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Space-time Turbo Codes with Adaptive Beamforming for MIMO-OFDM : Performance Analysis & Evaluation

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***Abstract:*-This paper proposes a MIMO-OFDM system with adaptive beamforming algorithm for smart antenna. Performance analysis of the combined scheme is presented using optimum turbo codes with transmit diversity on AWGN channel. The performance of the proposed system is tested for various modulation techniques such as BPSK, QPSK, 16-PSK& 256-PSK.Simulation results demonstrate that the proposed system has good ability of suppressing interference and significantly improves the bit-error rate (BER).Experimental results show that an adaptive beamforming gives the optimum performance on AWGN channels. Graphical User Interface has also been developed to automate the task of simulation that presents the result in a systematic manner.**

***Keywords*-LMS (least mean squares), space-time turbo code (STTC), spatial diversity, transmit diversity**

1. INTRODUCTION

The phenomenon of multipath propagation has contributed significantly towards deterioration of quality of signal received in a wireless communication system. Several techniques for multipath mitigation are in use in the current wireless communication technology standards. With the steady rise in the number of wireless devices active in the environment, the concept of beamforming has also gained popularity.

Recently, the space-time coded orthogonal frequency division multiplexing (STC-OFDM) system is a promising scheme for broadband communications. As wireless communication systems look intently to compose the transition from voice communication to interactive internet data, achieving higher bit rates becomes both increasingly desirable and challenging. Space-time coding (STC) is a communications technique for wireless systems that inhabit multiple transmit antennas and single or multiple receive antennas. Space-time codes make use of advantage of both the spatial diversity provided by multiple antennas and the temporal diversity available with time-varying fading. Space-time codes can be divided into block codes and trellis codes. Space-time trellis coding merges signal processing at the receiver with coding techniques appropriate to multiple transmit antennas. The advantages of space-time codes (STC) make it extremely remarkable for high-rate wireless applications. Initial STC research efforts focused on narrowband flat-fading channels. The decoding complexity of Space-time turbo codes STTC increases exponentially as a function of the diversity level and transmission rate. [1]

Among the existing air-interface techniques, orthogonal frequency division multiplexing (OFDM) [2]–[4] has shown a number of advantages and has attracted substantial interest. New wireless techniques, such as ultra wideband (UWB) [5], advanced source and channel encoding, various smart antenna techniques , space-time codes (STCs) [6], space division multiple access (SDMA) [1], beamforming, as well as other multiple-input multiple output (MIMO) [7], [8] wireless architectures are capable of offering substantial gain. To obtain the maximum possible diversity gain is the objective of the family of space-time block coding (STBC) [11] as well as space-time trellis coding (STTC) [12] schemes found in the literature [6]. The beneficial effects of second-order transmit and up to sixth-order receiver diversity was demonstrated in the context of STBC-aided MIMO-OFDM [13], [14]. Finally, beamforming mitigates the effects of interfering users roaming in the vicinity of the desired user [15], provided that their received signals are angularly separable.

The quality of a wireless link can be described by three basic parameters, namely the transmission rate, the transmission range and the transmission reliability. Conventionally, the transmission rate may be increased by reducing the transmission range and reliability. By contrast, the transmission range may be extended at the cost of a lower transmission rate and reliability, while the transmission reliability may be improved by reducing the transmission rate and range [16]. However, with the advent of MIMO assisted OFDM systems, the above-mentioned three parameters may be simultaneously improved [16]. Initial field tests of broadband wireless MIMO OFDM communication systems have shown that an increased capacity, coverage and reliability are achievable with the aid of MIMO techniques [17]. Furthermore, although MIMOs can potentially be combined with any modulation or multiple access technique, recent research suggests that the implementation of MIMO-aided OFDM is more efficient, as a benefit of the straightforward matrix algebra invoked for processing the MIMO OFDM signals [16].

Multi-antenna implementation such as MIMO and beamforming enhances the coverage and capacity in even the most challenging environments. Smart antenna utilizes the strong spatial correlation to process the received signal by antenna arrays with beamforming technique. It is able to provide high directional beamforming gain and reduces the interference from other direction under high spatial correlated MIMO channel.

