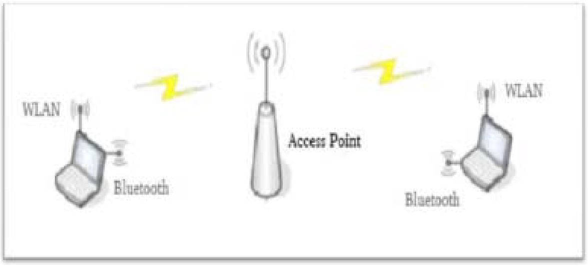

Fig. 5 Extended Architecture

4 Simulation Model for Bluetooth – WLAN Integration

In work [10], the interference Evaluation of Bluetooth and IEEE 802.11b based on increasing the power of WLAN over WPAN in order to minimize the mutual interference between them. In this work the main idea is to study the effect of interference to show the ability of the usage of WLAN to send and receive Bluetooth data. Systems Programming model consists of three main parts based Bluetooth-to-WLAN Integrated Network (B2WIN): BT1-AP1 part, AP1-AP2 (through WLAN) and AP2-BT1. It presents a simulation for synchronous communication between all three parts assuming that the absence of scatternet in Bluetooth networking (between the piconets). This assumption is important to study data exchange between piconets through WLAN coverage area. Also, the model shown in figure 6 assumes that access points (AP1 and AP2) have the ability to act as interface to maintain the differences between Bluetooth and WLAN described before.

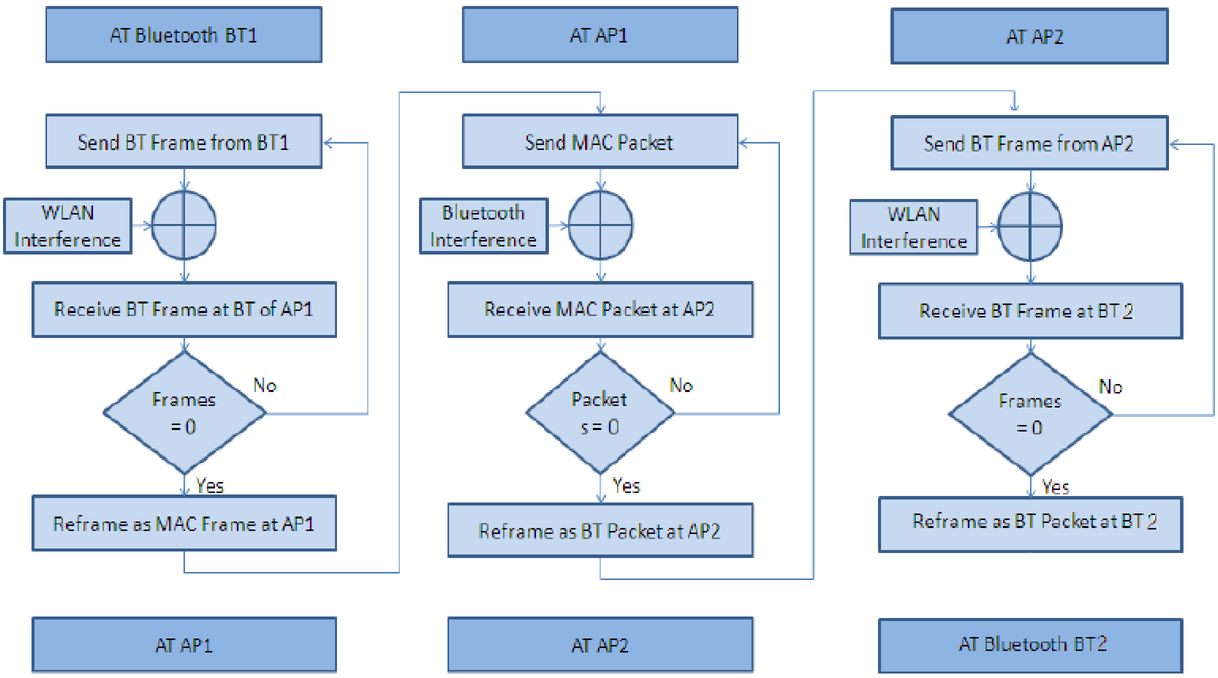

Fig. 6 Flowchart of proposed model

Simulation Model shows different BER values depending on number of bit errors in received Bluetooth packet divided by total number of received bits. Packet Error Rate also computed by simulation model by dividing the number of packets with errors by total number of bits in the received packet.

