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Implementation of an Adaptive MIMO System using Effective Minimization of Frame Error Rate

Leena Govekar, Y. S. Rao

Abstract: Paper Multiple Input Multiple Output (MIMO) is a technique which is now being widely used for wireless communication techniques such as 4G LTE. MIMO uses multiple antennas at the transmitter as well as at the receiver side in order to improve spectral efficiency although it increases the system complexity. Multipath propagation, which is the drawback for wireless communication, is used as an advantage in MIMO. This paper presents a model of Adaptive MIMO system in Simulink. The system adapts to specific transmit and receive diversity depending on the frame error rate. The proposed system uses 4 transmitting and receiving antennas, the number of antennas change as per the adaptation algorithm.

The data is sent in the form of frames with each frame carrying the desired number of bits. Here, we have implemented the Orthogonal Space-Time Block Coding (OSTBC) scheme in a MATLAB Simulink model and implemented an adaptive algorithm to change the quantity of transmitting and receiving antennas depending on the frame error rate (FER) value.

Keywords: MIMO, 4G LTE, Adaptive, Frame Error Rate (FER).

I. INTRODUCTION

With technological advancements in the telecommunication industry, the need for higher data rates and throughput along with the reliability is highly required. To maintain such features LTE system uses adaptive MIMO scheme which has a great impact on reliability and frame error rate of the system [7]. This paper presents a mathematical algorithm which is used for Orthogonal Space Time Block Coding (OSTBC) and adaptation mechanism. Depending on the current performance of the system frame error rate is calculated, which in turn issued to change the number of transmitting and receiving antennas. This does increases complexity as well as data redundancy of the system but it has a visible impact on system performance in terms of frame error rate. Multiple Input Multiple Output (MIMO) is one of the most important breakthrough in wireless communication.

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* Correspondence Author
Mrs. Leena Govekar*, Assistant Professor and Head, Department of Padmabhushan Vasantdada Patil College of Engineering, Mumbai, India.
Prof. Y. S. Rao, Vice Principal, Sardar Patel Institute of technology, Mumbai, India.

Due to the use of MIMO in LTE, it's possible to achieve lower bit error rate as well as higher data speed. Adaptive MIMO is nothing but for a given communication link, data will be transmitted and received using more number of antennas and number of transmit and receive antennas depend upon various factors such as amount of data, noise, channel parameters, etc. To improve the quality i.e. Frame Error Rate (FER) or the data flow of the connection for every user, signals at transmitting antennas and signals at receiving antennas are combined using various methods, as shown in Figure 1. This increases network's quality as well as operator's revenue.

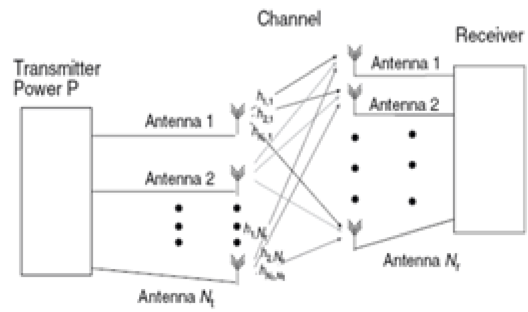

Fig. 1. Multiple Input Multiple Output System.

It is important to note that each antenna operates at same frequency in the MIMO system [2]. Therefore no extra bandwidth is required for multiple antennas. Also, the power required for a single antenna system is more than or equal to the total power required for all the antennas.

$$\sum_{k=1}^{N} pk \leq P \tag{1}$$

where the total number of antennas is N, the power of kth antenna element is pk, and the power required for single antenna element system is P [1]. Equation 1 makes sure that MIMO system does not consume more power than corresponding single antennas system.

II. SPACE TIME BLOCK CODES

These codes are derived from Alamoutis Scheme. The Relation between them being, STBC is just a generalized version of Alamoutis Code[10]. Key features are preserved in STBC while deriving from Alamouti's Scheme. The block codes used are orthogonal to each other and can attain complete broadcast diversity stated by the number of broadcast antennas. OSTBC's remain a more complicated variant of Alamouti's Space-Time Code. There is no difference in encoding and decoding on both receiver and transmitter.

