Examining Performance of Bluetooth Network In The Presence of Wi-Fi System

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Abstract: *More recently, there has been a growing interest in cognitive techniques, which allow devices and even whole networks to monitor the environment in order to dynamically select and use the channel that affects the least interference. This study aims at Simulation of Bluetooth performance with IEEE 802.11b interference and determination of the Bit Error Rate (BER) using Advanced Design System (ADS 2011 C). The study which employed the Agilent Advance Design system 2011 (ADS 2011) as methodology, reveals that the frequency offset and relative interference power of IEEE 802.11b with Bluetooth signal affect the Bluetooth network performance in terms of BER. Thus the study recommends that measurement should be done in order to include the impact of these components on Bluetooth network performance with the interference from IEEE 802.1lb system.*

I. Introduction

Many wireless technologies, especially those used to build local or personal area networks (i.e. WLANs or WPANs), operate into the unlicensed frequency bands, which can be exploited by multiple users and networks at the same time. For example, the 2.4 GHz ISM band is used worldwide by several technologies, such as Wi-Fi, ZigBee, and Bluetooth1. However, due to the mutual interference, the coexistence of different devices operating in proximity of each other can be troublesome. In the WLAN category the products based on the Wireless Fidelity (Wi-Fi) or the IEEE802.11b technologies are dominating. The IEEE802.11b offers speeds of up to 11Mbps and covers a range of up to 100 meters. With WLANs, applications such as Internet access and file sharing can now be doneact in the home or office environments with new levels of freedom and flexibility **[2]**. Both technologies occupy the 2.4GHz frequency band, there is potential for interference between the two technologies. Due to the common usage of Bluetooth devices and consequently the emphasis of the work presented in this dissertation is on the performance of the Bluetooth network with IEEE802.11b interference.

These problems of signal interference and performance degradation are what to be studied and analyzed by presenting a simulation environment for modeling the interference based on detailed Medium Access Control (MAC) and Physical (PHY) models. This framework will then be used to evaluate the impact of interference on the performance of Bluetooth and IEEE 802.11b. A simulation scenario is to be used in order to measure performance in terms of bit error rate and access delay. Further, this study aims at capturing Simulation of Bluetooth performance with IEEE 802.11b interference and determination of the Bit Error Rate (BER) using Advanced Design System (ADS 2011 C).

II. Literature Review

IEEE 802.11b Radio Technology

The IEEE 802.11b standard for Wireless Local Area Network (WLAN) is served to replace wired LAN computer network. The physical layer (PHY) covers the physical interface between devices and is concerned with transmitting raw bits over the communication channel. The IEEE 802.11b standard actually provides for three variations of the physical layer (PHY) **[11]**. These include Direct Sequence Spread Spectrum (DSSS), Frequency Hopping Spread Spectrum (FHSS), and Infrared. In practice, only the first one, DSSS has any significant presence in the market. The DSSS PHY option was designed specifically to conform to Federal Communications Commission (FCC) regulations (FCC) for operation in the 2.4GHz ISM band. For the DSSS operation the available bandwidth is divided into channels, each occupying approximately 20MHz. Although there are 11 channels identified for DSSS system in the US and Europe, there is a lot of overlap. When multiple access points (APs) are located in close proximity, it is recommended to use frequency separation of at least **[12]**. Therefore, the ISM band will accommodate three non-overlapping channels in a total bandwidth of 83.5MHz as illustrated in Figure 2.3 below.
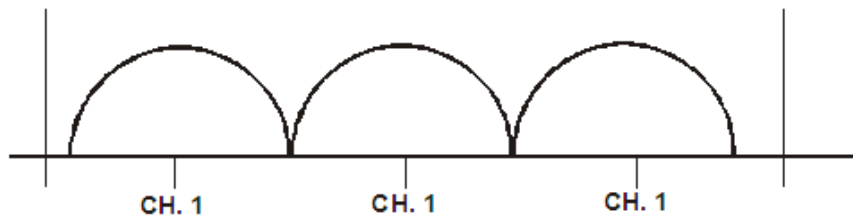
Figure 2.3 Three non-overlapping channels for DSSS operation in ISM band

In most of the WLAN products on the market based on the IEEE 802.11 b technology the transmitter is designed as a Direct Sequence Spread Spectrum Phase Shift Keying (DSSSPSK) modulator which is capable of handling data rates of up to 1Mbps. The system implements various modulation modes for every transmission rate, which are Differential Binary Phase Shift Keying (DBPSK) for 1 Mbps, Differential Quaternary Pause Shift Keying (DQPSK) for 2Mbps and Complementary Code Keying (CCK) for data rates of 5.5Mbps and 11Mbps [7]. The summary of IEEE802.11b data rate specifications are shown in table 2.3 .

