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BER Performance Analysis of a Cooperative Diversity-Based WBAN Using ZF-Precoded Alamouti Codes

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ABSTRACT: The booming growth of wireless technologies has augmented the demand for a high speed and reliable communication link with prolonged network lifetime. Such demands can be catered to with the design of energy efficient communication protocols. A robust way to combat multipath fading in wireless communication is by implementing diversity techniques. Cooperative communications have the advantage of link reliability and boosting energy efficiency. Cooperative communication is based on a new diversity technique known as cooperative diversity. This paper focuses on the cooperative diversity based wireless body area network (WBAN). The WBAN model considered in this paper can be served for healthcare services in order to mitigate the undesired effects of WBAN due to high path loss and fading as well as to keep a low transmit power while meeting the desired WBAN quality of services. The main objective of this research work is to evaluate the bit error rate performance (BER) of a cooperative diversity based WBAN by using (2x2) Alamouti's Space time block code (STBC) with a precoding scheme (STBC-PC) and a relay selection procedure (RSP).

KEYWORDS: Cooperative communication, Cooperative Diversity, WBAN, STBC, Precoded-STBC, Particle Swarm Optimization.

I. INTRODUCTION

The extensive use of wireless networks and an upsurge in the use of nanotechnology has led to miniaturization of electronic devices. Health monitoring systems combined with wireless communication constitute a class of wireless sensor networks known as WBAN. WBAN is a field developed in the past 15 years as a result of applying WPAN to communication on, near and around the human body. WPAN and WLAN are low power, short range wireless networks used to establish small size networks to exchange data. A BAN is a collection of wireless sensors placed around or in a human body that are used to exchange important information from a human body to remote stations. Such networks consist of tiny computing devices called sensor nodes along with a central unit called sink. These sensors may be placed in wearable objects such as belts, headsets, wrist watches etc. or may be attached to or implanted inside a human body to make WBAN. This paper provides a comparative study between cooperative relaying, STBC scheme and PSO scheme as well as their analysis and effect on the BER performance of the proposed wireless body area network.

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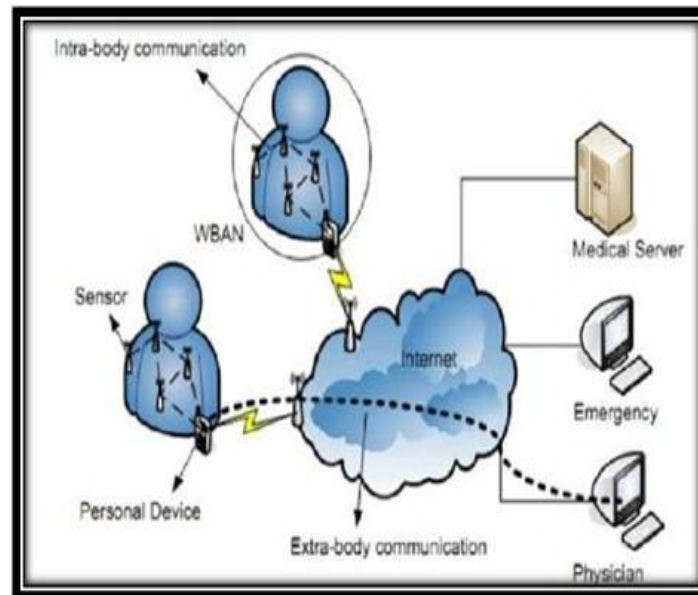


Fig1.Architecture of WBAN

II. BODY AREA NETWORK

A body area network as defined by IEEE is a communication standard optimized for low power devices and operation on, in or around the human body to serve a variety of applications including medical, consumer electronics / personal entertainment and other. BAN represents a natural union between connectivity and miniaturization. A BAN is defined formally as a system of devices in close proximity to a person's body that cooperate for the benefit of the user .

III. WIRELESS BODY AREA NETWORK

Increasing population and the rising costs of health care technology have triggered the introduction of novel technology driven enhancements to current health care practices. WBAN could offer great advancement in ubiquitous health care which has the potential to improve many aspects of everyday living leading to improved quality of life for many patients. The features of WBAN include:

- Limited energy resources,
- Ultra low transmit power,
- High path loss,
- Frequent change of network topology,
- Dynamic QoS requirements.