Errors occurred in Bluetooth address, that sent over WLAN is important. It is used to measure PER and they have a special interest since they represent address for communicating Bluetooth devices. Even one bit can made the connection invalid and the packet will be rejected.

In case of a big number of piconets shared the WLAN area, a bit errors in Bluetooth address may cause communication with the undesired piconet (address error).

In order to minimize the number of address retransmissions, Forward Error Correction (FEC) should be used to detect and correct bits error in address.

Table 3.1: Attributes for Matlab simulation model

Attribute	Value	notes
Number of BT Slots	1 slot (366bit/slot)	System can adapt 1, 3 and 5 slots
BT Payload length	0~2745 (Max.) bits	Generated randomly
BT Payload	0 or 1	Length based on BT Payload length
BT Header	54	Fixed, originally 18bit encoded using 1/3 FEC, encoding assumed.
BT Access Code	68	Fixed by BT Packet Format
WLAN interferes with BT	1 ~ 5	Random, 802.11g adapted in system
Length of interfering packet	48,96,192,288	bits/symbol in WLAN 802.11g OFDM
Interfering Position	Random	Any position randomly in BT frame
Number of BT Interfering nodes	1~5	WLAN Nodes that interfere BT transmission
Number of WLAN Interfering nodes	1~5	BT Nodes that interfere WLAN transmission

5 Results and Discussion

The system is modeled for different parameters using Matlab R2008.

5.1 Effect of number of interfering bits on system performance

Simulation results according to different lengths of interfering bits (from 10~100 bits) are shown in figure 7. Assuming that number of interfering nodes from both networks is constant and equals to two interferers.

Bluetooth communication takes place in two stages of modeled network from BT1 to AP1 and from AP2 to BT2, while WLAN communication takes place between AP1 to AP2 nodes.

5.2 Effect of length of interference on BER

The high values for BERs are expected since no channel coding or channel equalization is applied to the system to enhance the performance and reducing BER.

It is clearly shown from figure 6 that increasing the length of interfering bits increases BER proportionally. This result makes sense because the interfering bits are increased in more locations within the desired transmitted packet. Bluetooth packet from BT1 to AP1 and AP2 to BT2 and WLAN packet from AP1 to AP2 may change their bits according to the level of power, if Bluetooth and WLAN collide at the same time and frequency.

The average effect of WLAN interference on Bluetooth communication is around certain values even for multiple stages (the first stage BT1-AP1, and last stage AP2-BT2). This is acceptable since different stages of interference may substitute values of energy level for the received signal when decision is made at the receiver