Table 2.3: IEEE 802.11b data rate specifications

Data rates	Code length	Modulation	Symbol rate	Bits/symbol
1 Mbps	11bits (Barker sequence)	BPSK	1 MSps	1
2 Mbps	11 bits (Barker sequence)	QPSK	1 MSps	2
5.5 Mbps	8 bits (CCK)	QPSK	1.375 MSps	4
11 Mbps	8 bits (CCK)	QPSK	1.375 MSps	8

According to the FCC regulations (FCC 15.247) for operation in the 2.4GHz ISM and nominal power of the transmitter is 100mWatt or 20dBm. This signal strength was chosen to accommodate coverage of the approximately 100- meter radius area and to limit the battery power consumption.

Spread Spectrum Modulator

Direct Sequence Spread Spectrum (DSSS) is a transmission technology used in IEEE80.11b data transmissions where a data signal at the sending station is combined with a higher data rate bit sequence, or chipping code, that divides the user data according to a spreading ratio. The chipping code is a redundant bit pattern for each bit that is transmitted, which increases the signal's resistance to interference. If one or more bits in the pattern are damaged during transmission, the original data can be recovered due to the redundancy of the emission. The spread spectrum modulator is designed to generate DBPSK, DQPSK and CCK spread spectrum signals. The modulator changes its rate after the header, when data transmission uses DQPSK or CCK. The modulator can support data rates of 1, 2, 5.5 and 11Mbps. Differential Quadra phase (I/Q) modulation is used at the baseband for all modulation modes DBPSK, DQPSK and CCK. In the 11Mbps DBPSK mode, I and Q channels of the modulator are connected together [13].

Spread spectrum is employed in IEEE 802.11b to decrease the problem of interference due to other systems operating in the ISM band. By means of spread spectrum the energy radiated by the transmitter is spread out over a wider amount of the RF spectrum than would otherwise be used and thus increase the processing gain at the receiver where the signal is going to be dispread. The spreading is performed by multiplying (Exclusive Or) binary data by a pseudorandom (PN) binary waveform. In the case of DBPSK and DQPSK the PN code is an 11 -chip long Barker sequence. Barker codes are short unique codes that exhibit very good correlation properties. For the CCK modulation 8-chip long Walsh codes are employed. One of the essential reference points in the analysis is a Signal to Noise ratio (SNR) [6]. In this analysis the SNR is represented by energy per chip (Ec) to the power spectral density of noise (No) ratio as shown in the equation 2.5

$$\frac{E_C}{N_C} = \frac{\text{Transmiter - Signal - Strength}}{\text{No.(Chip\_Rate)}} \qquad (2.5)$$

The SNR depends on the chip rate of the system; consequently, for every transmission one of this quantity is going to be the same. The difference is going to be in the number of bits represented by a chip (length of the pseudorandom sequence), which means that energy per bit to noise ratio is going to differ from one data rate to another. The N_0 here is a power spectral density of the Additive White Gaussian Noise (AWGN) of the system and is going to be discussed further. The chip rate of the system is fixed at 11 Mchips/s.

DBPSK and DQPSK Modulations

The operation of the Differential Phase Shift Keying (DPSK) modulation can be better explained after understanding the regular phase shift keying (PSK). In a PSK, the M signal waveforms are represented in Equation 2.5 as follows:

$$S_m(t) = g(t).cos[\ 2f_c t + \frac{2}{M}(m-1)\ ] \qquad m=1,2......,M$$

$$= g(t).cos[\ \frac{2}{M}(m-1)\ .cos(2f_c t) - g(t).sin[\ \frac{2}{M}(m-1)]\ .sin(2f_c t), \qquad (2.6)$$

Where g(t) is a signal pulse shape, $cos[\ \frac{2}{M}(m-1)\ ]$ and $sin[\ \frac{2}{M}(m-1)\ ]$ are quadrature

components, $cos(2f_c t)$ and $sin(2f_c t)$ are carriers. The M represents possible phases of the carrier that conveys the transmitted information.

The 11 –chip direct sequence spreading increases the processing gain at the receiver of the DBPSK system

by $10\ Log\ \frac{11 chips}{1 bit} = 10.4 dB$. For DQPSK the processing gain is $10\ Log\ \frac{11 chips}{2 bit} = 7.4 dB$ since 2

bits are encoded in every chip. The practical data rate reached under the DBPSK modulation is 1Mbit/s or 1Msymbol/s, where each symbol is 11chips and 1Msymbol/s, represents one bit. For the DQPSK modulation the data rate reached is 2Mbps or 1Msymbol/s, where each symbol is 1 chip and represents two bits **[6]**.