Considering the advantages of these various MIMO techniques, there is a need to integrate them so that the whole system can benefit from these technologies. These three techniques have the same feature in the view of requiring the multiple antenna elements, but have the contradictive requirement for antenna element spacing. Because it is conflictive that the smart antenna works under high spatial correlated MIMO channel .while the spatial diversity technique work under low spatial correlated MIMO channel.

Thus, the combination of STC and OFDM is a promising scheme for future wideband multimedia wireless communication systems [2]. However, using multiple transmit antennas causes mutual interference either signals transmitted from different antennas of the same transmitter or the other user transmitters [10]- [11].

To minimize the interference from different directions, smart antennas can be used at the receivers which form the beam in the direction of the incoming multipath and reject the interference coming from other directions. The main objective of this work is to incorporate the adaptive beamforming for interference rejection in OFDM multiple input multiple output system so that BER can be improved.

Organization of this paper is as follows. Section2 present an Adaptive beamforming and Space-Time Block Coding in MIMO Using OFDM .Section 3 presents adaptive beamforming algorithms LMS whereas simulation results are given in Section 4 followed by the conclusions. In this paper the symbols [.]*, [.]T, and, [.]H, are conjugate, transpose and, conjugate transpose operators, respectively.

2. ADAPTIVE BEAMFORMING AND SPACE-TIME TURBO CODING IN MIMO USING OFDM

2.1 System model

Fig.1 presents the block diagram of the MIMO OFDM space-time turbo coded system with smart antenna. The OFDM transmission and reception are respectively presented in Fig.1 (a) & Fig.1 (b).

2.2 Transmitter Part

At transmitter first, the data is generated from a random source, consists of a series of ones and zeros. Data input bits are converted into symbol vector using modulation. Modulation scheme used to map the bits to symbols are BPSK, QPSK, 16 PSK, 256 PSK. The data modulated symbol sequence is fed into the ST Turbo coder. The ST Turbo coder maps the block of m-binary symbols into two sequences. The first sequence is generated using normal convolution code and second is generated using interleaved convolution code. The two output signals from STTC x1 and x2 termed as normal sequence & interleaved signal as shown in fig.(1).

Since the transmission is done block wise, when forward error correction (FEC) is used, the size of the data generated depends on the block size used, modulation scheme used to map the bits to symbols (BPSK,QPSK16 PSK,256 PSK), and whether FEC is used or not. The generated data is passed on to the next stage i.e to the FEC block.

Forward error correcting codes are applied to normal convolution code sequence and interleaved convolution code sequence. The error correcting codes are used, to avoid long run of zeros or ones, as the data generated is randomized. This results in ease in carrier recovery at the receiver. The randomized data is encoded using tail biting convolution codes (CC) with a coding rate of ½ .

2.3 Subcarrier allocation:

The subcarrier allocation separates data into set of 4 subcarriers and OFDM time symbol then passed onto the next stage, the IFFT, to convert into time domain.

2.4 IFFT :

An efficient way of implementing IDFT is by inverse fast Fourier transform (IFFT).

$$Sj(n) = \frac{1}{N}\sum_{n=0}^{N-1} x_j \exp(\frac{j2\pi kn}{N}) \qquad (1)$$

Hence IFFT is used in generation of OFDM symbol. The IFFT size (‘N’ value) is considered as 256 in simulations. This data is fed to the channel which represents AWGN model. The resulting signal at the transmitter can be expressed as

$$x(n) = \frac{1}{N}\sum_{n=0}^{N-1} X(k)\exp(\frac{j2\pi kn}{N}) \qquad (2)$$

Where, j is the number of transmitting antennas.

2.5 Channel

The channel is dispersive i.e. multipath components of the signal are created. Additive White Gaussian Noise (AWGN) is added in these multipaths in accordance to the SNR of these signals, i.e. for high SNR low noise is added while for low SNR high noise is added. Multipath may arrive at receiver from different directions.

In the Simulation two transmitted signals are scattered using 20 scattered sequences. Twenty random sequences are generated with the noise level as 10. Finally additive white Gaussian noise (AWGN) is added as a last component in the channel.

