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Performance Analysis Of MGSTC BLAST Spatial Multiplexing Scheme Aided Dual Polarized OFDM System On Secure Voice Frequency Signal Transmission

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***Abstract*—This paper emphasizes on comprehensive study for the performance evaluation of MGSTC BLAST spatial multiplexing scheme aided dual polarized OFDM system. Such simulated system incorporates various channel coding such as LDPC (Low Density Parity Checker), Turbo and signal detection such as BLUE, MMSE, MMSE-SIC and SD schemes under scenario of encrypted voice frequency signal transmission over Dual Polarized MIMO channel. It is noticeable from Matlab based simulation study that the system is very much robust and effective in retrieving audio signal under utilization of Turbo channel coding, 16-QAM digital modulation and MMSE-SIC signal detection techniques.**

Keywords—Dual Polarized, MIMO OFDM, Signal to noise ratio (SNR), BLUE, MMSE, MMSE-SIC and SD

I. Introduction

Spatial multiplexing is generally referred to transmitting multiple independent data streams over multipath channels. The multi-group space-time coding (MGSTC) scheme achieves both spatial multiplexing and spatial diversity simultaneously. In such scheme, the digitally modulated symbols are rearranged into four groups with each group consisting of eight symbols at a time. The total number of information bits processed in each group under each of the four space time encoder is sixteen as the low order digital modulations(16-QAM and 16-PSK)have been used.**[1]**

It is known from various literature reviewing that with application of multiple antennas at the transmitter and receiver ends of the wireless link , multiple-input multiple-output (MIMO) technique is capable of exploiting spatial degrees of freedom and improving spectral efficiency. In the dual-polarized multiple-input multiple-output (MIMO) antenna systems, where the antennas are grouped in pairs of orthogonally polarized antennas, are spatially-efficient alternative to conventional (single) polarized MIMO antenna systems**.** However, in this present study, an effort has been made to observe the performance of MGSTC BLAST spatial multiplexing scheme aided dual polarized OFDM system on secure voice frequency signal transmission.

II. Signal Processing Techniques

In our present study various signal processing schemes have been used. A brief overview of these schemes is given below:

A. Dual Polarized MIMO Channel

The channel $\mathbf{H}_{\chi} \in \mathbb{C}^{4x4}$ is a dual-polarized MIMO channel parameterized by a single parameter and can be modelled as:

$$\mathbf{H}_{\chi} = \mathbf{X} \odot \mathbf{H}_{w} \qquad (1)$$

Where, $\mathbf{H}_{w} \in \mathbb{C}^{4x4}$ denotes a single polarized MIMO channel having i.i.d. entries with (0, 1) , $\mathbf{X} \in \mathbb{C}^{4x4}$ is a matrix describing the power imbalance between the orthogonal polarizations. It is modelled as:

$$X = \begin{bmatrix} 1 & \sqrt{\chi} \\ \sqrt{\chi} & 1 \end{bmatrix} \otimes 1_{2\times 2} \qquad (2)$$

The parameter $0 \le \chi \le 1$ stands for the inverse of the cross-polar discrimination (XPD), where $1 \le \text{XPD} \le \infty$. The XPD refers to the physical ability of the antennas to distinguish the orthogonal polarization. In Equation 1, $\odot$ is the Hadamard product of **X** and $\mathbf{H}_{w}$. Equation 1 can be written in a block matrix representation as: **[2].**

$$\mathrm{H}_{\chi} = \begin{bmatrix} \mathrm{H}_{\mathrm{w},11} & \sqrt{\chi}\,\mathrm{H}_{\mathrm{w},12} \\ \sqrt{\chi}\,\mathrm{H}_{\mathrm{w},21} & \mathrm{H}_{\mathrm{w},22} \end{bmatrix} \qquad (3)$$

B. Low density parity-check matrix (LDPC)

In LDPC coding, ½.-rated irregular LDPC code is used with a code length of 1024 bits. Its parity-check matrix [H] is a sparse matrix with a dimension of 512 × 1024 and contains only three 1's in each column and six 1's in each row. The parity-check matrix [H] is formed from a concatenation of two matrices [A] and [P]([H]=[A]|[P]), each has a dimension of 512 × 512). The columns of the parity-check matrix [H] is rearranged to produce a new parity-check matrix [new H]. With rearranged matrix elements, the matrix [A] becomes non-singular and it is further processed to undergo LU decomposition. The parity bits sequence [**p**] is considered to have been produced from a block based input binary data sequence [**u**]=[$u_1u_2u_3u_4$…….u_{512}]$^{\mathbf{T}}$ and three matrices [P](of [new H]),[L] and [U]using the following Matlab notation :

p = mod(U\(L\z), 2);where**,** z = mod(P*u , 2);