CCK Modulation

For the CCK modes, the spreading code length is 8 chips and based on complementary codes. The transmitter inputs the data and portions it into 4-bits or 8-bits. At 5.5 Mbps, it uses 2 of those 4 bits to select one of 4 complex spread sequences from a table of CCK sequences and then DQPSK modulates that symbol with remaining 2 bits. At 11Mbps, 8 bits are used, where 6 bits are used to select one of 64 spread sequences for a symbol, and 2 remaining bits are used for modulation **[15]**. Thus, the total possible number of combinations of sequences and carrier phases is 256. CCK is a variation on M-ary Bi orthogonal Keying (MBOK) modulation where one of the M unique (nearly orthogonal) signal codeword is chosen for transmission. CCK uses the complex set of Walsh/Hadamard functions known as Complementary Codes. Walsh codes are formed by performing a simple operation as illustrated in Figure 2.5. For the 2-ary case, the basic symbols are formed by taking a 2 by 2matrix of 1 s and inverting the lower right quadrant of the matrix. To form the 4-ary case, take 4 of the 2x2 matrices and make a 4 x 4 matrix with the lower right hand quadrant again inverted. The procedure is repeated for the case and beyond **[1]**. The BPSK modulation is represented in the Equation 2.4 by the M = 2, two phases, whereas the QPSK is represented by M= 4, four phases.
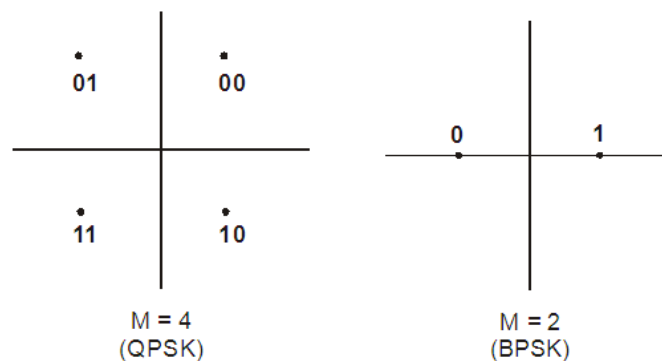This can be illustrated in the Figure 2.4

Figure 2.4: Signal space diagram for QPSK and BPSK signals

The Different Phase Shift Keying (DPSK) modulation differs from the PSK in a way that there is no direct phase assignment to every symbol; instead, the difference between the current and previous phase is detected and that change in phase indicates the change in the symbol. For example, in the simplest form of

DBPSK, 1 may cause a phase shift of 0 whereas 0 causes no phase change, or vice versa. At the receiver the phase of each symbol is compared with that of the previous symbol, which means that there is a need for delaying the received signal by one symbol length in time [22]. A phase change indicates a 1 is received, no phase change 0. The differential phase shift keying is employed in the IEEE 802.11b standard because differential modulation overcomes the need for coherent detection necessary in PSK systems, in other words there is no need for estimation of the carrier phase, and therefore the receiver design is much simpler. Spectrally the DBPSK signal is similar to that of a BPSK signal; however there is 1dBm advantage in processing gain.
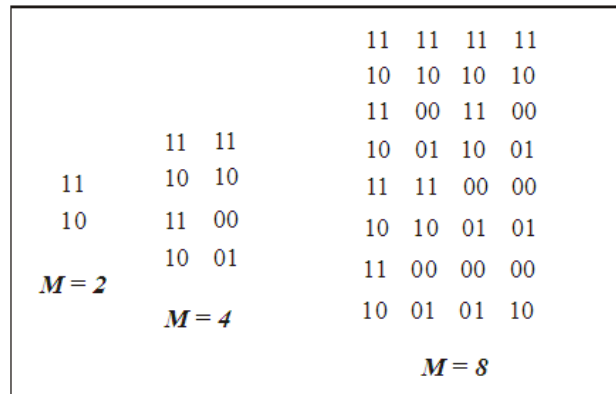

Figure 2.5 Forming Walsh Codes by successive folding

For the 5.5Mbps data rate 4 bits are encoded into the 8-word consequently the processing gain is only

$$PG = 10 \log \frac{8\,chips}{4\,bit} = 3dB \qquad (2.7)$$

However, for 11 Mbps data rate there is no spreading gain at all since 8 bits is encoded into the 8-chip sequence. To insure that the modulation has the same bandwidth as the lower data rates modulations, the chipping rate is kept at 1 I Mchip/s while the symbol rate is increased to 1.375MSymbol/s [6].

