PERFORMANCE ANALYSIS IN COEXISTENCE OF ZIGBEE WITH IEEE 802.11b in 2.4 GHz ISM BAND

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Abstract—IEEE 802.11 and IEEE 802.15.4 are two of the main standards for wireless communications and networking in the unlicensed 2.4GHz ISM band. IEEE 802.15.4 ZigBee standard and IEEE 802.11b/g Wireless Local Area Networks are often collocated, causing coexistence. Coexistence of devices functioning on these standards is important in scenarios such as wireless body area networks .In this paper, a framework that focus on analysing the interference of 802.11b WLAN to ZigBee with respect to the Bit Error Rate (BER) of ZigBee transmission. An interference model is made and BER in these environments is exploited. The model involves parameters like ZigBee and WLAN channel choice Channel type and Channel noise. This paper presents the performance degradation analysis in the ZigBee due to the presence of IEEE 802.11b interference at the 2.4GHz ISM band.

Keywords—ISM Band, Coexistence, WiFi, ZigBee, Interference, Bit Error Rate.

I. INTRODUCTION

In recent years, wireless communication technologies have been developed very fast. Besides our familiar WiFi, Bluetooth, many new technologies such as ZigBee, NFC (Near Field Communication) appeared. But the sequent problem is the unlicensed 2.4GHz (2.4~2.483GHz) ISM (Industrial Scientific Medical) band which is almost global availability becomes crowded. Therefore, the interference issue occurs immediately following a lot of wireless devices sharing the same 2.4GHz frequency band. Due to its worldwide availability, the 2.4GHz ISM unlicensed band constitutes a popular frequency band appropriate for the low cost radios. WPANs such as IEEE 802.15.4 and Bluetooth devices are operated in the 2.4GHz ISM band, while IEEE 802.11 has standards for Wireless Local Area Networks and microwave ovens operating in this band. Therefore, it is predictable that some interference will result from all these technologies working in the same environment and frequency space. IEEE 802.11b/g WLAN (Wireless Local Area Network), Bluetooth, ZigBee, cordless telephone and microwave oven utilize the 2.4GHz band. The study on how these technologies impact each other and their performance in the coexistence environment is important and interesting.

WiFi and ZigBee share the same 2.4 GHZ frequency band. Such technologies usually operate in proximity and have to co-exist with each other. WiFi uses same frequency band that is used by ZigBee but uses higher power level compared with ZigBee. The characteristics of both differ greatly resulting in asymmetric coexistence problem. The output power of 802.15.4 device is as low as 0dBm where as the output power of 802.11 devices is 15dBm or above. When both are used together ZigBee yield a smaller spatial footprint and hence less visible to WiFi. So ZigBee presence is not sensed by WiFi and can lead to collision. The sensing slot for 802.11 networks is 20μs while 802.15.4 sensing slot is 320μs. When ZigBee and WiFi use the channel at the same time, interference problem appears which causes loss of data being transmitted. This will result in retransmission in both ZigBee and WiFi until successful transmission is achieved [3]. This causes delay and mitigation in delivery ratio for both technologies. Moreover ZigBee need to wait longer to get free medium for transmission and with expected packet loss and retransmission faster draining of sensor battery is expected [5]. Interference between WiFi and ZigBee has been extensively studied in both industry and research communities. Under light WiFi traffic, ZigBee suffer less from collision with WiFi and can recover loss via retransmission. However, under moderate to high WiFi traffic, ZigBee performance is severely degraded [7]. With the proliferation of WiFi devices and high-rate applications, the amount of WiFi traffic in a typical home or enterprise environment will keep increasing, thus severely affecting the reliability of ZigBee WPANs for monitoring and control applications. On the other hand, ZigBee seldom interferes with WiFi since it targets low duty-cycle applications with low channel occupancy. Moreover, WiFi has higher transmission power, which forces ZigBee nodes to back off, and can dominate the ZigBee interference. Especially, ZigBee as a really new short distance wireless communication technology which is targeted at low data rate, low power consumption radio frequency applications has potential of developing. Thus, the interference problem between ZigBee and the most prevalent wireless technology WLAN attracts more and more attention.