The data to be transferred is shaped to form a matrix whose columns represent the quantity of transmitting antennas and rows indicating specified time blocks needed to transfer data. On the recipient end, accepted symbols are interpreted according to the rules set by the transmitter and later given to implement decision rules using the maximum-likelihood (ML) detector.

It is possible to attain the highest heterogeneity at the transmitter as well as the receiver side provided that it uses comparatively easy adaptation as well as a decoding algorithm. This is the reason why space-time block codes are used widely.

A. Alamouti Scheme

STBC's are built using Alamoutis coding technique. Alamoutis scheme is explained here mathematically using two transmit and one receive antenna[6]. In this work, OSTBC encoder and decoder is used with adaptation algorithm, which selects quantity of receive and transmit antennas depending upon Frame Error Rate (FER). At the transmitting side, two symbols are taken at a time for transmission from source and sent to the modulator. Modulated symbols are taken by Alamouti space-time block encoder, encoding matrix S is formed in this state by s_1 and s_2, where a pair symbol is mapped via two broadcast antennas inside two different time slots [11]. The Encoding matrix S is shown as:

$$S = \begin{bmatrix} s_1 & s_2 \\ -s_2^* & s_1^* \end{bmatrix} \tag{2}$$

The fading coefficients are considered fixed in the pair of sequential symbol transmitting stages. They are represented by $h_1(t)$ and $h_2(t)$ and they are described as:[4]

$$h_1(t) = h_1(t+T) = h_1 = |h_1| exp^{j\theta_1} \tag{3}$$
$$h_2(t) = h_2(t+T) = h_2 = |h_2| exp^{j\theta_2} \tag{4}$$

The receiver accepts two symbols denoted by r_1 and r_2 over two consecutive symbol duration for time duration t and t+T. The obtained signal is represented by

$$\begin{vmatrix} r_1 \\ r_2 \end{vmatrix} = \begin{vmatrix} s_1 & s_2 \\ -s_2^* & s_1 \end{vmatrix} \begin{vmatrix} h_1 \\ h_2 \end{vmatrix} + \begin{vmatrix} n_1 \\ n_2 \end{vmatrix} = \begin{vmatrix} h_1 + h_2 s_2 + n_1 \\ -h_1 s_2^* + h_2 s_1^* + n_2 \end{vmatrix} \tag{5}$$

To minimize the distance metric covering every probable state of s^{ffl}_1 and s^{ffl}_2, The maximum likelihood decoder accepts two signals (s^{ffl}_1 , s^{ffl}_2) from the signal array [5].

$$d^2(r_1, h_1 s_1^{ffl} + h_2 s_2^{ffl}) + d^2(r_2, -h_1 s_2^{ffl} + h_2 s_1^{ffl})$$
$$= |r_1 - h_1 s_1^{flf} - h_2 s_2^{ffl}|^2 + |r_2 - h_1 s_2^{flf} - h_2 s_1^{ffl}|^2$$

The decision rule, for phase-shift keying (PSK) signals, is represented as:

$$d^2(s_1^{ffl}, s_i) \le d^2(s_1^{ffl}, s_k) \vee \ne k$$
$$d^2(s_2^{ffl}, s_i) \le d^2(s_2^{ffl}, s_k) \vee \ne k$$

Following pair of combined signals, are build by combiner shown in Figure 4:

$$\begin{vmatrix} s_1^{ffl} \\ s_2^{ffl} \end{vmatrix} = \begin{vmatrix} h_1^* & h_2 \\ -h_2^* & h_1 \end{vmatrix} \begin{vmatrix} r_1 \\ r_2^* \end{vmatrix} = \begin{vmatrix} h_1^* r_1 + h_2 r_2^* \\ h_2^* r_1 + -h_1 r_1^* \end{vmatrix} \tag{6}$$

Figure 2 and Figure 3 shows the Alamouti type encoder and decoder. Data to be sent is modulated and then provided to ST encoder. As we're considering Alamouti scheme, encoder consists of a couple of transmit antennas as a component of the MIMO system [8]. Each antenna has channel, represented by different channel coefficients and two antennas are used to transmit the signal. Channel coefficients perform a significant role in designing the system. Complexity is bound to increase when the number of antennas increases [3].

