International Journal of Applied Information Systems (IJAIS) – ISSN : 2249-0868
Foundation of Computer Science FCS, New York, USA
International Conference and Workshop on Communication, Computing and Virtualization (ICWCCV 2015) – www.ijais.org

Ber and Per Analysis of IEEE 802.15.4, 802.15.1 and 802.11

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ABSTRACT
2.4 GHz ISM band constitute of many Wireless Personal Area Network (WPAN) technologies such as INSTEON, IrDA, Wireless USB, Bluetooth, Z-Wave, ZigBee, Body Area Network and Wireless Local Area network (WLAN) technologies such as Wi-Fi. Among these vast technologies, Bluetooth, ZigBee and Wi-Fi are the most popular and preferred ones. Now-a-days these technologies are used in industrial as well as medical applications, to mention a few. Therefore performance analysis and improvement of these three technologies needs to be taken care of.

This paper aims at evaluating the performance of these three leading technologies using two different parameters such as Bit Error Rate (BER) and Packet Error Rate (PER). When data is transmitted over a data link, there is a possibility of errors being introduced into the system. If errors are introduced into the data, then the integrity of the system may be compromised. As a result, it is necessary to assess the performance of the system, for which BER and PER provides an ideal way to achieve it. The BER and PER curves are plot against Signal-to-Noise Ratio (Es/No) for AWGN channels. The result highlights that when Signal-to-Noise ratio increases, BER and PER of the above mentioned technologies decreases. Also, the most preferred technology in WPAN i.e. ZigBee is having very low BER as compared to other technologies. The evaluation is performed using Simulink tool.

General Terms
Wireless, Performance, Parameters, Analysis.

Keywords
ISM Band, Bluetooth, Wi- Fi, ZigBee, Interference, PER, BER, Es/No.

1. INTRODUCTION
Wireless Communication is the fastest growing section of communication it has captured the world. Many applications including wireless sensor network, automated highways, factories smart homes and appliances and remote telemedicine have emerged from ideas to reality [1]. Recent advances in sensor integration and electronic miniaturization are making it possible to produce sensing with significant processing memory and wireless communication capabilities to create smart environments where scattered sensors could coordinate to a communication network. These wearable computing devices and ad-hoc smart environments impose unique requirements on the communication protocol design such as low power consumption, frequent make and break connections, resource discovery and utilization and have created the need for Wireless Personal Area Net-works (WPANs) [2].This is in contrast to Wireless Local Area Networks (WLANs) that typically cover a moderately sized geographic area such as a single building, or campus.

WLANs operate in the 100 meter range and are intended to augment rather than replace traditional wired LANs. They are often used to provide the final few feet of connectivity between the main network and the user. Users can plug into the network without having to look for a place to link their computer, or having to install expensive components and wiring [2].

A WPAN is a wireless ad hoc data communications system that allows a number of independent devices to communicate. WPAN is distinguished from other types of wireless networks in both size and scope. Communications in WPAN are normally confined to a person or object and extend up to 10 meters in all directions [2].

Due to its worldwide availability, the 2.4GHz Industry Scientific and Medical (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 [3].

This paper elaborates on BER, PER analysis of three ISM Band technologies i.e. ZigBee, Bluetooth and Wi-Fi but primarily focuses on ZigBee. In Section II, we address their overview. Section III describes the ZigBee and Bluetooth Simulink models. Section IV gives Result and Discussion. Section V concludes the paper and Section VI provides the future scope.

2. OVERVIEW
The 2.4 GHz ISM band include frequencies range of 2.4 – 2.4835 GHz. Its worldwide popularity is because of its free and unlicensed usage [4]. It can be used by anyone to transmit information. FCC (Federal Communications Commission) draws boundaries or regulations on the use of band. There are

many devices which share this band. It includes Wi-Fi (IEEE 802.11), Bluetooth (IEEE 802.15.1), ZigBee (IEEE 802.15.4), Wireless USB, Microwave oven, Cordless phones etc. [5] [7].

2.1 ZigBee/ 802.15.4

The IEEE802.15.4 (See Figure 1) [7] is a part of the IEEE family of standards for physical and link layers, the standard is designed to address applications with requirements including low data throughput, low power, short transmitting range and low cost.

The IEEE802.15.4 supports two PHY options based on DSSS (Direct sequence spread spectrum). The 2.4GHz PHY uses Q-QPSK modulation, whereas 780/868/915MHz uses BPSK (binary phase shift keying) modulation .Both of its 2.4GHz and 868/915 MHz can offer good BER (bit error rate) performance at low SNR (signal to Noise Ratio).