II. RELATED STUDY

Coexistence in unlicensed frequency bands is not a new problem in radio communication field. Many studies have done various works to explore the coexistence with different motivations. IEEE standard 802.15.2 [15] specifies the coexistence of wireless personal area networks (WPAN) with other wireless devices which operating in unlicensed frequency bands. It introduced coexistence mechanisms that are recommended use to facilitate coexistence of wireless local area network (WLAN) and WPAN.

Jin Shyan Lee et al. [3] have presented a comparison for four different protocol standards (Bluetooth, ultra-wideband, ZigBee and WiFi) for short range wireless communications with low power consumption. From an application point of view, Bluetooth is intended for a cordless mouse, keyboard, and hands-free headset, UWB is oriented to high bandwidth multimedia links, ZigBee is designed for reliable wirelessly networked monitoring and control networks, while WiFi is directed at computer-to-computer connections as an extension or substitution of cabled networks. He also proposed a study of these popular wireless communication standards, evaluating their main features and behaviors in terms of various metrics, including the transmission time, data coding efficiency, complexity, and power consumption. He believed that the comparison presented in this paper would benefit application engineers in selecting an appropriate protocol.

IEEE 802.15.4 [10] introduces BER of ZigBee network transmission based on its modulation type, spread and de-spread mechanism. And build a propagation model to estimate the PER. This is the most typical way to analyze interference from WLAN to WPAN and vice versa, many afterwards studies are based on this method.

Soo Young Shin et al. [16] describes a study on PER analysis of ZigBee under WLAN and Bluetooth interferences. An analytic model for the coexistence among ZigBee, WLAN and Bluetooth is built to evaluate the performance of IEEE 802.15.4 ZigBee respectively under the interference of IEEE 802.11b WLAN, Bluetooth or both.

Hong Seong Park et al. [17] explores mutual interference of IEEE802.15.4 and IEEE 802.11b, evaluates their performance under each other's interference. The performance evaluation includes PER, transmission delay, and throughput. This paper constructs network with fixed desired sender and receiver, by change amount of interfering sender and receiver, in order to achieve different volumes of interference strength. Besides the references we mentioned before, as a well known WPAN device, Bluetooth is also a typical study object under this topic.

Z-wave alliance [19] references the introduction in IEEE 802.15.4, and use four IEEE 802.15.4 devices with power amplifiers test these devices performance under WLAN interference. The test selects three IEEE802.15.4 channels for ZigBee transmission with 2MHz, 13MHz and 23MHz offsets from WLAN centre frequency, this means they are in, close to and away from the WLAN channel (North American standard).

Cooperative carrier signaling [20] enables coexistence of ZigBee and WiFi. Here a separate node called signaler is used Signaler have higher power than normal ZigBee transmitter. So WiFi can detect ZigBee transmitter's presence by detecting busy tone. The busy tone persists throughout the data and acknowledgement round trip. The main difficulty of CCS is that signalers busy tone should occur concurrently with data transmission. To overcome this difficulty a temporal channel hopping mechanism is used.

Zahir Aalam et al. [22] used PER, Link Quality Indicator (LQI), and energy detection mechanisms to detect the presence of significant levels of interference within the current channel. Once interference is detected, the coordinator instructs all the routers to perform energy detection scan on channels and then the measurement report's is sent to the coordinator. The coordinator selects the channel with the low noise levels and then requests all nodes in the PAN to migrate to this channel. In order to reduce the detection time and power consumption, we divide all ZigBee channels into three classes based on offset frequency. The energy detection scan will be performed from high priority class to low priority class to quickly identify the channel with acceptable interference level. The real implementation shows that the proposed frequency-agility based algorithm is simple but efficient, fast, and practical.

ZigBee Alliance [23] references many real ZigBee products as examples that explain ZigBee devices can performance well in realistic environment with real data traffic coexist. In the paper, 802.11b/g, Bluetooth, 2.4 GHz frequency hopping spread spectrum portable phones and numerous proprietary wireless technologies are working in one environment are specified as a realistic environment.