IV. DIVERSITY

In order to combat the effect of fading due to multipath propagation in wireless networks, diversity techniques are employed. The fundamental idea of diversity technique is to transmit multiple independent replicas of the same information bearing symbols to the receiver. This reduces the probability of all the replicas suffering severe fading simultaneously. One method of achieving diversity is to transmit the replicas of signals across different antenna's of the receiver that are spaced a few wavelength's apart. But due to strict size and complexity limitations on wireless terminals a new diversity technique called cooperative diversity is introduced.

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V. COOPERATIVE DIVERSITY

Cooperative diversity exploits the broadcast nature and inherent spatial diversity of wireless channels where in the terminals share their antenna's and other resources to create a virtual array through distributed transmission and signal processing. This technique employs a source, several relays between a source and a destination thereby forming a cooperative network. The relays help the source transmit the information symbols to destination. The same information symbols are transmitted through different relays. The information symbols are also directly transmitted from source to destination.

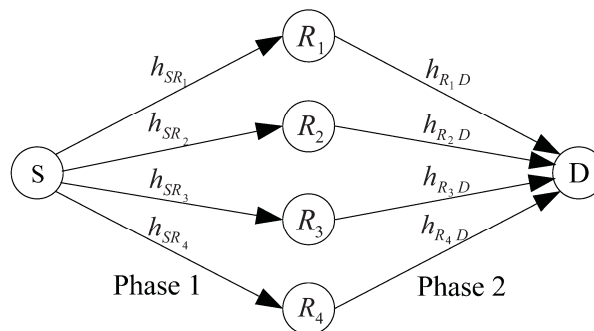


Fig2.Cooperative Diversity

VI. RELAY SELECTION PROCEDURE

The basic idea of relay selection is to allow the relay with best channel conditions to transmit the signals. Based on how the relays process the signals from source, two cooperative protocols, the AF protocol and DF protocol were proposed. In AF protocol the cooperative terminals simply forward the signal without decoding, thus provide less complexity. In DF protocol, the relay decodes and re-encodes the received signal, then it forwards it to destination. Compared to DF protocol, the AF protocol is much simple, offers low cost, less complexity and low computational power.

M-Relays

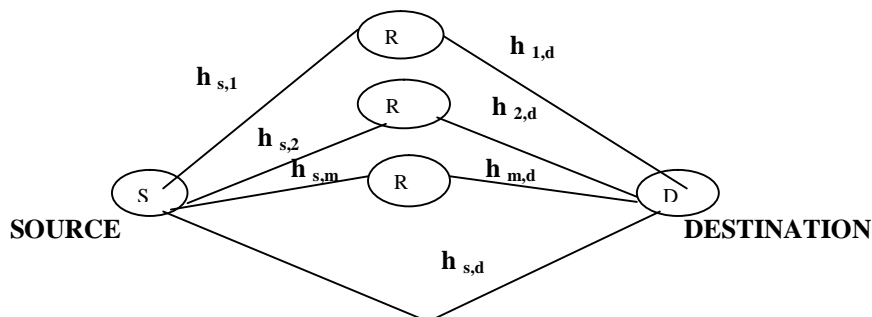


Fig3.Relay Selection Procedure

Relaying takes place in two phases:

- Broadcasting phase: The source broadcasts the message to both the relay nodes and the destination.
- Cooperative phase: The source and relays cooperatively forward the message to destination.

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VII. COOPERATIVE RELAYING

The concept of cooperative relaying is a promising means to counteract the effects of small scale fading. It builds on the concept of cooperative diversity and exploits alternative communication paths by getting assistance from other nodes in the vicinity of the sender and receiver of a currently affected communication link. These other nodes then act as relays i.e. a dedicated or temporarily elected wireless node that assists in forwarding information from a source node to a destination node. The relayed information flow hereby establishes a communication path concurrent to direct communication path from source to destination or to communication via other relays. Due to spatial and time diversities, the alternative path is uncorrelated from the fading effects on the direct link. On applying the principle of cooperative relaying on a WBAN the following output graph of BER performance versus SNR is obtained using MATLAB.

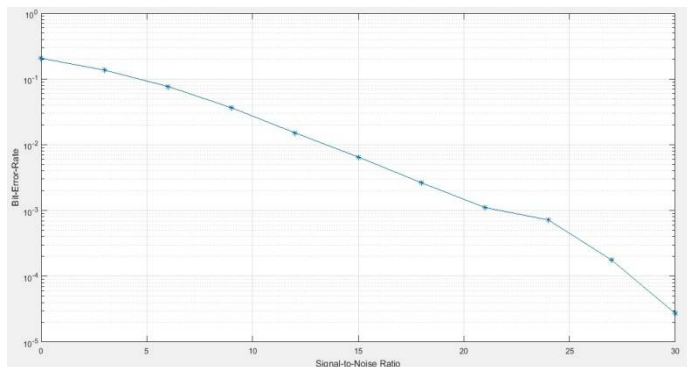


Fig4. BER performance with respect to SNR on application of Cooperative relaying technique.

