

A NOVEL METHOD FOR IMPROVING BIT ERROR RATE IN SENSOR NETWORKS BY USING ORTHOGONAL SPACE TIME BLOCK CODE (OSTBC) CODING

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ABSTRACT

For the designing of any network, lifetime and size of the network are the most important parameters in addition to that high data rate and low bit error rate also play an important role in the designing of any sensor network. In this paper, new transmission techniques for the transmission of sensors data has been proposed for sensor networks by combining various modulation and coding techniques into the network transmission. The proposed technique is used to improve the Bit Error Rate performance of the wireless sensor network, in most of the wireless sensor networks ,bits are converted into packets and these packets are transmitted from source to destination during that transmission the quality of physical layer is determined by the Bit Error Rate (BER) and the Packet Delivery Rate (PDR). The physical layer deals with transmission of bits over wireless link the designing constraints of this layer is modulation, diversity and coding. In this paper various modulation, coding and diversity techniques are incorporated into sensor network for reducing Bit Error Rate (BER). The proposed system divides the network into two types of nodes, first one is the sensor nodes, equipped with short distance transmission capability and another one is special nodes that are equipped with modulators and coders for transmitting data over long distance. This proposed system also extended for providing the secured data transmission by the use of various error detection and correction codes.

KEYWORDS

Bit Error Rate (BER), Orthogonal Space Time Block Code (OSTBC), Internet Of Things (IOT), Orthogonal Transform Division Multiplexing (OTDM), Space Time Coding (STC), Singular Vector Decomposition (SVD).

1. INTRODUCTION

Wireless Sensor Networks (WSNs) are the combination of many tiny sensing elements for transferring data from source to destination using multi-hop transmission. There are a number of applications in which real time monitoring is required so a huge amount of data is collected after the collection of this data various mathematical transformations are required to convert this raw data into useful information. Some applications require security of the data whereas for some applications such as wireless multimedia sensor network major concern is accuracy of the data and high data transfer rate. In agriculture, these networks can provide the report about the growth rate of plants. This can reduce labor work and the cost of production by Zhen, Hong, and Wang (2011) and Sun *et al.* (2011). However, sensor network has tiny nodes with limited transmission capability and limited battery lifetime so long distance transmission of data is also a challenging task in WSNs. According to an Article “Wireless Channel Propagation Characteristics and modeling research in Rice field sensor networks” by Gao *et al.* (2018), in wireless sensor network the quality of communication depends upon the condition of the environment where the sensor network is planned to operate for example the attenuation speed in wireless channel propagation is directly related to the development of the rice plant. In this paper author observed that crop plants suffer from different wireless channels effects such as reflection, scattering and diffraction, So various diversity techniques helps us to mitigate these effects in sensor networks. Farhang-Boroujeny and Moradi (2016) showed that, Orthogonal Frequency Division Multiplexing (OFDM) modulation technique played an important role in wireless communication systems due to its ability of high frequency selectivity and achieving high data transfer rate without any Inter Symbol Interference (ISI).

When data travel a long distance then several multipath effects like fading and reflection of signals are also coming into consideration. Diversity techniques are also playing an important role in any communication because these techniques mitigate the effect of multipath fading and shadowing from buildings and objects (Alamouti, 1998). According to a special issue on codes and graphs, in the applications where secure communication is required, the spread spectrum system plays an important role, for the applications

where the error control is the major requirement then channel encoder and decoder plays an important role because these codes automatically reduce the error in communication. In many applications where size and cost of the antenna is a major limitation, the cooperative transmission method is considered as better approach.

A Wireless sensor network can use generally cooperative relaying for increasing the lifetime of the sensor network. In wireless medium long distance communication requires more power than the short distance communication because after traveling long distance signals become weak.