2.6 Receiver

The MIMO OFDM receiver is shown in Fig. 1(b). At the receiver, the signals are received and combined with different path loss and different fading fluctuation. Receiving antennas used at the receiver are 2. The complex-valued propagation channel gains experienced between the two transmit antennas & two receiving antennas are represented by H. The received Signal from j transmitting antenna and P propagation paths is expressed as,

$$V(n) = \sum_{p=1}^{P}\sum_{j=1}^{2}[A \otimes H^{p}]S_j(n - p\Delta\tau) + G(n) \qquad (3)$$

The first thing done at receiver (in simulation) is estimation the angle of reception.

1. Find out the sum of power of all incident signals for each angle from (0º to 180º) of all elements.(As the sequences are scattered)
2. From the maximum peak in the power spectrum we can estimate the DOA’s of the desired signals.
3. Two transmitting & two receiving antennas are used .So at the receiver we get four copies of the received signal.

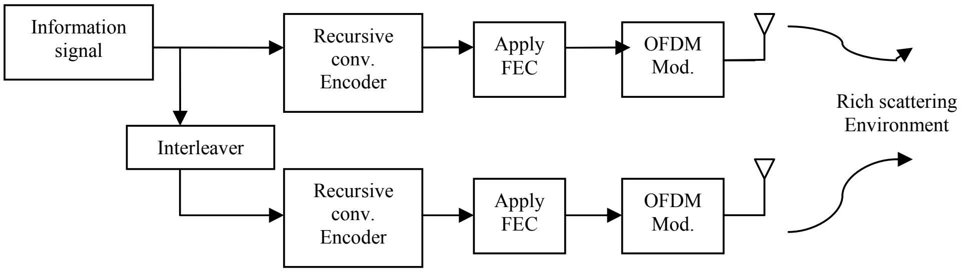

Fig.1 (a) STTC based MIMO-OFDM Transmitter

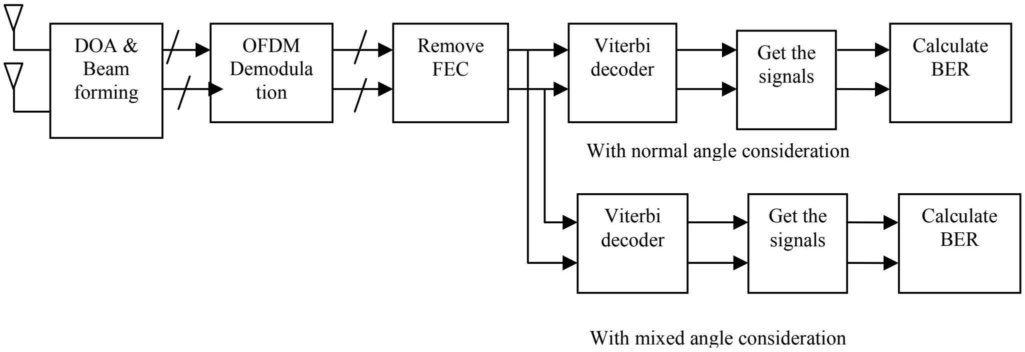

Fig.1 (b) STTC based MIMO- OFDM Receiver

Fig.1: Block diagram of ST-TURBO CODED MIMO- OFDM system using Adaptive beamforming at receiver

4. Two copies form normal sequences and two from interleaved sequence.

5.At the receive these two copies termed as normal angle reception signals i.e when the signal from transmitting antenna 1 Tx1, is received by the receiving antenna 1,Rx1.Same is the case for Rx2.So, two signals are obtained normal angle reception signal 1& normal angle reception signal 2.Now when reciving antenna 1 Rx1, received the signal from Transmitiing antenna 2 Tx2 it is termed as mixed angle reception. Same is the case for Rx2. So, two signals are obtained mixed angle reception signal 1 & mixed angle reception signal 2.

6. After estimating the angle of arrival an Adaptive beamforming algorithms LMS is used to minimize the interference. This algorithm is described in section III.

2.7 *FFT*

After receiving four copies of the signal, signals are fed to the FFT for frequency domain transformation.

2.8 *Removal of FEC*

After this FEC is removed from the normal angle reception signals & mixed angle reception signals.