The above graph states that on application of cooperative relaying technique among 10000 bits transmitted 1 bit has error at an SNR of 30 decibels.

VIII. SPACE TIME BLOCK CODING

STBC stands for space time block coding. It is an optional alternative to spatial multiplexing. These codes are transmitted using a block structure which enables simple decoding at the receiver. Its function is to transmit information over a multiple antenna wireless communication system. If there are N transmit antennas and decoder contains M receive antennas the goal of space time coding is to achieve maximum diversity of NM, the maximum coding gain and the highest possible throughput. Thus STBC can be considered as a modulation scheme for multiple transmit antennas that provide full diversity and very low complexity encoding and decoding.

IX. ALAMOUTI STBC

Alamouti STBC also known as orthogonal STBC (O-STBC) does not need CSI or knowledge of channel coefficients at the transmitter hence it is very useful from practical perspective. Consider a 1x2 MISO system:

Here $r = 1$ is the number of receive antennas and $t = 2$ is the number of transmit antennas. System model is as follows:

$$Y = (h_1 \ h_2) \begin{pmatrix} x_1 \\ x_2 \end{pmatrix} + w \quad \longrightarrow \quad \text{equation 1}$$

Here h_1 and h_2 are channel coefficients

In the first time instant the transmission is as follows:

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x_1 is transmitted by transmit antenna 1 and
 x_2 is transmitted by transmit antenna 2 and
 w is the additive white Gaussian noise (AWGN)
The symbol received y_1 is given as:

$$y_1 = \begin{pmatrix} h_1 & h_2 \end{pmatrix} \begin{pmatrix} x_1 \\ x_2 \end{pmatrix} + w_1 \longrightarrow \text{equation 2}$$

Here y_1 is the symbol received at the output of the first time instant.

In the second time instant:

$-x_2^*$ is transmitted by transmit antenna 1 and

x_1^* is transmitted by transmit antenna 2

Then symbol y_2 received at second time instant is

$$y_2 = \begin{pmatrix} h_1 & h_2 \end{pmatrix} \begin{pmatrix} -x_2^* \\ x_1^* \end{pmatrix} + w_2 \longrightarrow \text{equation 3}$$

On expanding equation 3 we have:

$$y_2 = -h_1 x_2^* + h_2 x_1^* + w_2 \longrightarrow \text{equation 4}$$

Then y_2^* at the receiver will be:

$$\begin{aligned} y_2^* &= -h_1^* x_2 + h_2^* x_1 + w_2^* \\ &= h_2^* x_1 + h_1^* (-x_2) + w_2^* \\ &= h_2^* x_1 + (-h_1^*) x_2 + w_2^* \longrightarrow \text{equation 5} \end{aligned}$$

Hence we have:

$$y_2^* = \begin{pmatrix} h_2^* & -h_1^* \end{pmatrix} \begin{pmatrix} x_1 \\ x_2 \end{pmatrix} + w_2^* \longrightarrow \text{equation 6}$$

Combining equation 2 and equation 6 we have:

$$\begin{pmatrix} y_1 \\ y_2^* \end{pmatrix} = \begin{pmatrix} h_1 & h_2 \\ h_2^* & -h_1^* \end{pmatrix} \begin{pmatrix} x_1 \\ x_2 \end{pmatrix} + \begin{pmatrix} w_1 \\ w_2^* \end{pmatrix} \longrightarrow \text{equation 7}$$

• Suppose :

$$\begin{pmatrix} y_1 \\ y_2^* \end{pmatrix} = \bar{y} \quad , \quad \begin{pmatrix} h_1 \\ h_2^* \end{pmatrix} = \bar{c}_1 \quad , \quad \begin{pmatrix} h_2 \\ -h_1^* \end{pmatrix} = \bar{c}_2 \quad , \quad \begin{pmatrix} x_1 \\ x_2 \end{pmatrix} = \bar{x} \quad , \quad \begin{pmatrix} w_1 \\ w_2^* \end{pmatrix} = \bar{w}$$

Then we have:

$$\bar{y} = \bar{c}_1 x_1 + \bar{c}_2 x_2 + \bar{w}$$

Here \bar{w} is the Gaussian noise vector with independent and identically distributed (iid) noise elements i.e. mean is zero variance of the noise elements is σ^2 and correlation between two noise elements is zero.