The IEEE802.15.4 physical layer offers 31 channels, 4 in 780MHz band for China (IEEE 802.15.4c), 1 in 868MHz band for Europe,10 in 915MHz for North America,16 in the 2.4GHz throughout of the world. The nominal radio data rates on these four frequency bands are 20kbps, 40kbps, and 250kbps [6].

ZigBee over IEEE 802.15.4, defines specifications for low-rate WPAN, provides self-organized, multi-hop, and reliable mesh networking with long battery lifetime. Currently, ZigBee is widely used in WSN and IOT applications.
Because 2.4GHz band is unlicensed RF band throughout the world, this paper mainly focuses on coexistence among

2.4GHz RF products, rather than Sub-GHz RF products, thus Sub-GHz ZigBee products are not studied on in this document [6].

2.2 Wi-Fi/ IEEE 802.11 a/b/g

Wireless fidelity (Wi-Fi) includes IEEE 802.11a/b/g standards for wireless local area networks (WLAN) (See Figure 1) [7], which are commonly used today to provide wireless connectivity in the home, office, and some commercial establishments.

Wi-Fi is a popular technology that allows an electronic device to exchange data wirelessly over a computer network, including high-speed Internet connections. The Wi-Fi Alliance defines Wi-Fi as any "wireless local area network (WLAN) products that are based on the Institute of Electrical and Electronics Engineers' (IEEE) 802.11 standards".

The IEEE 802.11a amendment to the original standard was ratified in 1999. The IEEE 802.11a standard uses the same core protocol as the original standard, operates in 5GHz band, and uses a 52-subcarrier orthogonal frequency-division multiplexing (OFDM) with a maximum raw data rate of 54Mbit/s, which yields realistic net achievable throughput in the mid-20 Mbit/s [6].

The IEEE 802.11b and 802.11g are amendments to the IEEE 802.11 specification that extends throughput from 54Mbit/s to 600Mbit/s using the same 2.4GHz band as 802.11b. The IEEE 802.11b and 802.11g operate in total of 14 channels available in the 2.4GHz band, each with a bandwidth of 22MHz and a channel separation of 5MHz. WLAN output powers are typically around 20dBm and operate within a 100m range [6].

This specification under the marketing name of Wi-Fi has been implemented all over the world.

2.3 Bluetooth/ IEEE 802.15.1

Bluetooth, also known as the IEEE 802.15.1 (See Figure 1) [7] standard, is a RF technology standard for exchanging data over short distances (using short-wavelength radio transmissions in the ISM band from 2400–2480MHz) from fixed and mobile devices, creating personal area networks (PANs) with high levels of security. Bluetooth is created by telecom vendor Ericsson in 1994 [8, 9,10,11,12].

Bluetooth operates in the range of 2400–2480MHz, which is in the globally unlicensed Industrial, Scientific and Medical(ISM) 2.4GHz short-range, radio frequency band. It uses a radio technology called frequency-hopping spread spectrum.
The transmitted data is divided into packets and each packet is transmitted on one of the 79 designated Bluetooth channels in a pseudo-random pattern. Each channel has a bandwidth of 1MHz. The first channel starts at 2402 MHz and continues up to 2480 MHz in 1MHz steps. It usually performs 1600 hops per second, with Adaptive Frequency-Hopping (AFH) enabled [10].

3. SIMULINK MODELS FOR ZIGBEE AND BLUETOOTH

MatLab Simulink is used to perform the simulation and analysis.

3.1 ZigBee Generic Simulink Model Performance evaluation

The generic model (See Figure 2) includes a transmitter , channel noise and receiver. The following major building blocks: Spreader, O- QPSK modulator, De-spreader, O-QPSK De- modulator, and an Additive White Gaussian Noise (AWGN) channel.

For 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. After modulation, noise is added to the modulated stream using the AWGN block [13].

The latter is then passed through the OQPSK demodulation block before being de-spread. The BER of the received data is calculated as follow: The received 32 Bits are sent to the de-spreader 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 and PER is calculated [13].