In the proposed scheme, network nodes are divided into two categories: in first category, nodes are used for sensing and these sensing nodes are having limited transmission capability. In Second category nodes are special modules which have long distance transmission capability where various modulation and coding techniques are used in the designing of these special nodes for improving the Bit Error Rate (BER) performance. If analysis is done on total power consumed, then most of the nodes power are consumed during transmission, so the lifetime of first category automatically increase by the use of these special nodes so introducing these strategies inside the network increase the lifetime of whole sensor network. Aly *et al.* (2019) proposed a Space-time coding Orthogonal Space Time Block Codes (OSTBC) technique for enhancing the Bit Error Rate (BER) performance, security, increased diversity gain and decrement in the fading effect. Hasna and Alouini (2003) demonstrated that Decode and Forward (DF) protocols performs better at low SNR. Baek and Song (2008) designed and analyzed the performance of cooperative diversity in MIMO-OFDMA system. Jing and Jafarkhani (2009) have analyzed the performance of single and multiple relays and calculate their diversity order. Decode and Forward (DF) protocols are generally used in WSNs where the information bits are detected, decoded and sent forward. Lu, Nikookar and Xu (2010) demonstrate that decode and forward protocols for reducing channel interference and additive noise at the relay.

In this paper by using the multiple access techniques data from different sensors are combined together and this data has been sent to the destination by the use of OSTBC encoding and modulation. System becomes more complex in comparison to the normal sensor network at transmission level but the advantage of this system is improvement in Bit Error Rate performance and transmission work is handled by some specific modules so network life time does not depend on the complexity of transmission protocols and all nodes power is not wasted in long distance transmission. Another advantage of using this method of transmission is that the dependency on internet or requirement of replacing the sensor nodes by the small IOT devices has been overcome by installing such type of communication networks (Arroyo *et al.*, 2019).

In Elhabyan and Yagoub (2014), the parameters for judging the performance of any sensor Network are average consumed power, packet delivery rate, network coverage and number of nodes in a particular area.

In WSNs, nodes perform two functions: first sensing the information and second transferring that information to destination. In Castanedo (2013), there are many topologies for arranging the sensor nodes and routing protocols for transferring the sensed information. In Din *et al.* (2014) & Han *et al.* (2014) has proposed many optimization technique for reducing the average consumed power.

The key contribution of this paper is modulation and coding technique are incorporated in the transmission of sensed data. After that simulation has been carried out for different type of modulation such as Frequency shift Keying (FSK) with diversity, Binary Phase shift keying (BPSK) with diversity, BPSK with OSTBC coding and BPSK, BFSK and QAM for different diversity order. The simulation results show the improvement in BER of the network by including the modulation and coding capability in the special nodes on the place of using complex routing algorithms for load sharing.

The rest paper is arranged as follows. In Section 2, detailed description of the proposed system. System evaluation and simulation results are presented in Section 3. This is followed by the Section 4 that do conclusion and showing the advantages of the proposed technique.

2. MATERIALS AND METHODS

The proposed network architecture is shown in Figure 1, which shows that data are coming from multiple sensor nodes, these sensor nodes sensing the data and the data from each sensor node is received in the special node at discrete time intervals. The special nodes perform the data acquisition, modulation and coding. Data received at special node is of two types useful and useless data, useless data include the noise signals and rest of the data is comes into the category of useful data and these are the observations from the detected target. The special node performs data fusion. The techniques which are used for the purpose of fusion are data association techniques (Akkaya & Younis, 2005), by using that technique data from different sensor nodes are combined together after that special node do modulation and coding for transmitting that data to the destination.

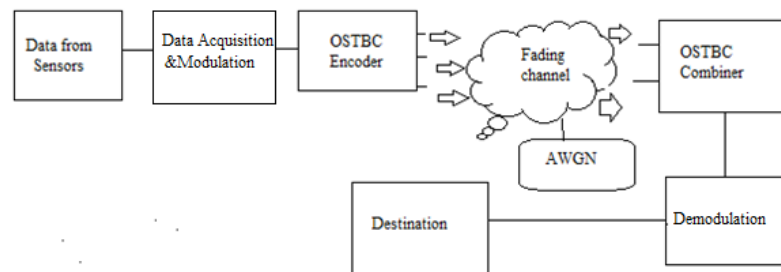


Figure 1. OSTBC coded data transmission from source to destination through Rayleigh fading channel. **Source:** authors' own elaboration.