• Properties of columns:

$$\bar{c}_1 = \begin{pmatrix} h_1 \\ h_2^* \end{pmatrix} \quad \text{and} \quad \bar{c}_2 = \begin{pmatrix} h_2 \\ -h_1^* \end{pmatrix}$$

$$\text{Observe that } \bar{c}_1^H = (h_1^* \quad h_2)$$

This implies that:

$$\begin{aligned} \bar{c}_1^H \bar{c}_2 &= (h_1^* \quad h_2) \begin{pmatrix} h_2 \\ -h_1^* \end{pmatrix} \\ &= h_1^* h_2 - h_2 h_1^* \\ &= 0 \end{aligned}$$

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This means that the inner product between these two columns is zero which means \bar{c}_1 and \bar{c}_2 vectors are orthogonal vectors, hence Alamouti code is also known as Orthogonal STBC.

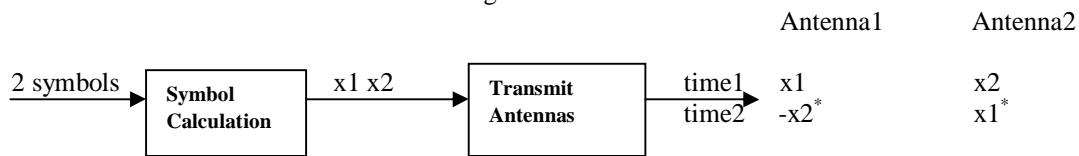


Fig5. Transmitter block diagram for Alamouti code

X. PRECODING

Precoding also known as optimal linear transformation is a technique which exploits transmit diversity by weighing the information stream. It is done to minimize the probability of decoding error. The transmitter sends the coded information to the receiver to achieve pre-knowledge of the channel. Channel covariance matrix at the transmitter is assumed to be known. The receiver is a simple detector and it does not have to know the channel state information (CSI). This technique will reduce the corrupted effect of the communication channel. Orthogonal STBC is used and a linear transformation unit is applied prior to transmission to take account of the channel covariance matrix. The following graph explains the improvement in BER performance with respect to SNR on applying cooperative relaying with precoded Alamouti scheme on a WBAN.

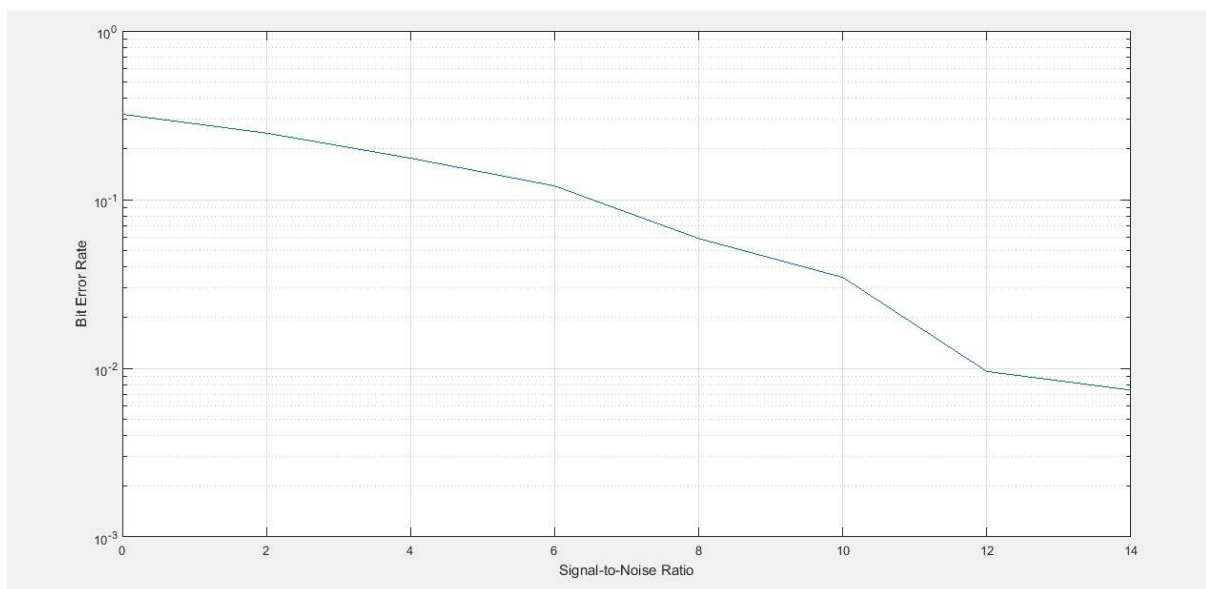


Fig6. BER performance with respect to SNR on application of cooperative relaying with precoded Alamouti scheme