III. ZIGBEE/IEEE 802.15.4 AND WIFI/IEEE 802.11B OVERVIEW

A. ZigBee/IEEE 802.15.4

IEEE 802.15.4 defines the Physical Layer (PHY) and Medium Access Control (MAC) of ZigBee, while the ZigBee Alliance defines the network and application layers. The 802.15.4 standard specifies operation in the ISM 2.4 GHz, 915 MHz and 868 MHz bands and two PHY options with both adopting direct sequence spread spectrum (DSSS). The basic channel access mode employs "carrier sense, multiple access with collision avoidance" (CSMA/CA). There are 16 ZigBee channels in the 2.4 GHz band, with each channel occupying 5 MHz of bandwidth. The maximum output power of the radios is generally 0 dBm and receiver sensitivities are -85dBm for 2.4 GHz and-92 dBm for 868/915 MHz. It uses binary phase shift keying (BPSK) modulation for both 868 and 915 MHz bands, and Offset Quadrature Phase Shift keying (OQPSK) modulation for 2.4 GHz band. Transmission range is between 1 and 100 m, heavily dependent on the deployment environment [18].

IEEE 802.15.4 supports both beacon-enabled and non-beacon-enabled communication. In a non-beacon-enabled network, a device simply transmits its data frames using un-slotted CSMA/CA to the coordinator.

In beacon-enabled network, the device uses the network beacon to identify available data transmit intervals. ZigBee devices can be classified into two major categories, full function devices (FFDs) and reduced function Devices. FFDs can perform network establishment, routing and management, while RFDs only support a subset of the ZigBee device functions, making them simple and low cost.

A ZigBee network usually consists of a ZigBee Coordinator, one or more ZigBee Routers, and multiple End Devices. A FFD can serve any of the three roles, while end devices tend to be RFDs. The ZigBee Coordinator is responsible for network setup and management. ZigBee Routers are used to route traffic between the network coordinator and end devices. Routers and coordinators can communicate with all the devices on the network, usually powered by main power supplies since they cannot go to sleep without adversely affecting the ability to route traffic through the network. End devices communicate with routers, incapable of peer to peer communication. They tend to be battery powered devices and spend most of their time in sleep mode. They periodically wake up, check for any messages buffered for them at their parent router, read their attached sensors, transmit the measured data, and return to sleep mode.

B. *WiFi/IEEE 802.11b*

IEEE 802.11 standard specifies PHY and MAC for WiFi. It defines 11 overlapping 22 MHz wide frequency channels in the ISM 2.4 GHz frequency band. As there are only two groups of three non overlapping channels, one group for channels 1, 6, and 11 is adopted for use in the US while the other group for channels 1, 7, and 13 is utilized in Europe. IEEE 802.11 has several versions, among which IEEE 802.11b has been widely applied in WiFi. IEEE 802.11b has a maximum transmission rate of 11 Mbps and uses the same CSMA/CA media access method defined in the original IEEE 802.11 standard. The 802.11b PHY layer incorporates DSSS modulation. Technically, the 802.11b standard uses Barker coding and Complementary Code Keying (CCK) as its modulation technique. It is the amendment of CCK coding that enables data rate to increase dramatically compared to original standard. Typical indoor range is 100 ft at 11 Mbps and 300 ft at 1 Mbps.