2.9 *Viterbi Decoder*

For decoding of the signals viterbi decoders are used. Four sequences are compared to find out which sequence has minimum value of error in bits. For this each sequence is matched with the input sequence to find out which sequence has minimum BER. Finally it gives the result in terms of recovered sequence & recovered mode i.e. normal reception mode or mixed reception mode along with the angle of recovery.

3. ADAPTIVE BEAMFORMING

This section describes adaptive beamforming algorithms LMS. Because of its simplicity and robustness, the LMS algorithm has become one of the most popular adaptive signal processing techniques adopted in many applications including antenna array beamforming. Moreover, there is always a tradeoff between the speed of convergence of the LMS algorithm and its residual error floor when a given adaptation step size is used.

3.1 *LMS-based adaptive beamforming Algorithm*

Firstly, we consider the LMS-based adaptive beamforming methods. The LMS algorithm is a popular solution used in beamforming technique. This algorithm is easy to implement with low computation and performs pretty well. The basic LMS algorithm is expressed as follow [8].

$$w(n+1) = w(n) + 2\mu x(n)e(n) \qquad (4)$$

The reference signal d (t) generated at the receiver is usually assumed to have similar statistical properties as the transmitted signal.

For the purpose of simulation, we will simply assume that the reference signal is identical to the incoming signal. The error signal e (n) = d (n) − y (n) is fed into the weight updating algorithm. The criterion for determining the weights is based on minimizing the mean squared error (MSE) between the beamformer output and the reference signal:

$$E(e^2) = E[(d-y)^2]$$

$$E(e^2) = E(d - w^H x)^2]$$

$$E(e^2) = E(d^2) - 2E(dw^H x) - E[(w^H x)^2]$$

$$E(e^2) = E(d^2) - 2w^H r - w^H R_{xx} w \qquad (5)$$

Where Rxx is the autocorrelation matrix of the received signal x and r = E[dx] is the cross-correlation between the reference signal and the received signal. The MSE surface is a quadratic function of w and is minimized by setting its gradient with respect to w to zero.

$$\Delta w[E(e^2)] = -2r + 2R_{xx} w = 0$$

Yielding the well-known Wiener-Hopf solution-

$$w_{opt} = R_{xx}^{-1} r$$

The LMS algorithm is a stochastic gradient optimization algorithm that converges to this solution. It is based on a traditional optimization technique called the Method of Steepest Descent. The weight vector is made to evolve in the direction of the negative gradient which points towards the minimum.

$$w(n+1) = w(n) + \frac{\mu}{2}\{-\nabla w[E(e^2(n))]\}$$

$$w(n+1) = w(n) + \frac{\mu}{2}\{2r(n) - 2R_{rr}(n)w(n)\} \qquad (6)$$

Where Rxx and r are given by

$$R_{xx}(n) = x(n)x^H(n)$$

$$r(n) = d(n)x(n)$$

This gives us a simple expression for weight updating:

$$w(n+1) = w(n) + 2\mu x(n)e(n)$$

The LMS algorithm is initiated with an arbitrary value w(0) for the weight vector at n=0. The successive of the weight vector eventually leads to the minimum value of the mean squared error. LMS algorithm can be summarized in following equations:

Output ,

$$y(n) = w^H(n)x(n)$$

Error,

$$e(n) = d(n) - y(n)$$

Weight ,

$$w(n+1) = w(n) + \mu x(n)e^*(n)$$

4. SIMULATION RESULTS

This section presents the simulations results which illustrate the performance of binary turbo codes combined with the adaptive beamforming for MIMO-OFDM. The performance is measured in terms of BER as a function of SNR. In the simulation all the graphs for BER shows the number of error bits in a total transmitted number of bits. Simulation results provided in this section allow the effect of various parameters on the performance to be observed. Various simulation parameters assumed are,

Code length = 100
FFT size=64
Number of carriers=4
Window type= Hamming

The system model has been tested for BPSK, QPSK, 16 PSK, 256 PSK modulations with an AWGN channel. The simulations as shown in Fig.3 are based on LMS algorithm. In the simulation, there are 2 transmitter antennas and the number of the receiving antennas is 2. The DOAs of two transmitter antennas for desired user are 10°, 90°. It has been observed that when the signals are scattered then it changes the angle of arrival i.e. the DOA's in this case are not 10º & 90º but at some other angles.