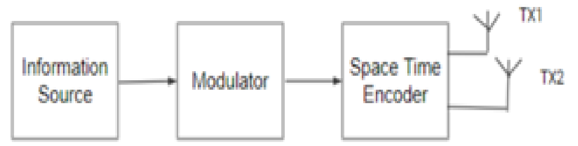

Fig. 2. Space-Time Encoder (Alamouti).

Once the signal is obtained, it is given to the channel estimator at the receiving end. Then, coefficients of estimator are mixed in the output from the combiner and the resultant is given to ML decoder. The demodulator then gets the recognized signal as an input. The original data which is sent is received at the demodulator.

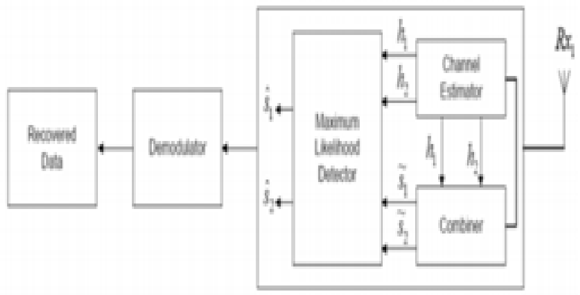

Fig. 3. Space-Time Block Decoder (Alamouti).

Orthogonal Space Time Block Codes are nothing but Alamouti code with increased number of antennas [5]. As number of antennas are increased, complexity also increases in case of OSTBC.

B. Four Transmit and One Receive Antenna

In this example, we've taken one receiving antenna and four transmitting antennas. s_1 denotes signal from antenna 1 (TX1), s_2 denotes signal from antenna two (TX2), s_3 denotes signal from antenna three (TX3), Signal from antenna four (TX4) is denoted by s_4. The mapping, encoding and transfer of signal is summarised in Table 1.

Table- I: OSTBC-Mapping Encoding for 4 transmit antennas.

	TX1	TX2	TX3	TX4
t	s_1	s_2	s_3	s_4
t+T	$-s_2$	s_1	$-s_4$	s_3
t+2T	$-s_3$	s_4	s_2	$-s_1$
t+3T	$-s_4$	$-s_3$	s_2	s_1
t+5T	s_1^*	s_2^*	s_3^*	s_4^*
t+6T	$-s_3^*$	s_4^*	s_1^*	$-s_2^*$
t+7T	$-s_4^*$	$-s_3^*$	s_2^*	s_1^*

For one receive antenna and four transmit antenna, channel coefficients must be modelled. h_1 be the channel coefficient for the 1st antenna, h_2 be the channel coefficient for the 2nd antenna, h_3 be the channel coefficient for the 3rd antenna and h_4 be the channel coefficient for the 4th antenna. Table II summarizes the Channel coefficients.

Table- II: OSTBC-Mapping Encoding for 4 transmit antennas.

	RX1
TX1	h_1
TX2	h_2
TX3	h_3
TX4	h_4

Fig. 4 shows OSTBC system diagram of one receiving antenna and four transmitting antennas. We've assumed that fading coefficients are constant over the channel.

$$h_1(t) = h_1(t+T) = h_1 = |h_1|exp^{j\theta_1} \quad (7)$$
$$h_2(t) = h_2(t+T) = h_2 = |h_2|exp^{j\theta_2} \quad (8)$$
$$h_3(t) = h_3(t+T) = h_3 = |h_3|exp^{j\theta_3} \quad (9)$$
$$h_4(t) = h_4(t+T) = h_4 = |h_4|exp^{j\theta_4} \quad (10)$$

where, θ_i and h_i are phase and amplitude difference between transmitter antenna i to receiver antenna j. Eight varying signals are received in eight varying time slots. Following are the signals received,