The LDPC encoded 1024× 1 sized block based binary data sequence [**c**] is formulated from concatenation of parity check bit **p** and information bit **u** as :

[c]=[p;u]

The first 512 bits of the codeword matrix [**c**] are the parity bits and the last 512 bits are the information bits. In iterative Log Domain Sum-Product LDPC decoding Algorithm, the transmitted bits are retrieved **[3,4].**

C. Best Linear Unbiased Estimation (BLUE)

In BLUE based signal detection scheme, it is assumed that the channel matrix $\mathbf{H}_{\chi}$ is deterministic and the covariance matrix R_{ee} (=E{NN^T}) of the contaminated noise N is positive definite and its inversion matrix R^{-1}_{ee} is known or can be estimated. The noise covariance matrix R_{ee} is of dimension 4 × 4. The estimated transmitted signal $\mathrm{X}_{\mathrm{BLUE}}$ using such scheme can be written in terms of Y(Received signal),$\mathbf{H}_{\chi}$ andR_{ee}, as**[5]**:

$$\mathrm{X}_{\mathrm{BLUE}} = (\mathbf{H}_{\chi}{}^{T} R^{-1}_{ee}\, \mathbf{H}_{\chi})^{-1} \mathbf{H}_{\chi}{}^{T} R^{-1}_{ee} \mathrm{Y} \qquad (4)$$

D. Minimum mean square error (MMSE)

In Minimum mean square error (MMSE) based signal detection scheme, the MMSE weight matrix is given by**[6]**

$$W_{MMSE} = (H_{\chi}{}^{H} H_{\chi} + \sigma_n{}^{2} I)^{-1} H_{\chi}{}^{H} \qquad (5)$$

Where $(.)^{H}$ denotes the Hermitian transpose operation and The detected desired signal $\tilde{\mathbf{X}}_{\mathbf{MMSE}}$ from the transmitting antenna is given by

$$\tilde{\mathrm{X}}_{\mathrm{MMSE}} = \mathrm{W}_{\mathrm{MMSE}}\mathrm{Y} \qquad (6)$$

E. Minimum mean square error successive interference cancellation (MMSE-SIC)

In Minimum mean square error successive interference cancellation (MMSE-SIC) scheme, the extended channel matrix $\overline{H}$ and the extended received signal $\overline{\mathrm{Y}}$ in terms of identity and null matrices are given by

$$\overline{H} = \begin{bmatrix} H_{\chi} \\ (\sqrt{\sigma^{2}{}_{n}})I \\ \end{bmatrix} \qquad (7)$$

$$\overline{\mathrm{Y}} = \begin{bmatrix} \mathrm{Y} \\ \mathbf{0} \end{bmatrix} \qquad (8)$$

On QR decomposition of $\overline{H}$, an orthogonal matrix $\overline{\mathrm{Q}}$ and upper triangular matrix $\overline{\mathrm{R}}$ are produced. Equation (9) is multiplied with $\overline{\mathrm{Q}}^{\mathrm{T}}$ to provide a modified form of received signal $\overline{\overline{\mathrm{Y}}}$ with neglected noise component

$$\overline{\overline{\mathrm{Y}}} = \overline{\mathrm{Q}}^{\mathrm{T}}\ \overline{\mathrm{Y}} = \overline{Q}^{T}\overline{H}\ X\ = \overline{\overline{R}}X \qquad (9)$$

Considering a single time slot, the transmitted four signals $\overline{\overline{\mathrm{X}}}_1, \overline{\overline{\mathrm{X}}}_2, \overline{\overline{\mathrm{X}}}_3$ and $\overline{\overline{\mathrm{X}}}_4$ in terms of four received signals $\overline{\overline{\mathrm{Y}}}_1$, $\overline{\overline{\mathrm{Y}}}_2$, $\overline{\overline{\mathrm{Y}}}_3$ and $\overline{\overline{\mathrm{Y}}}_4$ (First through Fourth rows of $\overline{\overline{\mathrm{Y}}}$ and neglecting other row data) and the components of matrix $\overline{\overline{\mathrm{R}}}$ in first through fourth row) can be obtained from a matrix equation as**[7]:**