Advance Design System (ADS) 2011

Advance Design System (ADS) 2011 is an electronic design automation software system produced by Agilent EEs of EDA, a unit of Agilent Technologies Inc. (NYSE). It is the world`s leading electronic design automation software for RF, microwaves, and high speed digital applications. In a powerful and easy-to-use interface, ADS pioneers the most innovative and commercially successful technologies, such as X-parameters and 3D EM simulators, used by leading companies in the wireless communication & networking, aerospace and defence industries [21]. It provides an integrated design environment to designers of RF electronic products such as mobile phones, pagers wireless networks, satellite communications, radar system, and high speed data links. Agilent ADS supports every step of the design process-schematic capture, layout, frequency-domain and time-domain circuit simulation, and electromagnetic field simulation-allowing the engineers to fully characterize and optimize an RF design without changing tools [4].

Modes of operation of ADS

The operation of the ADS can be performed in two ways that is the Circuit Simulation and the System Simulation.

Circuit Simulation

In its simplest form ADS has the same functionality as other SPICE programs like PSPICE. There is a graphical user interface to draw the circuit diagram (Schematic entry). Like many commercial SPICE programs, the software comes with significant number of predefined libraries. Since the focus of ADS is RF and microwave design, the majority of the devices in the library are RF and microwave devices. There are several different simulations that ADS can perform. Some of these can be found in traditional SPICE simulators [5,17]. The more complex simulation modes are also available in other design software like Microwave Office. The simulation modes that are likely to use in the project are given below.

A.　　　**DC Analysis**: The first step in any circuit simulation is the determination of the bias point. It takes into account the non-linear behaviour of the transistors and other circuit elements.

B.　　　**AC Analysis**: This analysis performs essentially a small signal analysis of the circuit. AC analysis is performed to determine the quiescent point. At this bias point the transistors and other non-linear circuit

elements are linearised. In other words the transistors are replaced by their equivalent circuits which are made from resistors, capacitor, inductors and voltage and current sources. This type of analysis is only appropriate for small signals.

C.   **S-Parameter Analysis:** This is essentially the microwave equivalent of AC analysis and the same comments apply. This analysis will be frequently used in the project and microwave circuit design.

D.   **Transient Analysis:** AC and S-parameter analysis linearise the circuit and operate in the frequency domain. Transient analysis predicts the performance of the circuit in the time domain **[4]**. It therefore includes all the non-linear properties of the components. This simulation can take significant amount of time and generate large amounts of data.

E.   **Harmonic Balance (HB):** When designing a circuit with non linear elements, usually we are only interested in the interaction of a couple of frequencies. This analysis takes into account the non-linear elements of the circuit and restricts the analysis to several important frequencies. This is usually faster than doing a complete transient analysis and then extracting the required information from the temporal signal by Fourier transform techniques. This is ideal for obtaining an estimate for the IMD3 products by simulating two tone test measurements. There are other simulation modes which are available in ADS. These are Large Signal S-Parameteres (LSSS), Circuit Envelope, Gain Compression (XDB), and Budget Analysis.

System Simulation

ADS also allows simulation of circuits and systems using digital signal processing. This circuit simulation is based on the data flow controller (Ptolemy) developed by University of California. This analysis tool is important because in modern communication systems the modulation scheme is digital and the received analogue signal requires significant amount of processing to extract the digital data **[5]**. (For example in the OFDM used in terrestrial digital television requires a FFT). ADS allows you to simulate part of your circuit using conventional circuit simulation tools and the rest of the system using the data flow controller.

Main Features of ADS

Key ADS features help simplify and speed the design flow. ADS Layout, for example, features an RFIC toolbar for easier, more efficient physical design and trace routing. Desktop DRC and LVS help verify and correct layouts against foundry design rule checks prior to tape out and catch errors early in the design cycle, all from the user's desktop**[4]**. In addition, ADS' integrated 3-D planar EM simulator, Momentum, combines full-wave and quasi-static EM solvers for simplified passive, interconnect and parasitic modeling. Moreover, the ADS design kit for the IHP 0.13 μm SiGe process (SG13S) used in a first project supports a complete ADS front-to-back design flow with design rule check for most recurring rules.

Benefits of ADS

The ADS environment provides a vast array of tools and features that enable analysis of almost any conceivable SI problem. The key features that are beneficial to Advanced Layout Solutions are: the ability to directly create S-Parameter models from Allegro PCB layout, the ability to mix modeling technologies in a single simulation, e.g. Touchstone, physical layout, the extensive library of components and utilities that aid the modeling of MGbit SERDES transceivers and channels, the ability to quickly analyze and characterize channels, running millions of data bits in just minutes **[4]**.