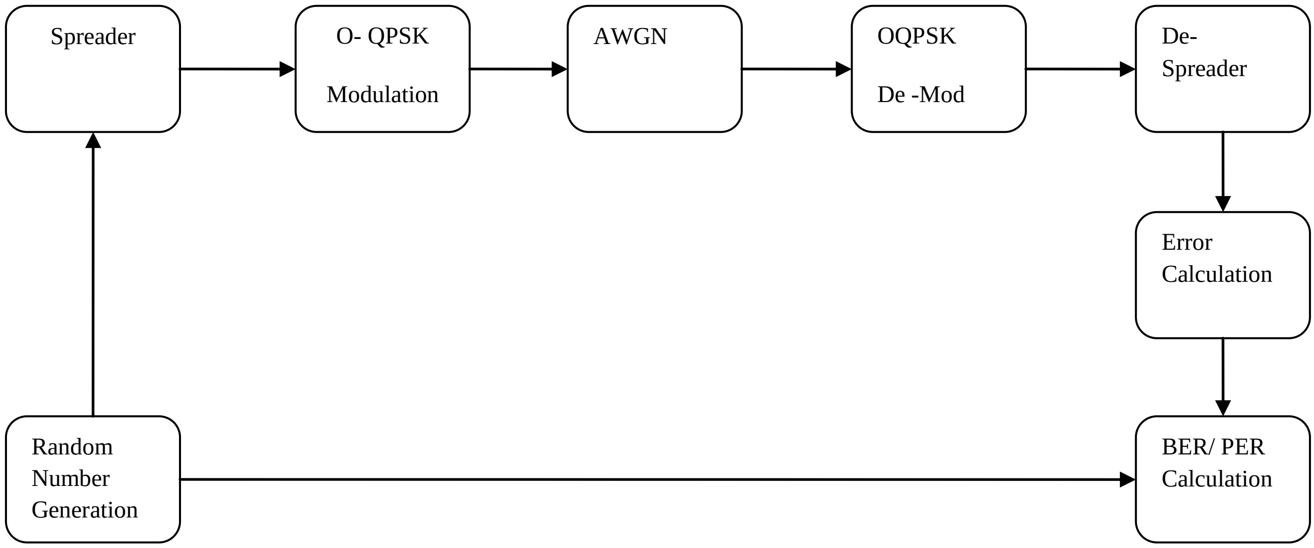

Fig 1: ZigBee Generic Simulink Model

3.2 Bluetooth Generic Simulink Model Performance evaluation

The Bluetooth Simulink model (See Figure 3) includes a Transmitter, Additive White Gaussian Noise (AWGN) channel and a Receiver. The Transmitter of Bluetooth includes Data Source block which generates Random Integers and convert those integers into bits. These bits are given as an input to the Framing block which performs CRC generation and encoding. Transmission bits are generated and given for modulation. Bluetooth performs GFSK modulation. After modulation, AWGN noise is added

These transmitted bits are captured by the Bluetooth Receiver which includes Radio and De-Framing blocks. The received bits from the transmitter and 79 possible hopping carriers are demodulated using Radio block. Later these bits are de-Framed and given for Error rate calculation. The transmitted and the received bits are compared for BER and PER analysis.

