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Implementation of MSK Modulation Scheme for Zigbee System / IEEE 802.15.4 Physical Layer

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ABSTRACT
In this work physical layer simulation of IEEE 802.15.4 / ZigBee protocol has been done. The proposed work is the implementation of ZigBee system according to the protocol description. In this work we have simulated ZigBee system first with conventional OQPSK modulation technique, then the simulations are performed for MSK modulation, which is through OQPSK modulation. Simulation results for BER showing the average 79.43 % improvement in BER for Proposed MSK compared with OQPSK modulation scheme. For a target BER of 10-2 the SNR required is 4 dB for this work i.e. for MSK, as compared to 10 dB for conventional OQPSK. Hence, an improvement of 6 dB less SNR. For a target BER of 10-2 the SNR required is 4 dB for this work i.e. for MSK, as compared to 5.2 dB with [1]. Hence, an improvement of 1.2 dB less SNR.

Keywords: *ZigBee, IEEE 802.15.4, MSK, OQPSK, BER, MATLAB.*

I. INTRODUCTION
Wireless communication has a wide spread in several fields such as industry, health, agriculture, and military [1]. The necessity of wireless sensor networks (WSNs) increases to enhance the system reliability, meanwhile decreasing the power consumption and avoiding the complexity of wired connections implementation [2]–[4]. ZigBee, as a long-term sustainable and reliable system operation, is considered as one of the effective communication standards of WSNs. It provides several advantages compared to other technologies such as: low power consumption, which leads to long battery life, low data rates, simplicity, and self-configuring preference [5]. ZigBee operates in three different frequency bands; 868 MHz, 900 MHz and 2.4 GHz. The most commonly used band in industrial applications is the 2.4 GHz. It is operating in the free-licensed industrial, scientific and medical (ISM) frequency band, which subsequently reduces the system cost [6]–[8], [2]The application of Zigbee Technology can be seen in home monitoring system, climate sensors communication, collection of data in small area in research field & industrial control etc. The major application of Zigbee transceiver is shown in wireless sensor networking and automatic control system such as home controlling, biotelemetry, personal caring (for senior citizens) etc. Home, industry and other organization automation is the major application of Zigbee transmission. Light (Power) control, Light machinery control, SCADA networking etc are some more.

The IEEE 802.15.4 wireless standard for low power, low data-rate sensor networks operate in the 2.4GHz industrial, scientific and medical (ISM) band. The ZigBee standard provides network, security, and application support services operating on top of the IEEE 802.15.4 Medium Access Control (MAC) and Physical Layer (PHY) wireless standard. It employs a suite of technologies to enable scalable, self-organizing, self-healing networks that can manage various data traffic patterns. Here we are try to reduce packet error rate and bit error rate the packet error rate (PER). PER is obtained from the bit error rate (BER) and the collision time. The BER is obtained from signal to noise and interference ratio using OQPSK modulation. By using a platform MATLAB/ SIMULINK. ZigBee as a short range WSN is usually used in indoor environments, in which it is subjected to the effects of wireless propagation, such as added noise and multipath fading. These effects may cause inter-symbol interference (ISI), increase the bit error rate (BER) at the receiver, and decrease the reliability of the entire system [9].

Here a comparatively analysis of Zigbee, Bluetooth and Wi-Fi technology is also present that will help us that how Zigbee is different than other wireless networking technologies [3]:

System	ZigBee	Bluetooth	Wi-Fi
Application	Monitoring & Control	Cable Replacement	Internet
System Resources	4-32 KB	250 KB	1 MB+
Battery Life (Days	100s-1000	1-7	Hours
Nodes in Network	255/65K	7	32
Baseband (kb/s)	20-250	720	11 Mbps
Distance	1-100m	1-10m	100m
Key Characteristics	Stability low Consumption low cost	Price, Easy use, High Data Rate	Very High Speed Large Network

Table 1: comparison of ZigBee with other protocols

II. ZIGBEE AND IEEE802.11.4 SPECIFICATIONS

Zigbee Alliance was established in August, 2001,The ZigBee specification, officially named ZigBee 2007.It offers full wireless mesh networking capable of supporting more than 64,000devices on a single network. It's designed to connect the widest range of devices, in any industry, into a single control network. The ZigBee specification has two implementation options or Feature Sets: ZigBee and ZigBee PRO. The ZigBee Feature Set is designed to support smaller networks with hundreds of devices in a single network. The ZigBee PRO Feature Set is the most popular choice of developers and the specification used for most Alliance developed ZigBee Feature Set, plus facilitates ease-of-use and advanced support for larger networks comprised of thousands of devices. Both Feature Sets are designed to interoperate with each other, ensuring long-term use and stability. The ZigBee specification enhances the IEEE 802.15.4 standard by adding network and security layers and an application framework. From this foundation, Alliance developed standards, technically referred to as public application profiles, can be used to create a multi-vendor interoperable solutions. For custom application where interoperability is not required, manufacturers can create their own manufacturer specific profiles.