IV. INTERFERENCE ANALYSIS OF ZIGBEE UNDER WLAN

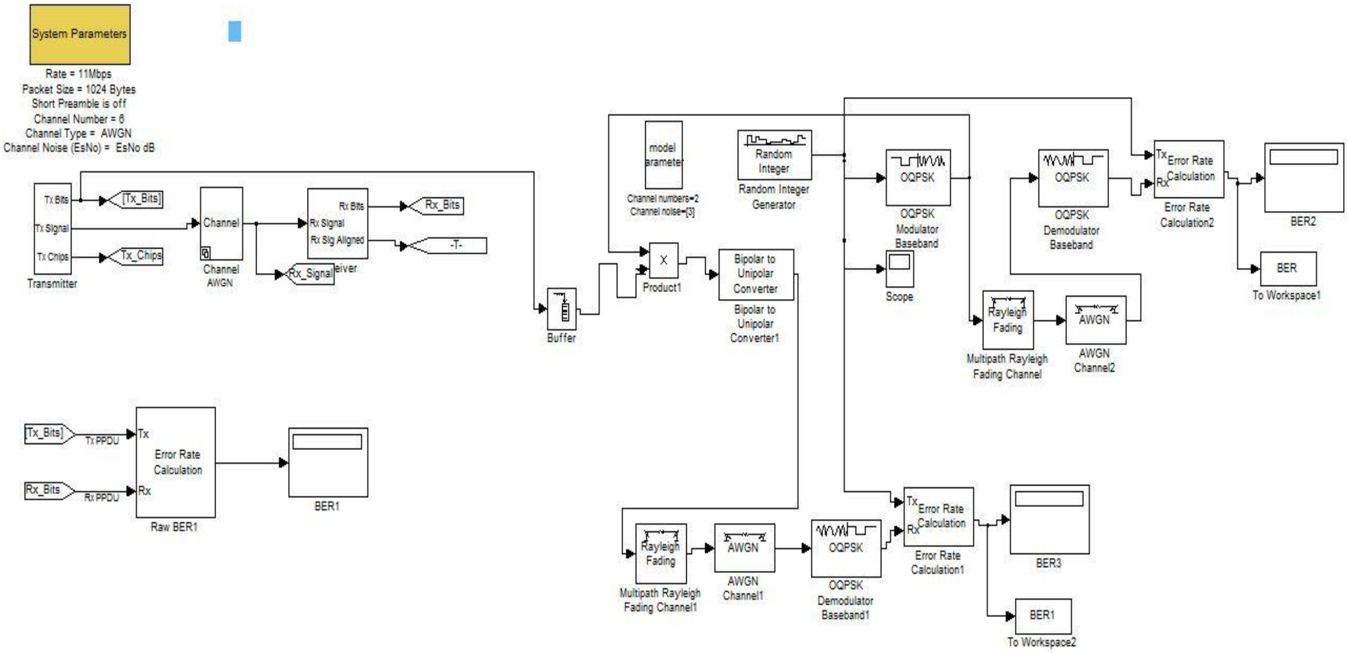

Fig. 1 Integration of ZigBee under WLAN

The integration of ZigBee under WLAN I shown in figure 1.

A. *IEEE 802.15.4 Model*

The generic model includes a transmitter, channel noise and receiver. The following major building blocks: Spreader, OQPSK modulator, De-spreader, OQPSK De- modulator, and Rayleigh channel.

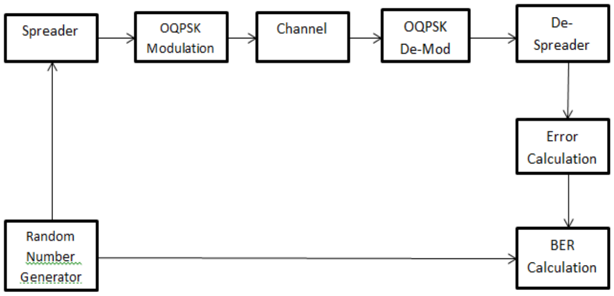

Fig.2 ZigBee Generic Simulink Model

In Figure. 2, the 2.4 GHZ model, a random integer generator block generates a number randomly between 1 and 16. Then, this integer is taken as input to the spreader block, which spreads it into 32 bits as defined by the ZigBee standard. Following that, the 32-bit-stream is taken as an input to the OQPSK modulation block. Modulated signal is passed through channel then passed to the OQPSK demodulation block before being de-spread. The received 32 Bits are sent to the despreader which converts them back to an integer. Then, the integer-to-bit converter converts the received integer to a 4- bit-stream. Finally, the 4- bit stream is compared with the original one and the BER is calculated.

B. *IEEE 802.11b Model*

The model implements IEEE802.11b PHY. It comprises of mainly three blocks transmitter, channel and receiver.Here, transmitter consists of the input signal. The integer data are transferred into the bit format. These bits are given to the PLCP Header portion of the transmitter part of WiFi model which consists of the Preamble bits and PLCP Header bits which comprises of Signal, Size, Length and CRC Header bits. Then output of this sub-block is given to the modulator block. The pulse sampling filter is used along with up sampling of modulated bits at central frequency.