$$r_1 = h_1 s_1 + h_2 s_2 + h_3 s_3 + h_4 s_4 + n_1$$
$$r_2 = h_1 s_2 + h_2 s_1 - h_3 s_4 + h_4 s_3 + n_2$$
$$r_3 = -h_1 s_3 + h_2 s_4 - h_3 s_1 - h_4 s_2 + n_3$$
$$r_4 = -h_1 s_4 - h_2 s_3 - h_3 s_2 + h_4 s_1 + n_4$$
$$r_5 = h_1 s_1^* + h_2 s_1^* - h_3 s_3^* + h_4 s_4^* + n_5$$
$$r_6 = -h_1 s_2^* + h_2 s_1^* - h_3 s_4^* + h_4 s_3^* + n_6$$
$$r_7 = -h_1 s_3^* + h_2 s_4^* - h_3 s_1^* - h_4 s_2^* + n_7$$
$$r_8 = -h_1 s_4^* - h_2 s_3^* + h_3 s_2^* + h_4 s_1^* + n_8 \quad (11)$$

The following four signals are build by the combiner as shown in Fig. 4:

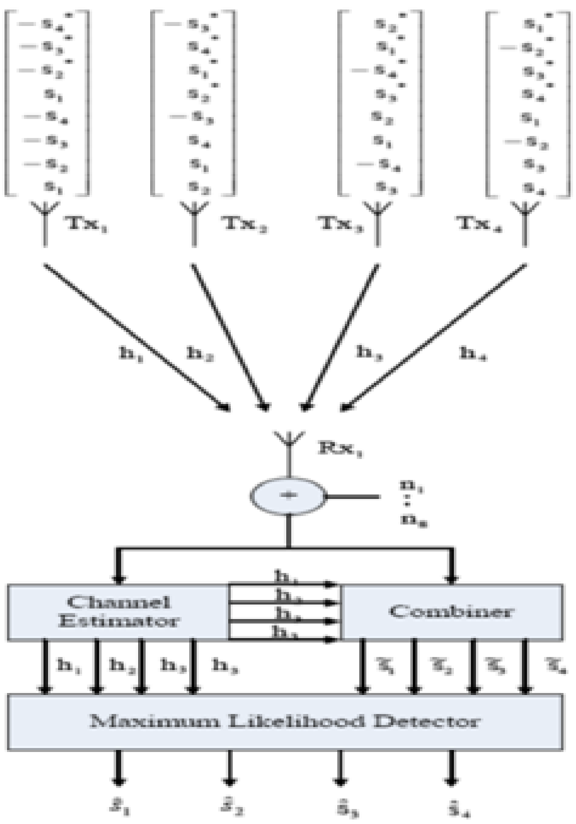

Fig. 4. Space-time Block Code Decoder scheme for 4 x 1 antenna configuration.

$$\tilde{s_1} = h_1^* r_1 + h_2^* r_2 + h_3^* r_2 + h_4^* r_2 + h_1 r_5^* + h_2 r_6^* + h_3 r_7^* + h_4 r_8^*$$
$$\tilde{s_2} = h_2^* r_1 - h_1^* r_2 - h_4^* r_3 + h_3^* r_4 + h_2 r_5^* - h_1 r_6^* - h_4 r_7^* + h_3 r_8^*$$
$$\tilde{s_3} = h_3^* r_1 + h_4^* r_2 - h_1^* r_3 + h_2^* r_4 + h_3 r_5^* + h_4 r_6^* - h_1 r_7^* - h_2 r_8^*$$

III. SIMULINK MODEL IMPLEMENTATION

Block diagram of Adaptive MIMO system using MATLAB Simulink is as shown in the Fig. 5

- A transmitter consists of a signal source, a CRC generator, QPSK modulator, and OSTBC encoder
- AWGN Channel defines noise parameters while the Rayleigh fading channel is used to implement multipath fading environment
- A receiver consists of OSTBC decoder, QPSK demodulator, CRC detector.