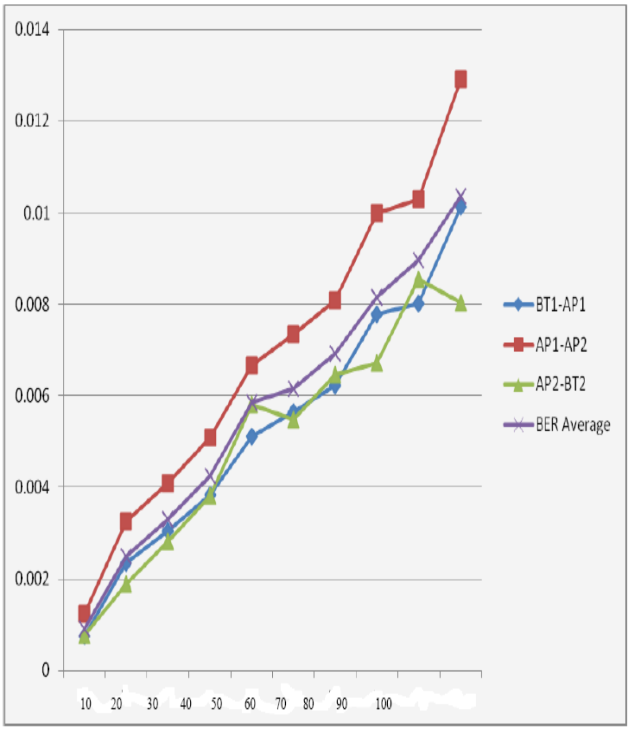

Fig. 7 Effect of length of interference in bit (x-axis) vs BER (y-axis)

The average end to end BER is calculated as shown in figure 6. It has been taken as an average value assuming interference effect from all stages at the same time.

Figure 8 shows the behavior of end to end interference from BT1 at stage1 to BT2 at stage 3. We see that values for BER fluctuate from 0.1 to 0.12 with average equal to 0.111. This result can be explained through the different interference stages that may change different locations of the desired signal. This can help to correct errors from previous interference sources. Values of end to end BER is high because no FEC is used in the model. If we compared this result with a model assuming FEC 2/3 hamming code for two stages of Bluetooth communication we can substitute a correction factor of value 1/5, this value obtained from the fact that FEC 2/3 is (15,10) block code can correct 1 error [9] out of 10 bits received. For two stages 2 bits can be corrected for end to end communication, resulting factor of 0.2.

Figure 8 also compare end to end BER with end to end BER behavior with 2 FEC added, the level of BER can be reduced by using more robust FEC techniques, and add enhancing of CCK in WLAN link between Bluetooth communications.

Comparing end to end BER values with and without FEC in figure 8 with each single BER in figure 7 shows that there are more techniques should be used to enhance channel conditions in each stage to provide acceptable level of BER for each stage and from end to end.

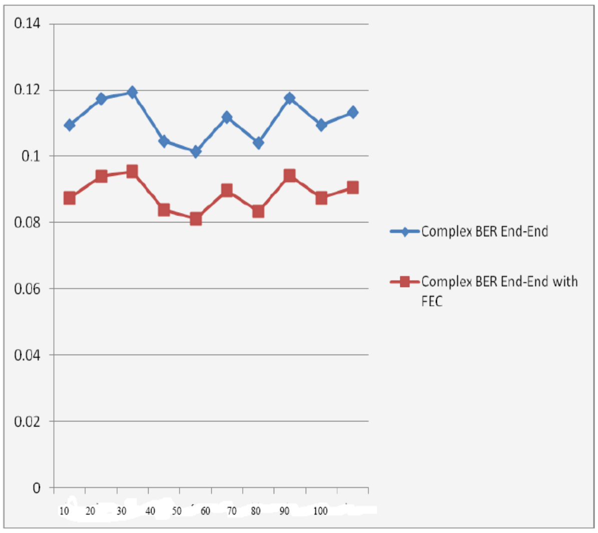

Fig. 8 Effect of length of interference on end to end BER

5.3 Effect of length of interference on PER

Bluetooth Packet considered being erroneous. If one of its address field is corrupted and did not detect by the system, security issues is considered.

Figure 9 depicts simulation for 100 times of packet transmission but preview three of them aligned with the average PER. We notice increasing length of interference bits from 10 to 100 changes the value for PER slightly on the model, this result is justified since the level of PER depends on the position of interference. Table 3.2 also support this result, where values of length of interference increased from 100 to 1000 bits of interference, we can safely said that FER is independent of length of interference. This result also applied for PER 2 from WLAN2 to BT2 as shown in figure 10, assuming the result obtained for PER1.

6 Conclusion:

Bluetooth and WLAN 802.11b networks can be integrated together to provide services as heterogeneous network. This integration is governed by level of Interference and Noise applied to the communication link between devices taking a part in the process of integration.