4.1 Graphical User Interface

The graphical user interface for this system is also developed which at present is for single user. It helps in simulating and testing the proposed system with and without smart antenna. The system parameters which can be controlled via the graphical user interface are:

1) Length of input sequence.
2) Angle of transmission of the transmitted signals
3) FFT size
4) No. of carriers
5) Number of bits to transmit on each carrier, 1 => BPSK, 2 => QPSK, 4 => 16PSK, 8 => 256PSK.
6) Guard type-No guard type, zero level guard periods, cyclic extension of end of symbols, cyclic extension of end of symbols with first half of guard period is zero.
7) Guard time-Number of sample to use for the total guard time
8) SNR range

The GUI provides options to the user to run simulation with & without smart antenna scenario. Currently, GUI has been prepared only for single user scenario however it can be modified for multi-user through minor additions in the interface.

The simulation result of Fig. 3 shows the snap shots of the GUI which shows BER comparison of proposed technique based on LMS for different modulation techniques. After specifying the required simulation parameters, the user can simulate the scenario for our proposed system. The simulation results except BER are displayed when the simulation is going on for different values of SNR whereas BER graph can be obtained when simulation is completed. The results displayed to the user via GUI are:

1) Plot of input sequence
2) Plot of DOA estimation
3) Polar plot of beamforming
4) Plot of recovered sequence
5) BER results of the system with &without smart antenna

It has been observed from GUI for different modulation technique that BER with smart antenna is better than the BER without smart antenna but there is very small deviation in BER for different modulation. Whereas it can be observed that as the degree of modulation is higher resolution of DOA estimation algorithm increased.

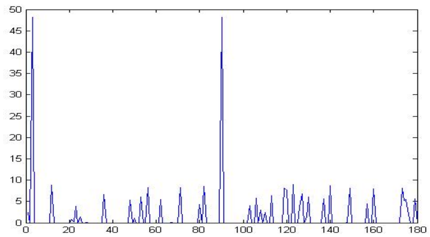

Fig.2 i) Power spectrum for angle -100 to100 (Max. peak at 6º & 90º)

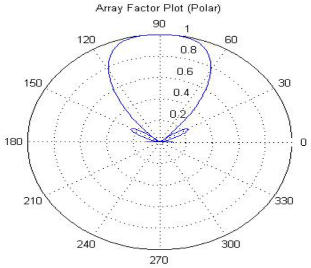

Fig. 2 ii) Polar plot (Beam at 90º)

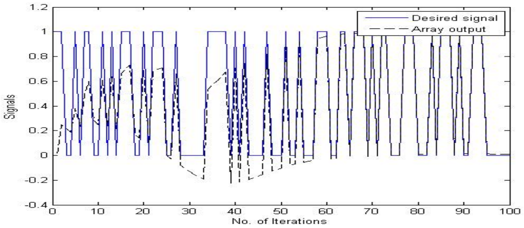

Fig.2 iii) Desired signal & array output

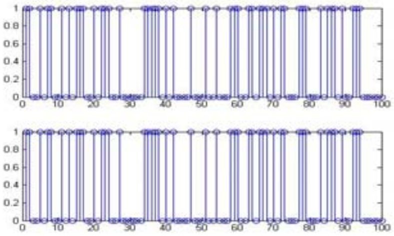

Fig.2 iv) Input sequence & Output sequence

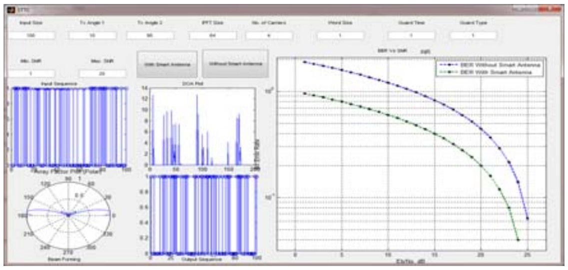

Fig.3 i) Simulation results for proposed system for BPSK

From the Fig.3 –i) it has been observed that for BPSK modulation DOA estimation algorithm cannot resolve the directions clearly.Beamforming algorithm forms sharp beam at 6º .From the BER graph it has been clear that there is deviation of approximately 0.1 to 0.4 between BER with & without smart antenna.