The sensing range characteristics are depending on the type of the sensors being used for the purpose of sensing. Such as for PIR sensor it is 20 feet's and for Inductive proximity sensor it is 50mm since these sensors are connected to radio transceiver board (Ex CC 2420), transmission range is determined by the transmission power used by the module. The module CC2420 supports the choice of several

power levels with 0dbm (eq. 1mw) being the maximum power which decides the transmission capability. Transmission range also depends on the environmental condition, obstacles etc. For WSN standard 802.15.4 the communication range is from 20m to 30m for indoor applications and 75m to 100m for outdoor applications. After that if we want to increase the communication range or speed of transmission then there are two solutions, first the use of special IOT devices connected to high speed Wi-Fi network, second solution is modulation and coding of the signals.

The incoming data from different sensors are combined together and modulated by any digital modulation techniques such as BPSK, BFSK or QAM etc. after that data is OSTBC encoded and transmitted via fading channel.

The OSTBC Encoder block encodes an input signal sequence using Orthogonal Space Time Block Code. In this case the input signal is sampled because fusion node inside the transmission module select the data at discrete time interval so sampled version of data is ready for transmission on that stage. The OSTBC encoder block supports many OSTBC encoding algorithms that are Depending on the rate and number of transmitting antenna used. In this section, OSTBC codes with 3 transmitting antenna and Rate3/4 is used here. In this paper, 3x2 MIMO is implemented using Alamouti algorithm. A complex orthogonal space-time block code, three consecutive symbols S_1 , S_2 and S_3 are encoded with the following space-time code word matrix:

$$\begin{pmatrix} S_1 & S_2 & S_3 \\ -S_2^* & S_1^* & 0 \\ S_3^* & 0 & -S_1^* \\ 0 & S_3^* & -S_2^* \end{pmatrix} \quad (1)$$

2.1. MATHEMATICAL MODELING OF OSTBC ENCODED SIGNAL

In this section, a brief description about the OSTBC encoding scheme for three transmit antennas and two receiving antennas are given, we are using a Orthogonal Space Time Block Code with three transmit antennas where the rate of this code is $\frac{3}{4}$. The input to the OSTBC encoder is a 3×1 vector signal and the output is a 4×3 vector signal. A random binary signal is modulated by using Binary phase shift keying (BPSK) after that this signal goes inside an OSTBC coder for transmission over a Rayleigh fading channel. The fading channel model has six independent links due to the three transmitting antennas and two receiving antennas. An additive white Gaussian noise (AWGN) is added at the receiver side and all signals are combined into a single stream for demodulation by using OSTBC combiner.

In the first time instant, antenna 1 transmits X_1 , antenna 2 transmits X_2 and antenna 3 transmits X_3 while during second time instant, antenna 1 transmits $-X_2^*$, antenna 2 transmits X_1^* and antenna 3 transmits 0, in third time instant antenna 1 transmits X_3^* , antenna 2 transmits 0 and antenna 3 transmits $-X_1^*$ and in fourth time instant antenna 1 transmits 0, antenna 2 transmits X_3^* and antenna 3 transmits $-X_2^*$.