Some of the characteristics of ZigBee include: Global operation in the 2.4GHz frequency band according to IEEE 802.15.4 Regional operation in the 915Mhz (Americas) and 868Mhz (Europe). Frequency agile solution operating over 16 channels in the 2.4GHz frequency Incorporates power saving mechanisms for all device classes Discovery mechanism with full application confirmation Pairing mechanism with full application confirmation Multiple star topology and inter-personal area network (PAN) communication Various transmission options including broadcast Security key generation mechanism Utilizes the industry standard AES-128 security scheme Supports Alliance standards (public application profiles) or manufacturer specific profiles.

III. ZIGBEE / IEEE 802.15.4 PROTOCOL ARCHITECTURE

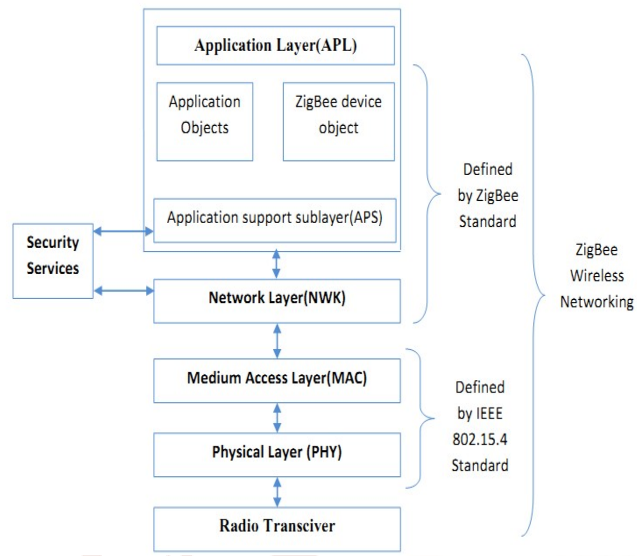

Figure 2: ZigBee/IEEE 802.15.4 Architecture

II. F. FREQUENCY BANDS AND DATA RATES

The standard specifies two PHYs:

1. 868 MHz/915 MHz direct sequence spread spectrum (DSSS) PHY (11channels) 1 channel (20Kb/s) in European 868MHz band 10 channels (40Kb/s) in 915 (902-928)MHz ISM band.

2. 2450 MHz direct sequence spread spectrum(DSSS) PHY (16 channels) 16 channels (250Kb/s) in 2.4GHz band.

III. ZigBee System

The main objective of this work is to simulate and physical level simulation of IEEE 802.15.4 ZigBee protocol. For this we have simulated the ZigBee system for IEEE 802.15.4. In this process first we have implemented the ZigBee system with existing OQPSK modulation, than the system is being implemented using MSK using OQPSK by using platform MATLAB.

PHY (MHz)	Frequency band (MHz)	Spreading parameters		Data parameters		
		Chip rate (k-chip/s)	Modulation	Bit rate (kb/s)	Symbol rate (k-symbol/s)	Symbols
868/915	868-868.6	300	BPSK	20	20	Binary
	902-928	600	BPSK	40	40	Binary
2450	2400-2483.5	2000	O-QPSK	250	62.5	16-ary Orthogonal

Table 2:Frequency Bands & Data Rates of ZigBee IV.

A comprehensive model for ZigBee transceiver has been built in MATLAB Simulink. The details of this model are presented in this section. A block diagram for the transceiver model is shown in Fig. 3.

A. ZigBee Transmitter Model

Before transmitting the input data through the transmission channel, three stages of signal processing are required: signal generation, spreading and modulation, as depicted in Fig. 3.

1. Binary Generator: Each four bits of input data stream of 250 kbps is mapped into a symbol [3]. Thus, the symbol rate is 62.5 Kilo symbols per second. The 'Random Integer Generator' in the Simulink library is used with 2-ary number and 1/250000 sampling time.
2. Pseudo-Noise (PN) Sequence Generator: This block in Simulink is used to generate the 16-ary PN sequences with 32-bit chip sequence, where the chip rate is 2Mcps.
3. Direct Sequence Spread Spectrum (DDSSS) Spreading:
   The symbol is used to select one of the 16-ary PN sequences resulting in 2 Mega DSSS. In Simulink, this process is performed through two steps: first, the input data stream and PN code are converted to non-return-tozero (NRZ) format, and then they are multiplied to generate a wide-band DSSS signal. Pulse shaping is achieved using the half sine signal as given in Eq.1

   $$p(t) = \begin{cases} \sin\left(\pi \frac{t}{2T_c}\right) & 0 \le t \le 2T_c \\ 0 & otherwise \end{cases} \quad \textbf{Eq.1}$$

   where, T_c is the chip period.
4. Offset Quadrature Phase Shift Keying (OQPSK) Modulation: The spread signal is modulated using OQPSK modulation and transmitted over the fading channel.