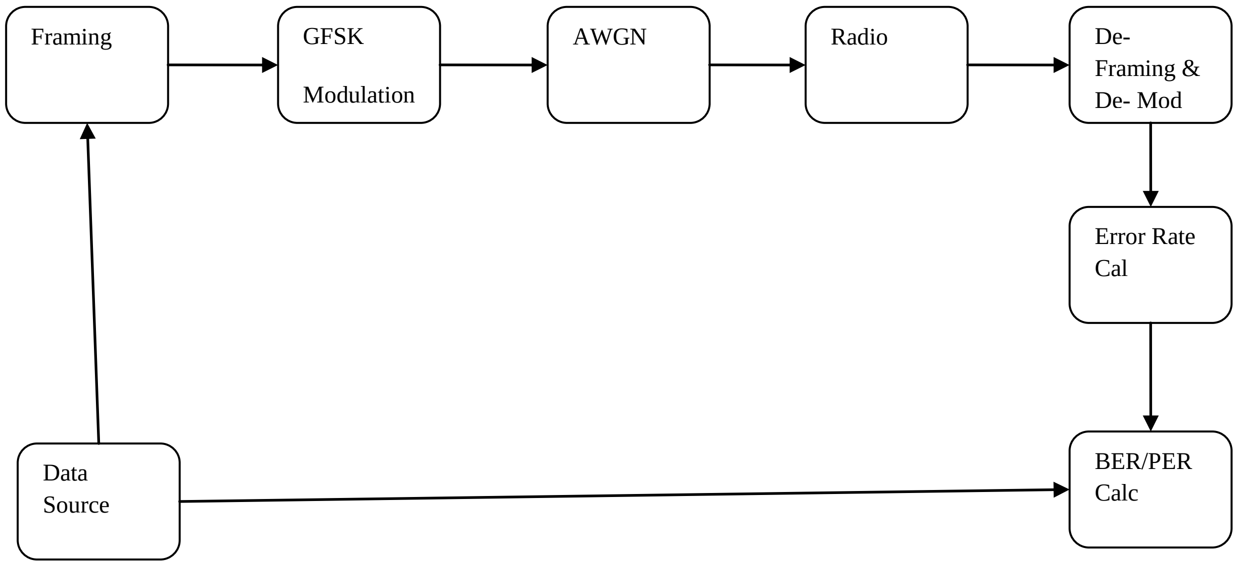

Fig 2: Bluetooth Generic Simulink Model

4 RESULTS AND DISCUSSIONS

This section provides a graphical representation of individual BER and PER analysis of ZigBee, Bluetooth and Wi-Fi technologies . Simulink modeling tool is used for depiction. The PER is obtained from the bit error rate (BER), where the BER is obtained from the signal-to-interference plus-noise ratio (SINR), in our paper Symbol Energy to Noise density (Es/No).

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.

Packet Error Rate is defined as Number of packets in error divided by Total Number of packets sent. We have used the same simulated set of data to derive PER for different Es/ No. where $PER = 1 - (1 - BER)^{N}$) hypothesis is largely used in networking community. A packet is declared incorrect if at least one bit is erroneous.

In order to compare the effects of noise on different digital modulation employed by Bluetooth, Wi- Fi, ZigBee , we characterize the SNR as a function of energy transmitted per bit or symbol.

SNR= Es/ No.B.Ts; where Es & Ts represent the energy per transmitted symbol (expressed in watts) & the symbol transmission period, No is the Noise added by channel defined in terms of Power spectral density (in W/Hz), B is considered as Bandwidth (in Hz) of the signal at the reception.

4.1 BER Analysis.

The BER of wireless technogies depends on the folowing factors:

1) *Interference:* The interference levels present in a system are generally set by external factors and cannot be changed by the system design. However it is possible to set the bandwidth of the system. By reducing the bandwidth the level of interference can be reduced. However reducing the bandwidth limits the data throughput that can be achieved.

2) *Increase transmitter power:* It is also possible to increase the power level of the system so that the power per bit is increased. This has to be balanced against factors including the interference levels to other users and the impact of increasing the power output on the size of the power amplifier and overall power consumption and battery life, etc.

3) *Lower order modulation:* Lower order modulation schemes can be used, but this is at the expense of data throughput.

4) *Reduce bandwidth:* Another approach that can be adopted to reduce the bit error rate is to reduce the bandwidth. Lower levels of noise will be received and therefore the signal to noise ratio will improve. Again this results in a reduction of the data throughput attainable.

It is necessary to balance all the available factors to achieve a satisfactory bit error rate.

4.1.1 BER and PER analysis for Bluetooth

Bluetooth simulink model consist of transmitter, channel and reciever. The output graphs of BER v/s Es/No [See Figure 3] and PER v/s Es/No. (See Figure 4) are a result of following scenario:

Modulation and De- modulation scheme used for Bluetooth system is Binary Gaussian shaped FSK with modulation index h as 0.32 and normalized bandwidth as BT is 0.5 for M=2. Generally, the modulation index for bluetooth lies between 0.28 and 0.35. The choice of this type of modulation is due to bandwidth efficiency, simple and small transreceiver implementation of GFSK system and its characteristic of channel envolop, which is desirable in fading environment. For Demodulation samples per symbol are 100 and frequency deviation is $10^{(6)}$ Hz.

AWGN channel noise is simulated to provide a real environment between transmission and receiver. The input signal power and symbol period provided is 0.1 W and $10^{(-6)}$ s respectively.

Bluetooth radio employs frequency hopping FHSS technique with a frequency of 1600 Hz for 79 channels.