At the receiver side the received signal is given by the following equations:

Received signal at first time slot:

$$Y_1(1) = \begin{pmatrix} G_{1,1} & G_{2,1} & G_{3,1} \end{pmatrix} \begin{pmatrix} X_1 \\ X_2 + n(1) \\ X_3 \end{pmatrix} \quad (2)$$

$$Y_2(1) = \begin{pmatrix} G_{1,2} & G_{2,2} & G_{3,2} \end{pmatrix} \begin{pmatrix} X_1 \\ X_2 + n(1) \\ X_3 \end{pmatrix} \quad (3)$$

Received signal at second time slot:

$$Y_1(2) = \begin{pmatrix} G_{1,1} & G_{2,1} & G_{3,1} \end{pmatrix} \begin{pmatrix} -X_2^* \\ X_1^* + n(2) \\ 0 \end{pmatrix} \quad (4)$$

$$Y_2(2) = \begin{pmatrix} G_{1,2} & G_{2,2} & G_{3,2} \end{pmatrix} \begin{pmatrix} -X_2^* \\ X_1^* + n(2) \\ 0 \end{pmatrix} \quad (5)$$

Similarly, we can write down the received signals equation for third and fourth time slot where $n(3)$ and $n(4)$ are AWGN, that are added during these slots after that combiner combines all signals and estimate the transmitted signal vector as:

$$\begin{pmatrix} \hat{x}_1 \\ \hat{x}_2 \\ \hat{x}_3 \end{pmatrix} = \frac{1}{\|H\|^2} \sum_{j=1}^M \begin{pmatrix} G_{1,j}^* r_{1,j} + G_{2,j}^* r_{2,j} - G_{3,j}^* r_{3,j} \\ G_{2,j}^* r_{1,j} - G_{1,j}^* r_{2,j} - G_{3,j}^* r_{4,j} \\ G_{3,j}^* r_{1,j} + G_{1,j}^* r_{3,j} + G_{2,j}^* r_{4,j} \end{pmatrix} \quad (6)$$

Where \hat{x}_k represents the k^{th} symbol in the OSTBC code matrix G_{ij} represents the estimate for the channel for i^{th} transmitting antenna and j^{th} receiving antenna. The values of i and j range from 1 to N (the number of transmitting antennas) and 1 to M (the number of receiving antennas).

Where $H^2 =$ summation of channel power per link.

2.2. BER ANALYSIS

The Bit Error Rate (BER) of the proposed scheme; the BER is defined as the number of bits in error divided by the total number of transferred bits during the studied time interval so:

$$BER = \frac{\text{Total number of bit errors}}{\text{Total number of bits received}}$$

When, we talk about the performance of any sensor network then packet delivery Rate (PDR) is defined as the ratio of the number of packets successfully received by all cluster heads to the number of packets generated so both PDR and BER are related to the information or the data transferred from source to destination. These two parameters are related to the transmission capability of any sensor network so if the BER performance of any network is improved then this improvement automatically reflect in the packet delivery rate or in other words reduction in the BER is the increment in the PDR.

3. SIMULATION RESULTS

In this section, the proposed scheme of transmission is compared to the conventional modulation schemes such as BPSK, BFSK and QAM with diversity. Set of architectures are evaluated in terms of modulation with OSTBC coding and modulation with diversity techniques. The performance of these network architectures is discussed in the following subsections. A BPSK modulated system with diversity of 6 is considered and compared this with OSTBC coding of rate $\frac{3}{4}$. After that the effect of changing the modulation technique is studied. For simulation a random binary data is created. For the selected OSTBC code the output signal power is 2.25 W and the channel symbol period for this simulation is 7.5×10^{-4} sec due to the code rate $\frac{3}{4}$. All the parameters used in simulation are collected in Table 1.

Table 1. Simulation parameters.

Type of Channel	Rayleigh Fading Channel
Type of modulation	BPSK,BFSK,QAM
Diversity order	6
Number of Subcarriers	1024
Carrier Frequency	2Ghz
FFT size	64
Cyclic prefix	0%
Number of Monte carlo simulation	2e6
E_b/N_0 (dB)	0 to 30 dB

Source: authors' own elaboration.