Mitigation of Interference and noise can be achieved using the ordinary interference reduction mechanisms proposed by Bluetooth SIG and IEEE 802.15.1 TG2. This is implemented in Bluetooth devices supporting Bluetooth standard 1.2.

For daily communications, level of interference between nodes in the shared coverage area of Bluetooth and WLAN is acceptable, as one could exchange objects between Bluetooth devices seamlessly.

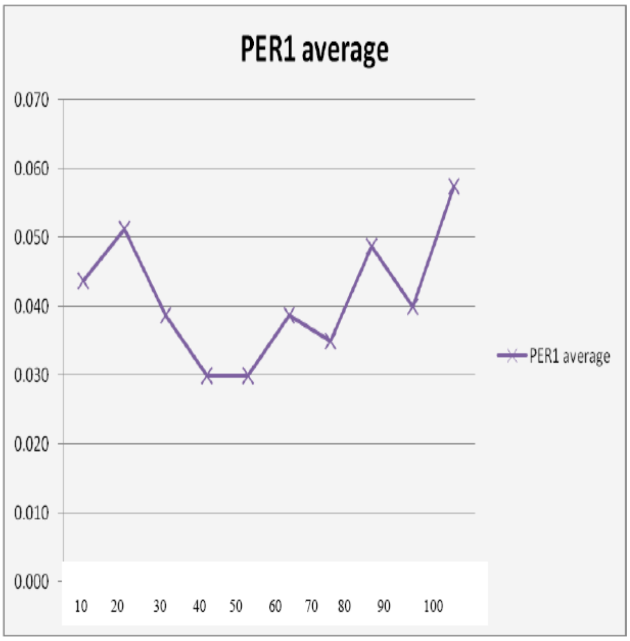

Fig. 9 Effect of length of interference in bits on Bluetooth PER 1

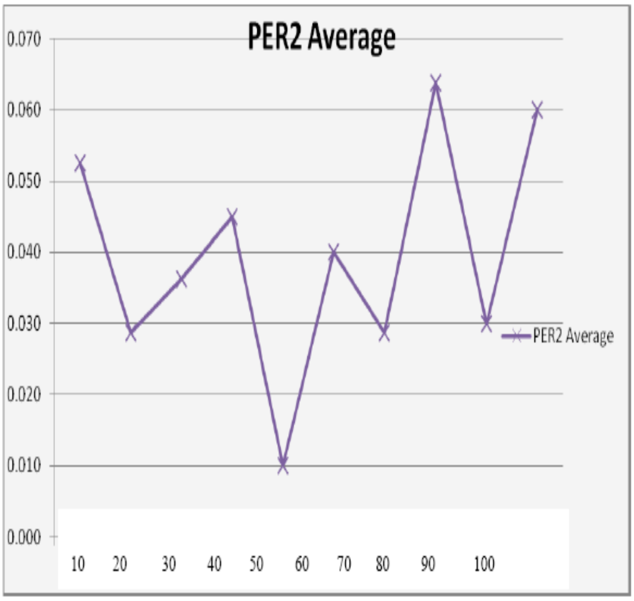

Fig. 10 Effect of length of interference in bits on Bluetooth PER 2

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Mohammad Abu Shattal has a Master degree in Communication Engineering - June 2011- from Mut'ah University – Jordan. Shattal received his a bachelor degree from AL-Yarmouk University Place: Irbid, Jordan i- June 2006. He is now a full part lecturer at Al-Hussein Bin Talal University. His research interests are Wireless Networking and Communication Systems.

Abdel-Rahman Al-Qawasmi is an associate professor at Almajmaah University-Electrical Engineering Department. He received his Master PhD degrees from Kiev University of Civil Aviation Ukraine in 1999. He published more than 25 scientific papers in DSP and Wireless Communication systems. He was a Director of Computer center (2010-2011) and the head of Communications and Electronics department in Philadelphia University (2005-2010).