III.   Methodology

Having discussed on literature review, this part covers the concepts and methodologies of analyzing the Bluetooth network's performance with IEEE 802.11b coexistence using Agilent Advanced Design System 2011 (ADS 2011). In addition, the schematic of the test bench will be shown; this includes the sub networks used in Bluetooth transmitter and receiver as well. It will also cover briefly about ADS 2011 to give better insight on the procedure and method used to design the test bench.

Design Using Ads 2011

In order to design the Bluetooth network with IEEE802.11b coexistence test bench, the libraries and components needed include:

• WLAN 802.11b Library
• Measurement components such as spectrum analyzer and Bit Error Rate Tester
• Filters, Modulator, Demodulator,
• Simulation license for Digital Signal processing and RF network.

The Test Bench Design

The test bench of Bluetooth network's performance with IEEE 802.1Ib coexistence shown in figure 3.1 is designed by using Agilent Advanced Design System 2011, which is abbreviated as ADS 2011. Simulations on this test bench are then conducted to determine the impact of interactions between these two networks which are using different standards.

In this simulation, a number of parameters are used which include Bluetooth signal source or transmitter as the desired signal, IEEE 802.11b 5.5 Mbps CCK signal source as the interfering signal, Bluetooth receiver and other measurement components such as spectrum analyzer and Bit Error Rate tester. Accurate models of modulations for the desired and interfering channels are used in this simulation. In addition, simulations include realistic models for transmitter filters, receiver filters, non-linearity amplifier and phase noise.

In the simulations, Bluetooth network's performance degradation is determined. The simulation results of Bluetooth network's Bit Error Rate (BER) with interference from IEEE802.11b signal is presented in graphs as the function of relative power and frequency offset of interfering IEEE802.11b signal by using the tools available in ADS 2011. The result of the simulations shows BER when collisions occur between the desired and interfering networks. The interfering signal is applied at 100 percent duty cycle at a constant frequency.

IV.   Result And Discussion

This section discuses the results that were obtained from the simulation of the Bluetooth network with 802.11b coexistence test bench as discussed in previous section.

Simulation Results

The simulation results of this test bench are presented in graphs. The graphs will show how the frequency offset and relative interference power of IEEE 802.11b with Bluetooth signal affect the Bluetooth network performance in terms of BER. From the BER obtained from the simulation, the raw packet data rate (PER) of Bluetooth network will be analyzed by applying Mathematical model.

Effect of Interference power on BER of Bluetooth Network

Table 4.1 shows the data obtained after the simulation for BER of Bluetooth network in conjunction with the frequency offset and relative interference power of IEEE 802.11b with Bluetooth signal. The data is plotted in figure 4.2 .

Table 4.1 Relationship of BER and the Relative Interference Power (dB) of IEEE802.11b.

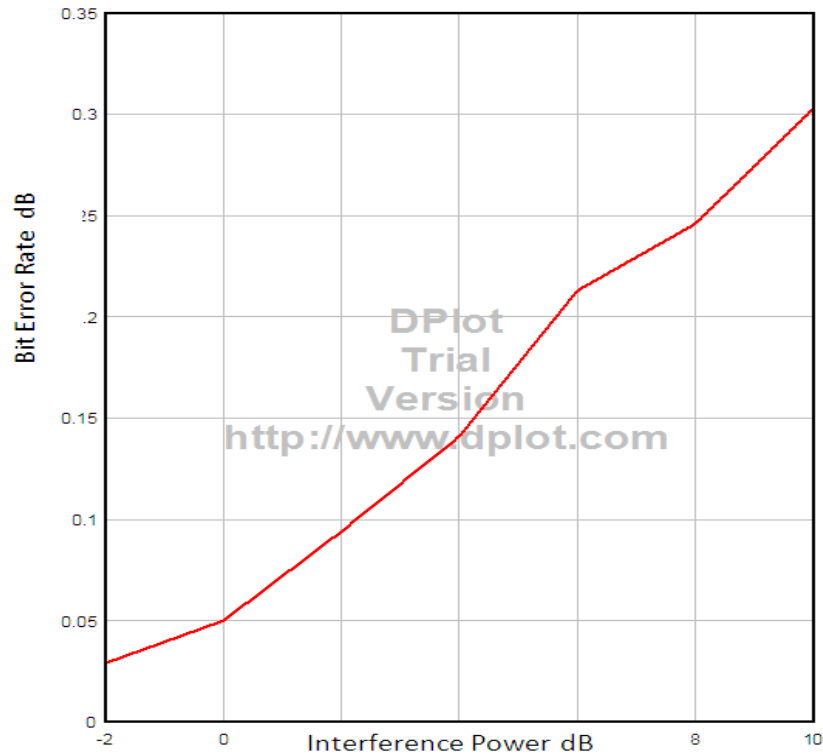| Relative Interference Power (dB)	Bit Error Rate
-2.000	0.029
0.000	0.050
2.000	0.094
4.000	0.141
6.000	0.213
8.000	0.246
10.000	0.303