B. Channel Characteristics

The widespread AWGN is used to simulate background noise of the time-varying channel. The medium of the data transfer is closed, and thus there are multipath fading effects. Since ZigBee is generally used in a closed environment, it will be affected by small-scale Rayleigh and Rician fading. Obstacles in the transmission path of the signal result in multipath copies of the signal with different delay times. If a_k denotes the complex path gain and τ_k defines the path delay of the signal via the k^{th} path, then the impulse response of the channel is given by:

$$h_n = \sum_k a_k \, sinc\left[\frac{\tau_k}{T_s} - n\right]$$

where, T_s is the input sampling period, and nis the number of samples. By referring to the set of samples at the input of the channel as s_n , then the output is given by:

$$x_n = \sum_i s_{n-i} h_n$$

In case of Rayleigh fading, there is no direct path along a line of sight, and all received signals are reflected copies. The 'Multipath Rayleigh Fading Channel' block is used in the model with 0.001 max Doppler shift. In Rician fading, there is a signal component with direct path to the receiver. The 'Multipath Rician Fading Channel' Simulink block is used with k-factor of 1 to model this effect. The k-factor represents the ratio between the power in the line-of-sight component, and the power in the diffused component. Four multipath components with path delays [0, 1, 5, 10] ns and average path gains of [0, -2, -3, -5] dB are used for simulation. To match the realistic channel, all these impacts are considered during the model design.

C. ZigBee Receiver Model

The original signal is extracted by adding a filter and/or an equalizer to the receiver model. The filter is used to remove the added noise on the signal, and the equalizer works to compensate the unwanted impact of the channel such as attenuation, amplification, delay and phase shift. In this work an adaptive linear equalizer is added to the receiver model to achieve the two tasks at the same time. The signal is obtained at the receiver by using OQPSK demodulation block. The received 2 Mbps signal is de-spreaded by using the same PN sequence, which was used at the transmitter side. The received signaland the PN sequence must be synchronized before multiplication.

IV. PROPOSED ALGORITHM

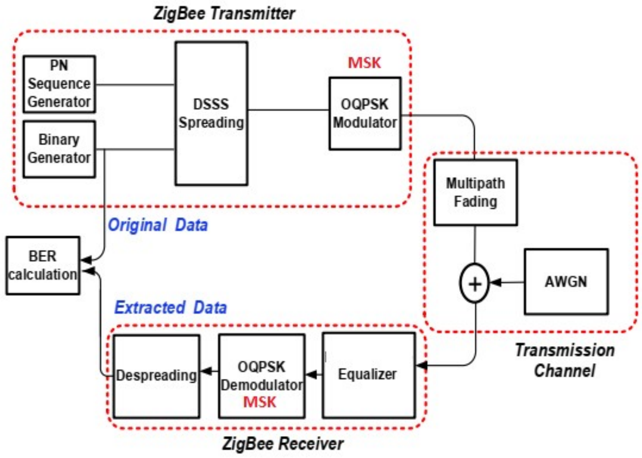

Figure 3: Proposed Algorithm

1. Take the input signal bit stream.
2. Convert Bit sequence into symbols, i.e. generation of symbols for MSK 1 & 0 for MSK & 0 to 15 OQPSK.
3. Perform DSSS Mapping Replacing Symbols with the appropriate PN (Pseudo Noise) Sequence.
4. Perform Serial to Parallel Conversion.
5. Now perform Raised Cosine Pulse Shaping & or Root Raised Cosine shaping for half-half parts.
6. Then MSK modulation through OQPSK is performed separately for both the halves.
7. After modulation both the half portions are add-up, the combined signal is ZigBee compatible signal, which can be transmitted over wireless communication channel.
8. When signals are communicated through a wireless channel, it is contaminated by noise. In this work we have taken AWGN noise model.
9. At the reception the obtained signal from wireless channel is required some pre-processing first. The signal is filtered by a filter with Channel Impulse Response (CIR), but it also inserts some attenuation.
10. For detection of original the signal from received combined signal Matched Filter is used, which performs Root Raised Cosine filtering or Square Root Raised Cosine filtering.
11. MSK through OQPSK, demodulation is performed for demodulation of the signal.
12. This demodulated signal requires Header Correlation, which is required because of Filter Delay, hence it is Compensation.
13. To get the original bit sequence DSSS Demapping with logical operation like XOR/ XNOR, reverse is applied to extract original bit stream of symbol.
14. Finally, after extraction of original bit stream, BER calculation & plotting of BER vs SNR is performed.