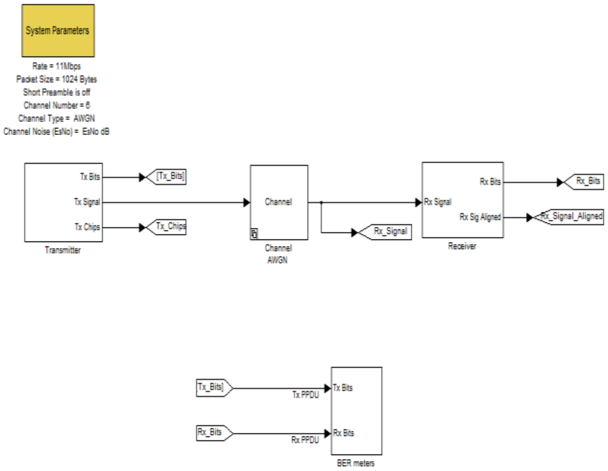

Fig.3 Simulink model of IEEE 802.11b

The integer to bit converter is used to convert the incoming data into bits. Here, input data is integer values that represent the transmitted speech signal. The output of integer to bit converter block is given to the framing block is shown in Figure 3.

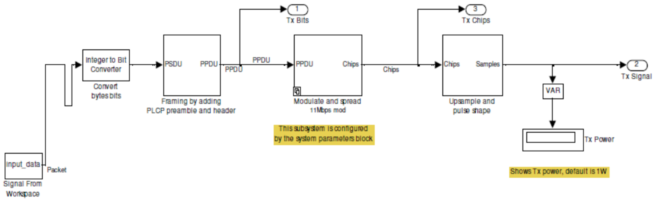

Fig.4 Transmitter block of IEEE 802.11b

In Figure 4, the framing is needed to add PLCP preamble, PLCP Header and PSDU bits. It is known that these PLCP preamble and PLCP Header and PSDU bits are used for synchronization, error correction code bits and length of the packets and it is also useful to detect end of the packets. The outcome from above is known as PPDU. This PPDU is transmitted to next block for further processing. After that, based on data rates (1Mbps, 2Mbps, 5.5Mbps and11Mbps) modulation scheme and code length has been decided.

For the 1Mbps data rate both PLCP bits and PSDU bits are processed in combination. Barker symbol is used to represent one bit. Similarly, in case of 2Mbps data rate, whole PSDU bits are divided in PLCP header and PSDU bits. Both are modulated separately and then barker coding is done. In case of increased data rates of 5.5 and 11 Mbps, CCK is used to encode 4 bits per carrier. Both PLCP and PSDU are also operated separately. QPSK (Quadrature Phase Shift Keying) is used for modulation purpose.

The modulated output is given to the pulse shaping filter for the purpose of filtering and sampling. The pulse shaping filter consists of a RRC (Root Raised Cosine) with roll-off factor of 0.3.After that, all these samples are transmitted to the receiver side through wireless fading channel.

The Channel Block Consists of the three fading channels such as Additive White Gaussian Noise, Multipath Rayleigh Fading channel and Multipath Rician Fading Channel. Any one of these channels could be selected for the error performance analysis of the transmission of the input signal through IEEE802.11b WiFi model. AWGN channel is used.

Now, all these transmitted data are received at the Receiver front end which is consisting of pulse shaping filter of the same RRC roll of factor that has been used at the transmitter side of 0.3 values.

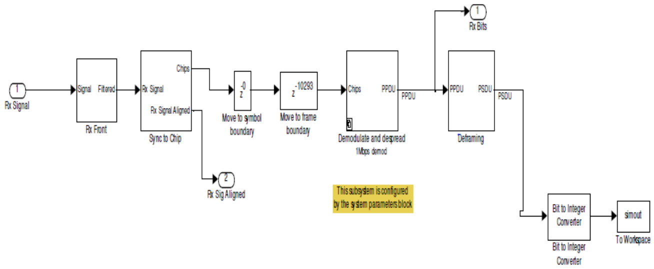

Fig.5 Receiver of IEEE 802.11b

Output of this Receiver front end is given to the Synchronization Chip. This block is used to synchronize received samples with transmitted samples. These synchronized samples are demodulated and de-framed is shown in Figure 5. Then outcome of de-framing block is in binary or bit form. These are converted into the integer form using bit to integer converter. The outcome of de-framing block is given to the BER meter where Transmitter bits and Receiver bits are compared in order to generate the error performance.

At first received bits are given for down sampling to the central frequency than it is given to the Receiver pulse shaping filter. After that it is given to the demodulator of PSK modulation scheme. Then the PLCP de-framing and received bits are converted into the integer form.