Figure 4.2 Graph of BER VS Relative Interference Power of IEEE 802.1Ib
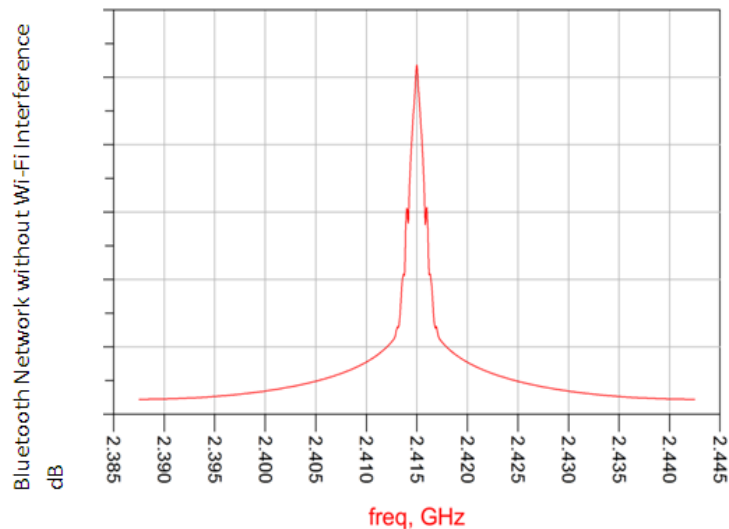

Figure 4.3 Graph of Bluetooth Network without Wi-Fi Interference

Simulation result of the Bluetooth network`s BER used by IEEE802.11b relative interference power is depicted in the figure 4.2. The plot in Figure 4.2 shows the relationship of Bluetooth network's BER when relative interference power of IEEE802.11b with Bluetooth transmitting power increases. In this dissertation, the relative interfering power of IEEE 802.11b compared to Bluetooth transmitting power varies from -2dB to 10dB. This plot clearly shows that when relative interference power increases, the BER of the Bluetooth network will increase. This shows that increasing of IEEE802.11b interfering signal power causes the BER of the Bluetooth to increase and consequently degrade the performance of the Bluetooth network. As default, when the center frequency of the Bluetooth signal and the IEEE 802.11b signal is (RF Offset = 0.0 MHz), the BER of the Bluetooth network is significantly high and that is not acceptable in the transmission of Bluetooth data packet over the networks. Generally, the threshold between acceptable and unacceptable performance is chosen to be a Bluetooth raw BER of 0.001 which will be used later to calculate the Packet Error Rate (PER) using Mathematical model. The 0.001 BER of Bluetooth network is considered allowable in data transmission

of Bluetooth network. However, figure 4.3 shows the graph of Bluetooth Network without the interference which only showed the spreading of the Bluetooth spectrum because it acts singly and hence no performance degradation occurred on the network.

4.3.2 Effect of Interference Power on Delay of Bluetooth Network
Table 4.2 shows the data obtained after the simulation for the delay and relative power of IEEE802.11b with Bluetooth transmitting power. The data is plotted in figure 4.4.

Table 4.2 Relative Interference Power (dB) of IEEE802.11b and Delay

Relative Interference Power (dB)	Delay
-8.000	2.000
-6.000	2.000
-4.000	2.000
-2.000	2.000
0.000	2.000
2.000	2.200
4.000	2.200

Simulation result of a Bluetooth network's BER parameterize IEEE802.
Figure 4.4 shows relationship between the Delay and the relative interference powe graph shows that when the relative interference power increases, from -8dB the delay does not
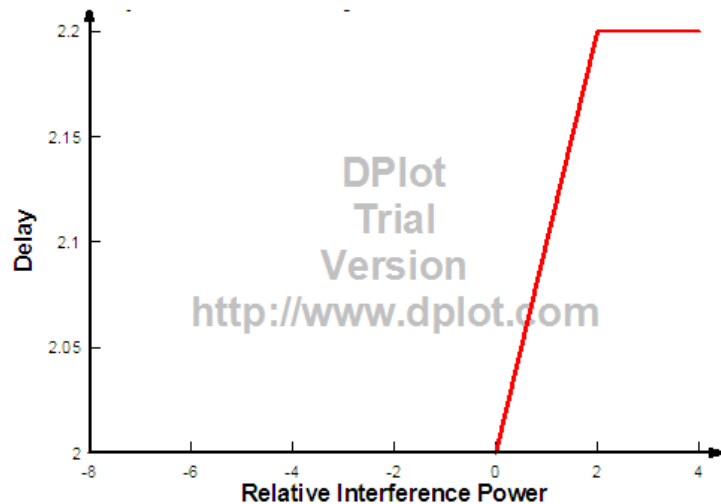