Algorithm for MSK Generation from OQPSK

1. Generation of input random binary sequence of +1's & -1's.
2. Arrange these bits into even & odd symbols.
3. Perform rectangular pulse shaping on the even & odd symbols, delay the odd symbols by T.
4. Multiply the even symbols by $\cos(\pi/2T)$ & odd symbols by $\sin(\pi/2T)$ & transmit.
5. Add additive white Gaussian noise (AWGN) for the given value of Eb/No.
6. Multiply I-arm by $\cos(\pi/2T)$ & Q arms by $\sin(\pi/2T)$ & integration is done for 2T time period.
7. Hard decision decoding is performed on the integrator output for I-arm, at every 2T; this will give us even bits xe.
8. Similarly, on Q arm, with a delay time T, at every 2T time period, hard decision decoding is performed on the output of integrator, for obtaining odd bits' xo. Count the bit errors.
9. Repeat the above steps for more values of Eb/No & plot the graph for simulation results.

V. SIMULATION RESULTS

In this work physical layer MSK modulation implementation of IEEE 802.15.4 ZigBee has been done. First with the help of existing OQPSK modulation technique the IEEE 802.15.4 ZigBee protocol, system was implemented, then using MSK through OQPSK modulation the system was implemented again. Several MATLAB/Simulink simulations were done to evaluate the performance of Zigbee/IEEE 802.15.4 physical layer. The simulation results show how the BER versus the SNR values were affected when varying communication parameters such the input data rate, the level of the AWGN power and number of bits per symbol.

V. SIMULATION RESULTS

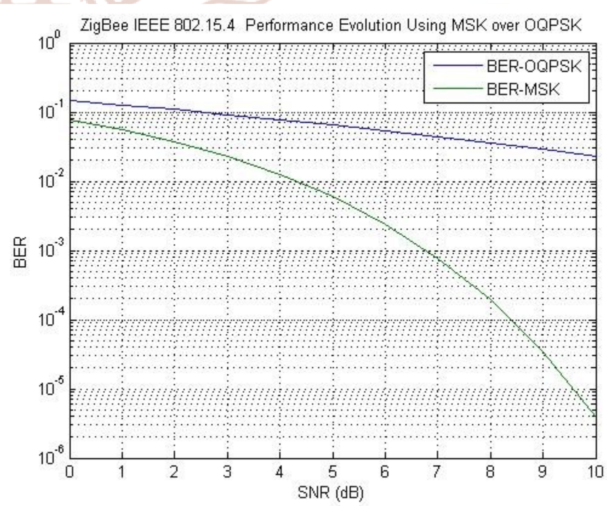

Figure 4: BER Performance of ZigBee for OQPSK & MSK

Target BER	SNR (dB)		
	OQPSK - GA [1]	OQPSK - PSO [1]	MSK
10-1	0	0	0
10-2	5.2	5.3	4
10-3	9.8	10	7
10-4	11	12	8.2
10-5	------	------	9.5
10-6	-------	-------	11

Table 2: Simulation Results Comparison with [1]

VI. CONCLUSION

In this work physical layer simulation of IEEE 802.15.4 / ZigBee protocol has been done. The proposed work is the implementation of ZigBee system according to the protocol description. In this work we have simulated ZigBee system first with conventional OQPSK modulation technique, then the simulations are performed for MSK modulation, which is through OQPSK modulation. Simulation results for BER showing the average 79.43 % improvement in BER for Proposed MSK compared with OQPSK modulation scheme. For a target BER of 10-2 the SNR required is 4 dB for this work i.e. for MSK, as compared to 10 dB for conventional OQPSK. Hence, an improvement of 6 dB less SNR. For a target BER of 10-2 the SNR required is 4 dB for this work i.e. for MSK, as compared to 5.2 dB with [1]. Hence, an improvement of 1.2 dB less SNR. Based on the results of this work, one would choose the 868 MHz or 968 MHz MSK Physical Layer to optimize the hardware cost and implement the 2.4 GHz Physical Layer to maximize data rate. But, overall we can conclude that due to minimum variations in MSK, the BER probability is less in MSK systems.

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