The above graph shows the improvement in BER performance obtained on applying Precoded Alamouti scheme. It can be seen that among 1000 bits transmitted 1 bit is in error at an SNR of 14 decibels. On comparison with the previous graph wherein only cooperative relaying scheme was applied it can be seen that 10^{-3} BER was obtained at 24 decibels whereas on applying the precoded Alamouti scheme together with cooperative relaying we can see that 10^{-3} BER is obtained at 14 decibels which is a significant improvement in performance characteristics.

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XI. PARTICLE SWARM OPTIMIZATION

Particle Swarm Optimization (PSO) was invented by Russel Eberhart and James Kennedy in 1995. It belongs to the field of swarm intelligence and collective intelligence and is a subfield of computational intelligence. PSO is an evolutionary algorithm whose function is to provide the best possible output across a given condition. Such evolutionary algorithms which are capable of making self decisions on the basis of the defined input and output characteristics wherein within these characteristics and within a particular input range a minimum value or maximum value is desired. In the proposed system model a codebook is generated from PSO technique. In PSO codebook an objective function is defined which is same as the mathematical relation to be established. Thus PSO is a technique to find out that code corresponding to which the system provides minimum error to obtain the best possible results. The following graph shows the comparative study between the BER performance of Precoded Alamouti scheme and PSO codebook optimized precoded Alamouti scheme on a wireless body area network.

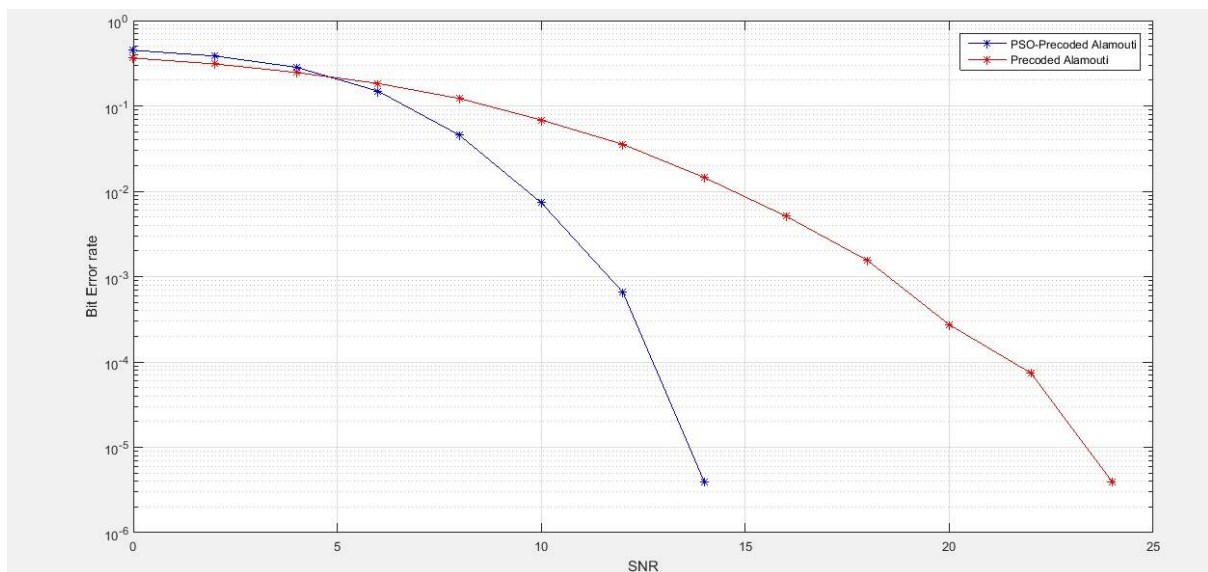


Fig.7.Comparitive study of BER performance characteristics with respect to SNR

XII. CONCLUSION

The comparative study of various techniques used for efficient and reliable communication on a WBAN proves that Alamouti is a very important transmission scheme and it's a key milestone in the development of wireless systems such as WBAN because the decoding at the receiver is simple due to the orthogonal structure of Alamouti and also it does not need channel state information at the transmitter (CSI). Alamouti along with the evolutionary algorithm PSO further optimizes the system performance by giving the best possible outcome for a given condition.

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