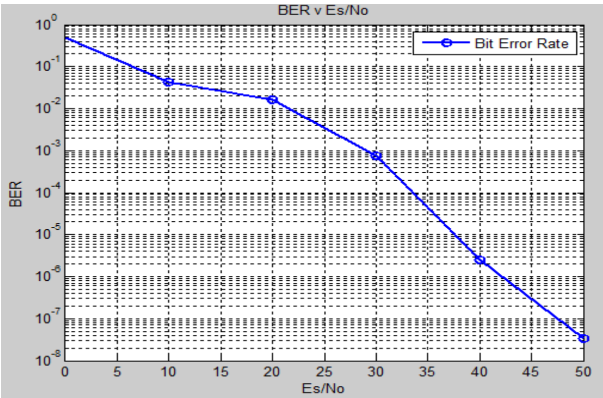

Fig 3: BER v/s Es/No analysis for Bluetooth

It can be seen from the graph that when Es/ No is 50 db BER is $10^{(-8)}$ and PER is $10^{(-7)}$

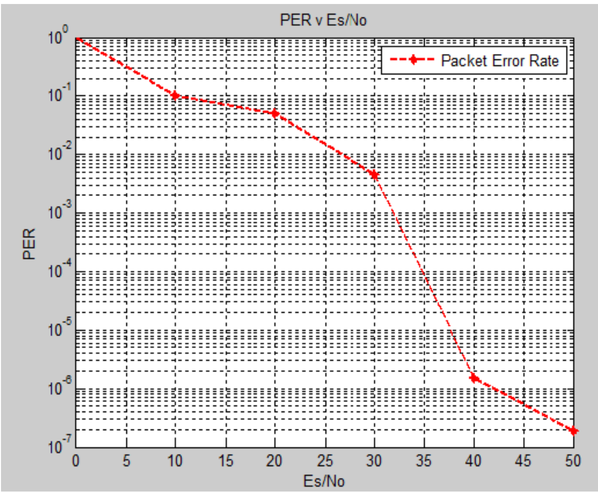

Fig 4: PER v/s Es/No analysis for Bluetooth

4.1.2 BER and PER analysis for Wi-Fi

The graphs of BER v/s Es/No (See Figure 5) and PER vs/ Es/No (See Figure 6) for Wi-Fi technology are due to the following scenario:

This IEEE 802.11b simulink model povides 11 Mbits/sec by differevtial BPSK (DBSK) with DSSS using an 11 chip Barker code, the chip rate is 11 Mchips/sec. The last rate is obtained using Complementary code keying (CCK) also at 11 Mchips/sec. The number of Bits per Interger is 8.

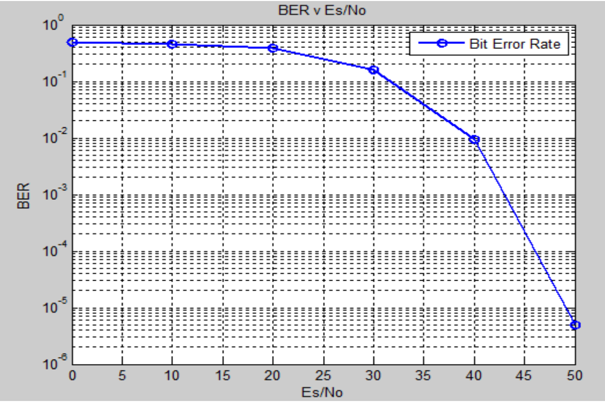

Fig 5: BER v/s Es/No analysis for Wi-Fi 802.11b

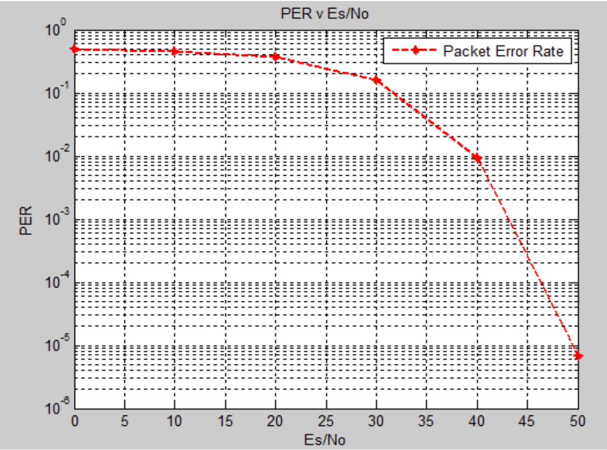

Fig 6: PER v/s Es/No analysis for Wi-Fi 802.11b

As it can be seen from the graphs that when the above mentioned scenario is provided as input to the model the BER and PER of Wi-Fi comes out to be $10^{(-6)}$ for Es/No of 50 db.