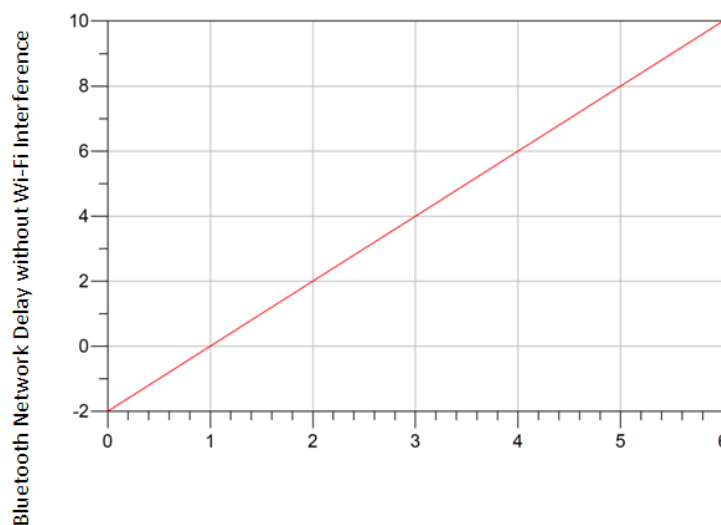**Figure 4.4**   Graph of Delay VS Relative Interference Power of IEEE 802.1Ib

Figure 4.5   Graph of Bluetooth Network Delay without Wi-Fi Interference

Figure 4.4 shows relationship between the delay and the relative interference power. The graph shows that when the relative interference power increases, from -8dB the delay does not change, that is, it is constant at 2. However, at 2dB relative interference power the delay increases. At 4dB interference power also, the delay remains constant at 2.

For reliable communication, the attenuation (Relative Interference Power) and Delay over the range of frequencies of transmission should be constant. This was obeyed at the beginning i.e. from -8dB to 0dB. However, as relative interference power continue to iincrease , the delay changes because of high interference which eventually causes the Bluetooth performance degradation. But because of the absence of the interference in figure 4.5, the Bluetooth transmitting power shows increase without any degradation as a straight line

V.   Summary, Conclusion And Recommendation

Summary

In summary of this study, a schematic for performance analysis of the Bluetooth network in the presence of the interfering IEEE 802.1Ib radio transmissions has been developed. This schematic design can be used to capture the performance impact of Bluetooth packet reception with the interference of the IEEE 802.1Ib signal when these two technologies collocated in the same area. The relationship of Bluetooth network's BER and the IEEE 802.11 b interfering power and frequency offset have also been determined in the dissertation. With regards to interference analysis between the Bluetooth System and IEEE 802.1Ib system, the dissertation can also be extended on simulation and performance analysis of the impact of the Bluetooth transmission on the IEEE 802.1Ib network which operates also in the same 2.4 GHz ISM band.

Conclusion

The result of the study determined that when Bluetooth WPAN and IEEE 802.11b WLAN co-exist in the same location, the Bluetooth transmitter must have sufficient high of transmission power relatively to IEEE 802.11b transmission power so that the Bluetooth networks do not suffer network failure or severe error in data reception. However, since the Bluetooth has very low transmission power, approximately 1 mW for the operation over distance of up to 10m, compared to IEEE 802.1Ib WLAN which has 100mW of transmission power for operation within the range of 100m, therefore, the Bluetooth PAN must be located far enough from IEEE 802.1Ib WLAN environment so that the interference signal not degrade the Bluetooth network performance seriously.

Recommendation

To further improve the estimation of the Bluetooth network performance with the presence of the IEEE 802.11b WLAN system, the following recommendations are given so that they can be used for future improvement ;
Distance between the collocating of Bluetooth and IEEE 802.11b

The simulation does not include the distance between the Bluetooth network and IEEE802.11b. Distance plays an important role in wireless transmission. The most essential components of the wireless data transmission such as path loss   and noise will have impact on the receiving signal strength on Bluetooth receiver. Hence, measurement should be done in order to include the impact of these components on Bluetooth network performance with the interference from IEEE 802.1lb system so that better estimation can be made when these two technologies collocated in the same location.