CRC generator is given an input frame. CRC generator appends the number of bits to this frame. These bits are checksum bits which are added for error detection. The checksum of the entire input frame is calculated and added at end of the frame. Now, this checksum is calculated again at the receiver end if this checksum matches with the one which was transmitted indicates that there is no error in the received frame.

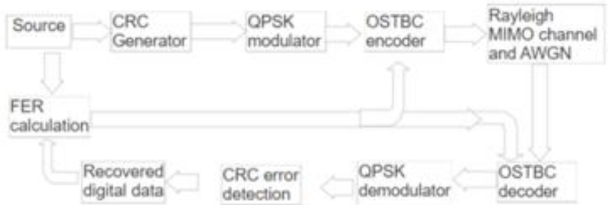

Fig. 5. Adaptive MIMO system block diagram.

The adaptive MIMO communication system discussed in Figure 5 is implemented in Simulink block diagram environment which is also suitable for a real-time environment. Few of the blocks used are retrieved from different communication toolboxes while few of them are user defined MATLAB functions embedded in different Simulink models.

A. Transmitter

Transmitter consists of a Bernoulli Binary Bit Generator, CRC Generator, QPSK Modulator and OSTBC encoder. Bernoulli Bit Generator is used to generate random binary numbers following Bernoulli distribution. We can even specify probability of occurrence of zeros and ones. This block outputs a column vector with the number of rows as frame size.

B. CRC Generator

As discussed CRC generator is used for checksum generation. For the generation of checksum, we need to provide a polynomial. As MIMO is widely used in LTE standard, in this model we have used polynomial which is commonly used in case of 4G LTE. The generator polynomial in LTE is $g(x) = x^{24} + x^{23} + x^{18} + x^{17} + x^{14} + x^{11} + x^{10} + x^7 + x^6 + x^5 + x^4 + x^3 + x^1 + 1$. QPSK modulator modulates the input frame.

C. OSTBC Encoder

Inputs to this block are the number of transmitting antennas in real time and modulated input signal to be transferred. We used a MATLAB function 'comm.OSTBCEncoder' to use the space coding. This function accepts number of transmit antennas as a parameter. Depending on the input received from adaptation algorithm, specific object with the specific number of transmit antennas is created.

D. Rayleigh MIMO and AWGN Channel

Although no channel model on software can perfectly describe a real-time channel environment and behavior because physical channels are stochastic by nature, they strive to obtain as much precision as possible. AWGN channel is used to mimic a random additive noise channel. Rayleigh channel is used to implement the effect of multipath propagation in Simulink. It acts as a real-time channel and provides multiple paths for signal as well.

E. OSTBC Combiner

This block is similar to OSTBC encoder. It has 3 inputs namely number of transmit antennas, Channel Estimation, and received signal which is to be decoded. Channel estimation is obtained from the Rayleigh Multipath channel. Depending upon the quantity of transmitting antennas, multiple copies of these signals are received. OSTBC decoding using respective Space-Time codes is performed based on this number of transmitter (number of received signal copies) and receiver antennas.

F. Frame Error Rate Calculation

At the start of the simulation, we decide the error rate we desire to achieve. This rate is then compared with actual error rate which is calculated at run time. The entire frame is discarded if there is an error.

G. Adaptation Algorithm

Algorithm 1: Adaptation Algorithm
Result: Integer Values for N_t and N_r
initialization
set value of µ
get target Frame Error Rate(FER)
get actual FER during runtime
Error= Target FER-Actual FER
$[N_t, N_r] = [N_t, N_r]+\mu\times[0.9\ 1.1]\times\text{signum(Error)}$
round(N_t) round(N_r)

Thus Algorithm 1 gives us the new value for the quantity of receiving antennas and transmitting antennas depending upon these errors between desired and actual frame error rate.

IV. RESULTS

We simulated the multiple antenna system with various possible antenna configurations. To find the performance of the implemented OSTBC algorithm, we first calculated parameters such as the Frame Error Rate (FER) and the Throughput of the system with reverence to Signal to Noise Ratio (SNR). These calculations were made for different antenna configuration as shown in the Figure 6 and Figure 7.