3.1. EFFECT OF OSTBC CODING

Figure 2 shows the BER of the proposed technique in comparison to the BPSK with diversity order 6. In OSTBC coded transmission of BPSK modulated signal out of 100000 received bits only 48 bits are in error. The BER reaches about 0.0013 at 9dB, whereas in diversity transmission this value is 0.0009 at 9dB. These results showed that there is little bit different in the BER performance of both techniques.

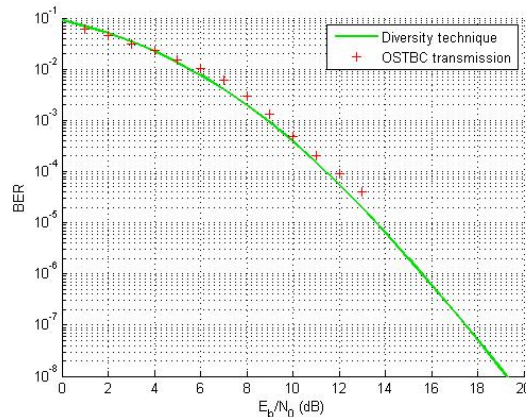


Figure 2. BER of the OSTBC transmission in comparison with diversity transmission of order 6. **Source:** authors' own elaboration.

3.2. EFFECT OF MODULATION TECHNIQUE AND DIVERSITY

Figure 3 shows the effect of changing the modulation technique on the proposed techniques if we use the BFSK in place of BPSK then the performance of OSTBC transmission techniques does not improve the performance of the network in comparison to the Diversity techniques. In the transmission of OSTBC coded FSK, out of 240 received bits 101 bits are in error. BER is 0.0077 at 9dB, for coherent FSK with diversity order 6. The BER is 0.0791 for non-coherent FSK with diversity order 6. For OSTBC coded transmission of FSK modulated wave it is too large that is 0.4714 at 9 dB. The BER performance of these technique is shown in Figure 3.

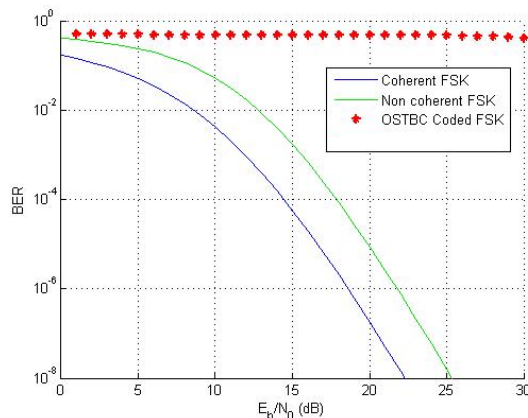


Figure 3. BER of the OSTBC transmission of FSK signal in comparison to the FSK with diversity order 6. **Source:** authors' own elaboration.

The Performance Comparison of all the transmissions are collected in Table 2.

Table 2. Comparative Performance.

Mode of transmission	BER at 3dB	BER at 6dB	BER at 13 dB	Performance
OSTBC coded BPSK	0.0306	0.0100	4×10^{-5}	Good
OSTBC coded BFSK	0.5104	0.4803	0.4782	Very Poor
Diversity transmission of Coherent BPSK	0.0344	0.0077	1.92×10^{-5}	Good
Diversity transmission of Coherent BFSK	0.0915	0.0346	3.84×10^{-4}	Comparatively Low
Diversity transmission of Non-Coherent BFSK	0.3134	0.1952	0.0084	Moderate

3.3. EFFECT OF DIVERSITY ORDER FOR DIFFERENT MODULATION TECHNIQUES

For agriculture field applications, diversity techniques play an important role to overcome the difficulties arise due to several multipath effects. In wireless sensor network transmission of signal inside the channel depends upon the growth of plants so in such type of situations diversity techniques helps us in estimating the original signal. In that section we also see the effect of using diversity order inside the system.