References

[1].   Howitt, I. (2001). WLAN and WPAN Coexistence in UL Band. Transactions on Vehicular Technology, vol. 50, pp. 1114-1124.
[2].   Dari, T. & Pramoid, V. (2005). Fundamentals of Wireless Communication. Cambridge, MA: Cambridge University Press, Second Edition.
[3].   Golmie, N. & Mouveaux, F. (2001). Interference in the 2.4 GHz ISM band. Impact on the Bluetooth access control performance, vol. 8, pp.2540–2545.
[4].   Simon, M. K. & Alouini, M. S. (2000). Digital Communication over Fading Channels. New York: Wiley, First Edition.
[5].   Fainberg, M. & Goodman, D. (2001). Analysis of the interference between IEEE802.11b and Bluetooth systems. IEEE Vehicular Techn. vol.2, pp.967– 971.
[6].   Proakis, J. G. (2001). Digital Communications. New York: McGraw Hill, Fourth Edition.
[7].   Golmie, N. ,Van Dyck, R.E. & Soltanian, A. (2001). Interference of Bluetooth and IEEE802.11. simulation modeling and performance evaluation. Modeling, Analysis, and Simulation of Wireless and Mobile Systems, Rome, Italy.
[8].   Bluetooth Special Interest Group, http://www.bluetooth.com/Bluetooth/Technology, (visited on 12th October, 2011).
[9].   http://eesof.tm.agilent.com/news/wireless_networking.html, Wireless Networking   Design , October 17, 2001, (downloaded on 23rd February, 2012   )
[10].   Stahl, W., Zurbes, S., Matheus, K. & Haartsen, J. (2000). Radio network performance of Bluetooth, vol.3, New Orleans, LA, pp. 1563–1567.
[11].   Haartsen, J.C. (2000). The Bluetooth radio system. IEEE Personal Communication, vol. 7, pp 28-36.
[12].   Halford, S. , Halford, K., Webster, M. & Andren, C. (1999). Complementary code keying for rake-based indoor wireless communication. Circuits and Systems, vol.4, pp. 427–430.

[13]. Chiasserini, C.F. & Rao, R.R. (2000). Performance of IEEE802.11 WLANs in Bluetooth environment. Wireless Communications and Networking, vol.1, pp.94– 99.

[14]. Goodman, D. J. (1997). Wireless Personal Communications Systems. Addison Wesley, Sixth edition.

[15]. Specification of the Bluetooth System. Core, Version 1.0 B. Available: http://www.bluetooth.com, (downloaded on 10th August,2011)

[16]. Jeruchim, M. C., Balaban, P. & Shanmungan, K. S. (2000). Simulation of Communication Systems. Kluwer Academic/Plenum Publishing, Second edition.

[17]. Agilent EEs of EDA home page. (http://www.agilent.com/find/eesof), (visited on 2nd April, 2011).

[18]. Read, R. (1998). The Essence of Communications Theory. Prentice Hall, Third Edition.

[19]. Soltanian, A. & Van Dyck, R.E. (2001). Performance of the Bluetooth system in fading dispersive channels and interference. IEEE Global Telecommunications, vol.6, San Antonio, TX, pp.3499–3503.

[20]. Jakes, W.C. (1974). Microwave Mobile Communications. New York: Wiley.

[21]. Lansford, J., Stephens, A. & Nevo, R. (2001). Wi-Fi (802.11b) and Bluetooth.Enabling coexistence, vol. 15, pp. 20–27.

[22]. Pedersen, G. F. & Eggers, O. (2000). Inital investigations of the Bluetooth link. IEE Vehicular Technology, vol.1, Tokyo, pp. 64–69.

[23]. Graham, R.L., Knuth, D. E. & Patashnik, O. (2000). Concrete Mathematics. Reading, MA: Addison-Wesley, Second Edition.

[24]. Chiasserini, C.F. & Rao, R. R. (2002). Coexistence mechanisms for interference Mitigation between IEEE 802.11 WLANs and Bluetooth, Computer and Communications Societies, vol.2, New York, pp. 590–598.

[25]. Zyren, J. (1999). Reliability of IEEE802.11 WLANs in Presence of Bluetooth Radios. Santa Rosa, California: IEEE Press 802.15-99/073r0.

[26]. Chow, J. & Beaulieu, N. C. (2000). Analysis of cochannel interference in angle modulation Systems. Computers and Signal Processing, vol.1, pp. 123–127.