V. BER ANALYSIS

This section provides a graphical representation of individual BER analysis of ZigBee, and WiFi technologies. The BER is obtained from the signal to interference noise ratio (SINR). In this paper Symbol Energy to Noise density (E_s/N_o) is used.

As the name implies, a Bit error rate is defined as the rate at which errors occur in a transmission system. This can be directly translated into the number of errors that occur in a string of a stated number of bits. BER is equal to Number of Bits in Error divided by Total Number of Bits sent.

In order to compare the effects of noise on different digital modulation employed by WiFi and ZigBee, characterize the SNR as a function of energy transmitted per bit or symbol. SNR = E_s/N_o, where Es represent the energy per transmitted symbol (expressed in watts), No is the Noise added by channel defined in terms of Power spectral density (in W/Hz).

A. BER Analysis for WiFi

The graph of BER v/s Es/No for WiFi technology is due to the following scenario. This IEEE 802.11b Simulink model provides data rates of 2, 5.5, 11Mbps. It provides 2 Mbps by Differential Quaternary Phase Shift Keying (DQPSK) modulation with DSSS using an 11 chip Barker code.

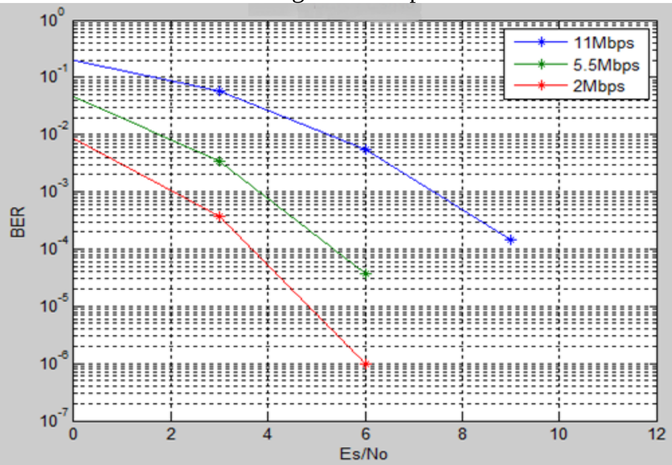

Fig.6 BER for IEEE 802.11b Modes

For 5.5 Mbps and 11Mbps CCK modulation and DSSS using an 8-chip long Walsh codes are used. Figure 6 shows the Bit Error Rate graph for IEEE 802.11b having Data rate of 2 Mbps, 5.5 Mbps and 11 Mbps.

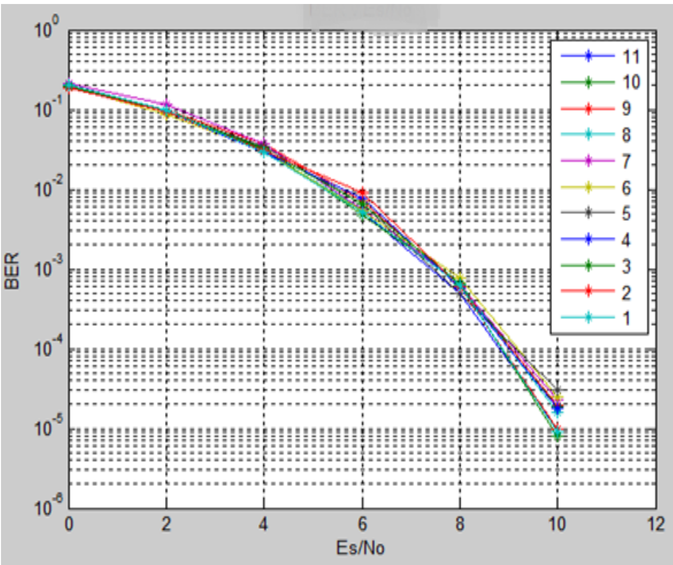

Fig.7 BER for IEEE 802.11b

Figure 7 shows the Bit Error Rate graph for each channels present in the IEEE 802.11b.