As shown in Figure 6, the FER value for a given number of transmitter antennas decreases significantly with increase in the number of receive antennas, at given value of SNR. Also after a particular value of SNR, FER value of all of the antenna configurations higher than 2 transmitter and 2 receiver antennas becomes zero. During such signal to noise conditions, we can use lower antenna configurations to achieve desired FER values, in order to save system resources. Similarly saturation in the value of throughput as shown in Figure 7 can be seen for configurations higher than 2X2. An adaption algorithm can be designed to obtain desired values of throughput or FER or both.

The adaption algorithm was designed to achieve the desired value of FER based on the observations done on the change in the FER value with respect to SNR. The change in the number of antennas with respect to time can be seen in Figure 8 to Figure 13. For 8dB SNR, the antenna configuration stayed 4X4. The target FER was also not achieved. At 16dB SNR, the target FER was reached in both cases. For target FER 0.01, antenna configuration was 1X1 for longer time compared to target FER 0.001. At 24dB SNR, the target FER was also reached in both cases. Although in this case the final FER was much lower than the target FER and thus the configuration was 1X1 for a much longer period. The achieved results are summarized in Table 3.

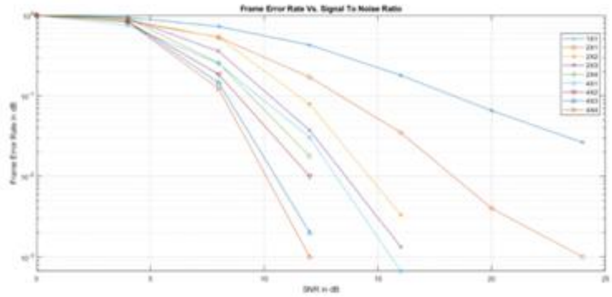

Fig. 6. Frame Error Rate Vs SNR.

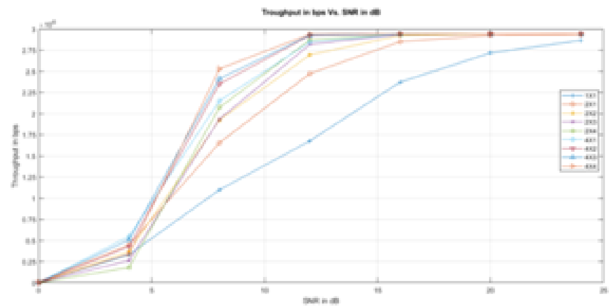

Fig. 7. Throughput Vs SNR.

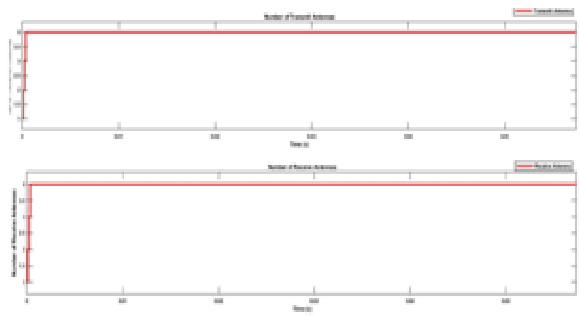

Fig. 8. No. of receiving and transmitting antennas for SNR = 8 dB and target FER = 0.01.

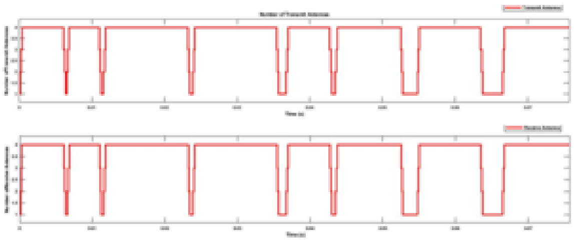

Fig. 9. No. of receiving and transmitting antennas for SNR = 16 dB and target FER = 0.01.

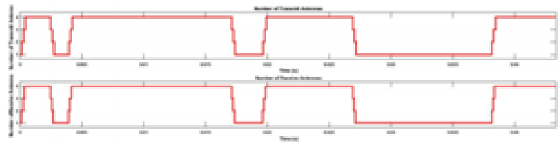

Fig. 10. No. of receiving and transmitting antennas for SNR = 24 dB and Target FER = 0.01.