4.1.3 BER and PER analysis for ZigBee

The BER v/s Es/No (See Figure 7) and PER v/s Es/No (See Figure 8) is a result of following scenario:

The Zigbee simulink model uses O-QPSK technique for modulation as well as de-modulation. In this channel White Gaussian noise is added to the transmitted signal. Here we choose AWGN channel because the average noise power in all channel is zero. Number of bits per symbol is provided as 2 for input signal power of 0.1 w and symbol period as 4* $10^{(6)}$ s. The data rate provided is 250 kbps. Bandwidth for ZigBee signal is maintained at 5Mhz but most of the energy of IEEE 802.15.4 is within 2 MHz.

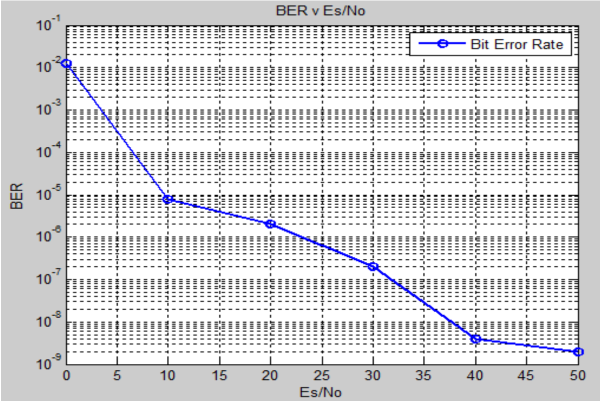

Fig 7: BER v/s Es/No analysis for ZigBee

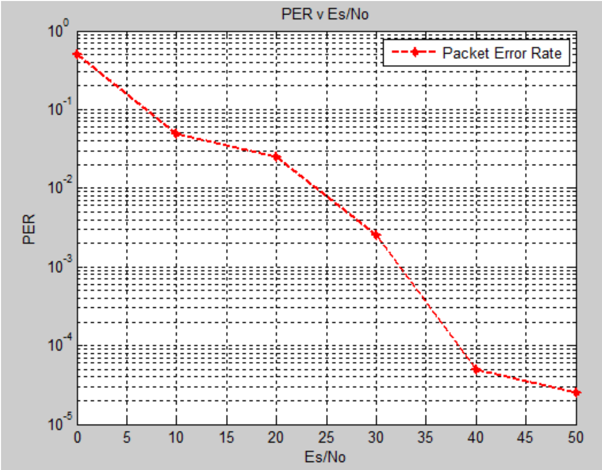

Fig 8: PER v/s Es/No analysis for ZigBee

The graphs depicts that the BER and PER achieved from the above mentioned scenario are $10^{(-9)}$ and $10^{(-5)}$ respectively for Es/No of 50 db.

5. CONCLUSION

In this paper, we have taken into consideration three popular 2.4 GHz ISM band technologies i.e. ZigBee, Bluetooth, Wi-Fi. We have simulated ZigBee (IEEE 802.15.4) and Bluetooth (IEEE 802.15.1) models using MatLab Simulink tool. From these models we have plot BER and PER graphs. We have taken Signal-to-Noise Ratio (Es/No) factor to perform analysis. It is concluded that when Es/ No factor increases, BER of ZigBee, Bluetooth, Wi-Fi decreases. Also BER of ZigBee is better than the other two technologies. Same is concluded for PER also. At lower Es/No, the difference between BER and FER is less but at higher Es/No, the difference is more since PER is always greater than BER.

For the above mentioned scenarios of these three technologies the following BER and PER is obtained when the Es/ No range is provided between 0 -50 in Table 1. However if the scenarios are changed the expected output may vary.

Table 1: Analysis of BER and PER for Es/No.

2.4 GHz ISM Technologies	For Es/No= 50 BER obtained	For Es/No= 50 PER obtained
ZigBee	10^$^{(-9)}$	10^$^{(-5)}$
Bluetooth	10^$^{(-6)}$	10^$^{(-6)}$
Wi-Fi	10^$^{(-8)}$	10^$^{(-7)}$

6. FUTURE SCOPE

BER and PER analysis of these three technologies in a co-existing environment can be performed for better understanding of them.. As these technologies are very popular and handy to use in our day-to-day life, they are bound to come in close proximity of each other. This will affect their performance in terms of BER and PER. Thus analysis of the same will be carried forward. Moreover, advanced interference mitigation techniques such as Smooth Adaptive Frequency Hopping (SAFH) algorithm of Bluetooth can also be applied to check the resultant BER and PER in a co- existing environment.

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