B. BER Analysis for ZigBee

The BER v/s E_b/N_o graphs in figure 7 is a result of following scenario. The ZigBee Simulink model uses OQPSK technique for modulation as well as de-modulation. In this channel White Gaussian noise is added to the transmitted signal when AWGN channel is used because the average noise power in all channels is zero. The data rate provided is 250kbps. Bandwidth for ZigBee signal is maintained at 5 MHz but most of the energy of IEEE 802.15.4 is within 2MHz.Rayleigh channel is used and it is compared with AWGN.

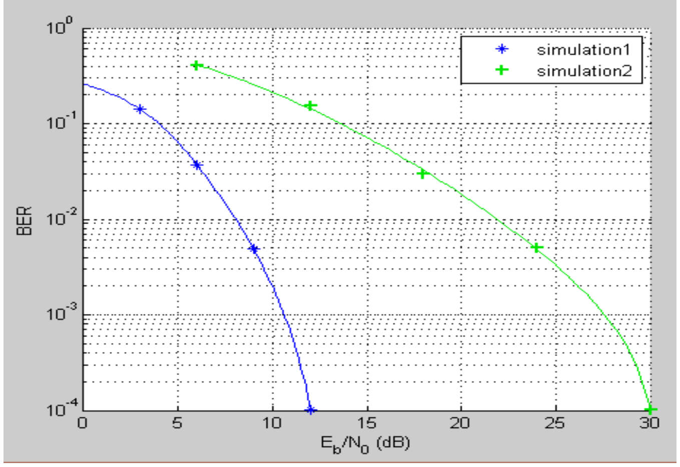

Fig.8 BER of ZigBee model

In Figure 8, simulation1 and simulation2 indicates the use of AWGN channel and Rayleigh channel.

C. BER for ZigBee under IEEE 802.11b Interference

Except for a few channels that are far away from the WiFi central frequency, most of channels overlapped with the WiFi channels have 2 MHz, 3 MHz, 7 MHz, and 8 MHz offsets from the WLAN channel frequency. Therefore simulations are performed in these four scenarios.

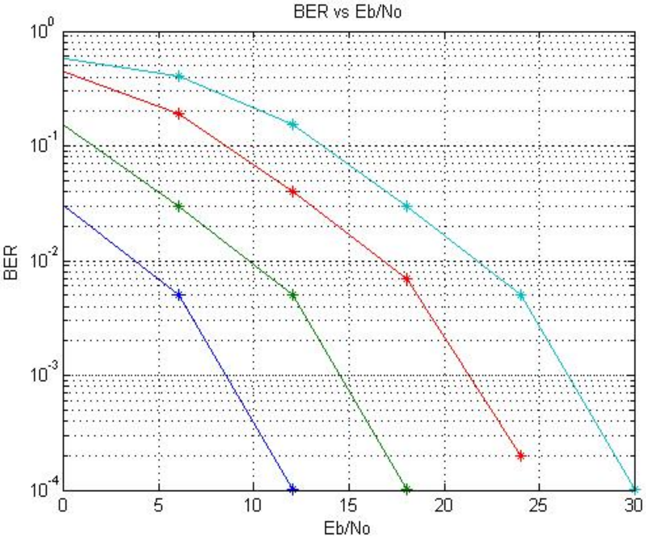

Fig.9 BER of ZigBee based on Offset Frequency

In the figure 8Light Blue line represents the simulated BER of 2 MHz offset channels, Red line represents the simulated BER of 3 MHz offset channels, Green line represents the simulated BER of 7 MHz and The Dark Blue line represents the simulated BER of 8 MHz offset channels between WiFi and ZigBee.

From the figure 9, the BER drop drastically as the offset frequency increases. The graph proves that most interference power is around the central frequency of WiFi so Safe Offset Frequency is a critical parameter, which guides the ZigBee deployment in order to mitigate the WiFi interference.

VI. CONCLUSION

In this paper, ZigBee performance was thoroughly evaluated under WiFi interferences. A simulation model has been introduced which completely reflects the ZigBee and WiFi coexistence features. Both analysis and simulation results show that ZigBee may be severely interfered by WiFi and that a Safe Offset Frequency can be identified to guide ZigBee deployment. The offset frequency 8 MHz is a safe offset frequency in the WiFi coexistence region. ZigBee provides satisfactory performance when the WiFi interference is not significant. In the event of significant WiFi interference, the ZigBee channel with minimum Bit Error Rate is chosen for data transmission.

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