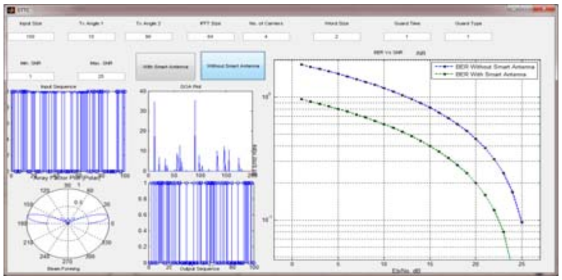

Fig.3 ii) Simulation results for proposed system for QPSK

From the Fig.3 –ii) it has been observed that for QPSK modulation DOA estimation algorithm can resolve the directions comparetively clearly as in previous case. Beamforming algorithm forms sharp beam at 10º .From the BER graph it has been clear that there is deviation of approximately 0.1 to 0.4 between BER with & without smart antenna.

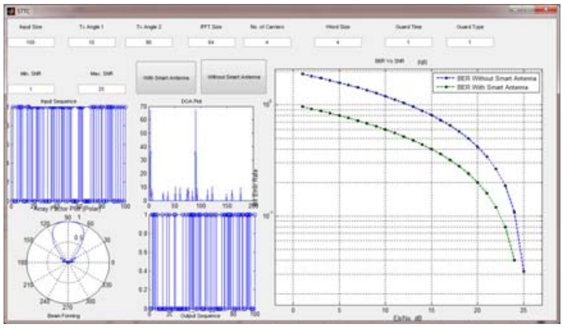

Fig.3 iii) Simulation results for proposed system for 16-PSK

From the Fig.3 –iii) it has been observed that for 16-PSK modulation DOA estimation algorithm can resolve the directions clearly.Beamforming algorithm forms sharp beam at 90º .From the BER graph it has been clear that there is deviation of approximately 0.1 to 0.4 between BER with & without smart antenna.

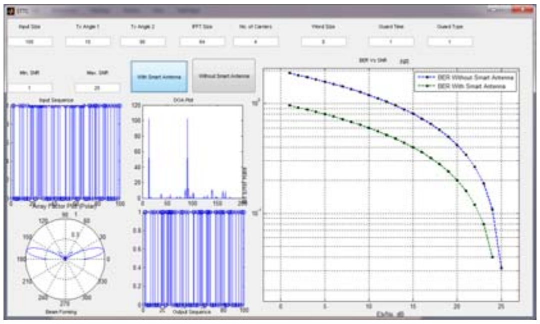

Fig.3 iv) Simulation results for proposed system for 256-PSK

From the Fig.3–iv) it has been observed that for 256-PSK modulation DOA estimation algorithm can resolve the directions clearly.Beamforming algorithm forms sharp beam at 10º .From the BER graph it has been clear that there is deviation of approximately 0.1 to 0.4 between BER with & without smart antenna.

From the simulation results presented here it can be concluded that modulation techniques used has its impact on the BER performance is negligible in the proposed STTC based MIMO-OFDM system.

5. CONCLUSION & FUTURE WORK

The proposed system is a combination of MIMO-OFDM with adaptive beamforming. In this research work it has been shown that this combined system can effectively mitigate interference. The use of LMS adaptive beamformer in the STTC-OFDM system enhances the system performance in terms of BER. From the simulation results it is observed that BER performance of the system with smart antenna is improved. The deviation between the two cases i.e. with & without smart antenna is larger at low SNR value and it decreases as SNR value increases. From the results it is also clear that performance of the system remains same irrespective of the different type of modulation techniques. It can be concluded that the proposed system has the ability of suppressing interference that results in significant improvement in the bit-error rate (BER).

In this research work testing of the proposed system is carried out considering AWGN channel only. Work can be extended for different channel conditions also. Furthermore, OFDMA can be used to get a MIMO-MU (multiuser) system. Rake receiver can also be used along with the adaptive beamformer for multipath mitigation to study the effect on BER in a multipath environment.

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