For different diversity orders, the calculated BER for different modulation techniques such as Phase shift keying (PSK), Frequency shift keying (FSK) and 4-Quadrature amplitude modulation (4-QAM) is compared in this section which is given in Figures 4, 5, 6. These figure shows how we can improve the BER of any modulation technique by increasing the diversity order. In the agriculture field application, a variable diversity schemes for different growth time will improve the performance of sensor networks.

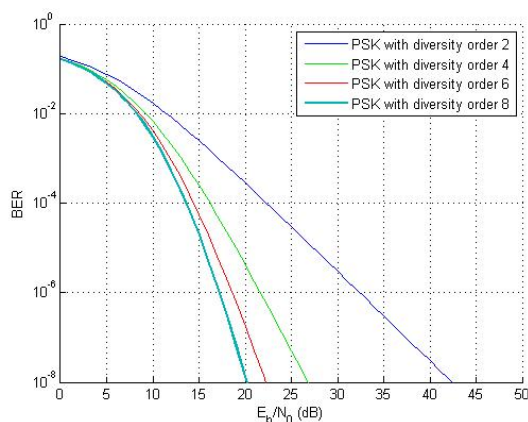


Figure 4. BER of the PSK signal with changing diversity order. **Source:** authors' own elaboration.

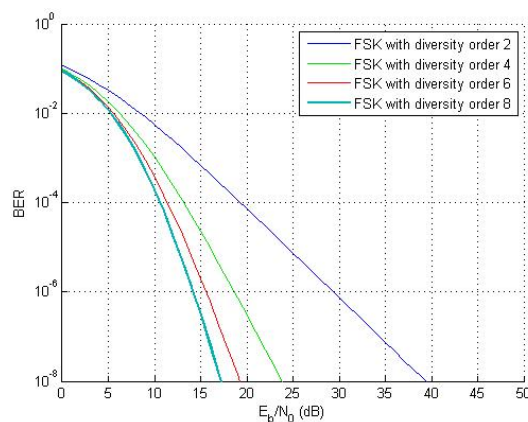


Figure 5. BER of the FSK signal with changing diversity order. **Source:** authors' own elaboration.

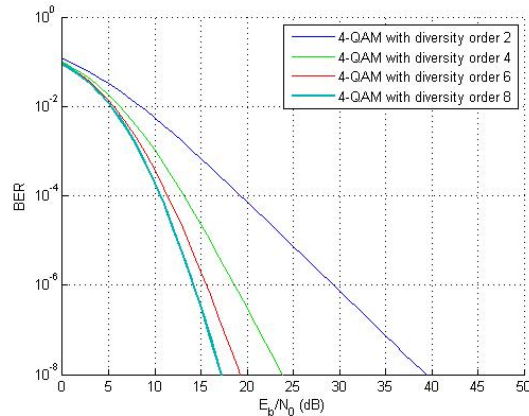


Figure 6. BER of the 4-QAM signal with changing diversity order. **Source:** authors' own elaboration.

4. CONCLUSIONS

An OSTBC coding, diversity and modulation based architecture is proposed for the transmission of data in sensor network. These techniques improved the BER performance of the sensor network. We considered a network with OSTBC coded transmission of BPSK signal. The modulation scheme PSK, FSK and 4-QAM were investigated with different diversity order. For the comparative performance evaluation, we considered the transmission of PSK modulated wave with diversity order 6 and compared that with OSTBC encoded transmission. The proposed transmission shows its superiority over the complex routing algorithm based transmission of sensor network data. In many cases where installing a long antenna is not good choice then by using OSTBC transmission approach, we can achieve the good BER performance. The proposed technique is basically based on sensor fusion or data fusion where data from several sensors are combined together and after that instead of sending a huge amount of data only useful data are send to the destination by means of coding and modulation, the proposed network is applicable and can be practically beneficial for high data rates applications such as wireless multimedia sensor network where transmission quality of video and image signal is the requirement of system.

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