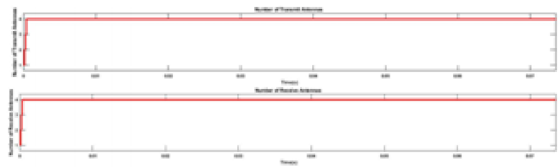

Fig. 11. No. of receiving and transmitting antennas for SNR = 8 dB and Target FER = 0.001.

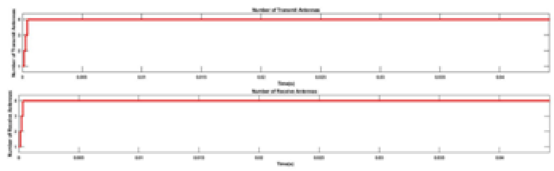

Fig. 12. No of receiving and transmitting antennas for SNR = 16 dB and Target FER = 0.001.

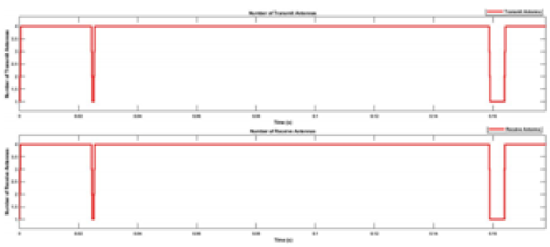

Fig. 13. No. of receiving and transmitting antennas for SNR = 24 dB and Target FER = 0.001.

Table- III: Achieved Frame Error Rate for specified SNR and Target FER

SNR (dB)	For Target FER = 0.01	For Target FER = 0.001
8	0.1218	0.1162
12	0.0101	0.00154
16	0.01005	0.00134
20	0.01002	0.00102
24	0.00877	0.0001954

V. CONCLUSION AND FUTURE SCOPE

In this paper the design of an adaptive MIMO system using OSTBC encoder is discussed. The OSTBC algorithm provides improvement in the value of FER as the antenna system complexity increases. After a particular value of SNR, all configurations provide minimum possible FER for any SNR condition. At such signal conditions it is not necessary to use complex antenna configuration. The 2X4 configuration performs better than 4X1 configuration and comparable to 4X2 configuration. Thus 2X4 configuration can be used at SNR values higher than 12dB instead of 4X1 or 4X2 configurations. The adaptation algorithm implemented changes the quantity of broadcasting and receiving antennas depending on FER values. At higher SNR values, the target FER is achieved relatively quickly and lower antenna configurations are maintained for the longer time. The 4X4 configuration gives the best performance at lower SNR values and is used by the algorithm to reach the target FER. Here, simple and easy adaptation algorithm is used. Certain advanced Neural network algorithms such as Least Mean Square, perceptron learning rule, etc. can be used to improve performance and minimise the Frame Error Rate.

LIMITATIONS

In this paper, it is believed that the parameters for the channel are previously known to the receiving end. The OSTBC decoder must know the number of signal copies that the receiver antennas are receiving in order to use the respective space-time block code. This is done by sending a special packet to notify the receiver about increase or decrease in the antenna number.

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AUTHORS PROFILE

Mrs. Leena Govekar, Currently pursuing Ph.D in Electronics and Telecommunication Engineering from Mumbai University, doing research in the field of 'Software Defined Radio'. She was Assistant Professor and Head of Department of Padmabhushan Vasantdada Patil College of Engineering, Mumbai, India.

Prof. Y. S. Rao, Pursued Ph.D in Electronics Engineering from IIT Bombay. He has varied experience in the fields like Embedded Systems, Digital Power Electronics, Vlsi Design and Wireless Sensor Networks. He has published over 50 technical research papers till now. He is currently Vice Principal of Sardar Patel Institute of technology, Mumbai, India. He has been awarded by IEEE Computer Society, Washington D.C.,USA, at the International Design Competition (CSIDC-2002), for the project "Swift Doc".