$$\overline{\overline{Y}}[(:,1)] = \begin{bmatrix} \overline{\overline{Y}}_1 \\ \overline{\overline{Y}}_2 \\ \overline{\overline{Y}}_3 \\ \overline{\overline{Y}}_4 \\ \overline{\overline{Y}}_5 \\ \overline{\overline{Y}}_6 \\ \overline{\overline{Y}}_7 \\ \overline{\overline{Y}}_8 \end{bmatrix} = \begin{bmatrix} \overline{\overline{R}}_{1,1} & \overline{\overline{R}}_{1,2} & \overline{\overline{R}}_{1,3} & \overline{\overline{R}}_{1,4} \\ 0 & \overline{\overline{R}}_{2,2} & \overline{\overline{R}}_{2,3} & \overline{\overline{R}}_{2,4} \\ 0 & 0 & \overline{\overline{R}}_{3,3} & \overline{\overline{R}}_{3,4} \\ 0 & 0 & 0 & \overline{\overline{R}}_{4,4} \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \end{bmatrix} \begin{bmatrix} \overline{\overline{X}}_1 \\ \overline{\overline{X}}_2 \\ \overline{\overline{X}}_3 \\ \overline{\overline{X}}_4 \end{bmatrix}$$

(10

F. Sphere Decoding (SD)

In Sphere Decoding (SD) scheme intends to find the transmitted signal vector with minimum ML metric, that is, to find the ML solution vector. However, it considers only a small set of vectors within a given sphere rather than all possible transmitted signal vectors. SD adjusts the sphere radius until there exists a single vector (ML solution vector) within a sphere. It increases the radius when there exists no vector within a sphere and decreases the radius when there exist multiple vectors within the sphere. Let y_{jR} and y_{jI} denote the real and imaginary parts of the received signal at the jth receive antenna, that is, y_{jR}=Re{y_j} and y_{jI}=Im{y_j}. Similarly, the input signal x_i from the ith antenna can be represented by x_{iR} = Re{x_i} and x_{iI} = Im{x_i}**[8].** The received signal in case of 4 x 4 antenna configuration can be expressed in terms of its real and imaginary parts as follows:

$$\begin{bmatrix} y_{1R}+jy_{1I} \\ y_{2R}+jy_{2I} \\ y_{3R}+jy_{3I} \\ y_{4R}+jy_{4I} \end{bmatrix} = \begin{bmatrix} h_{11R}+jh_{11I} & h_{12R}+jh_{12I} & h_{13R}+jh_{13I} & h_{14R}+jh_{14I} \\ h_{21R}+jh_{21I} & h_{22R}+jh_{22I} & h_{23R}+jh_{23I} & h_{24R}+jh_{24I} \\ h_{31R}+jh_{31I} & h_{32R}+jh_{32I} & h_{33R}+jh_{33I} & h_{34R}+jh_{34I} \\ h_{41R}+jh_{41I} & h_{42R}+jh_{42I} & h_{43R}+jh_{43I} & h_{44R}+jh_{44I} \end{bmatrix} \begin{bmatrix} x_{1R}+jx_{1I} \\ x_{2R}+jx_{2I} \\ x_{3R}+jx_{3I} \\ x_{4R}+jx_{4I} \end{bmatrix} + \begin{bmatrix} n_{1R}+jn_{1I} \\ n_{2R}+jn_{2I} \\ n_{3R}+jn_{3I} \\ n_{4R}+jn_{4I} \end{bmatrix} \qquad \textbf{(11)}$$

Where, $h_{ijR} = Re\{h_{ij}\}, h_{ijI} = Im\{h_{ij}\}, n_{iR} = Re\{n_i\}$. The real and imaginary part of Equation (**11)** can be respectively expressed as*:*

$$\begin{bmatrix} y_{1R} \\ y_{2R} \\ y_{3R} \\ y_{4R} \end{bmatrix} = \begin{bmatrix} h_{11R} & h_{12R} & h_{13R} & h_{14R} \\ h_{21R} & h_{22R} & h_{23R} & h_{24R} \\ h_{31R} & h_{32R} & h_{33R} & h_{34R} \\ h_{41R} & h_{42R} & h_{43R} & h_{44R} \end{bmatrix} \begin{bmatrix} x_{1R} \\ x_{2R} \\ x_{3R} \\ x_{4R} \end{bmatrix} - \begin{bmatrix} h_{11I} & h_{12I} & h_{13I} & h_{14I} \\ h_{21I} & h_{22I} & h_{23I} & h_{24I} \\ h_{31I} & h_{32I} & h_{33I} & h_{34I} \\ h_{41I} & h_{42I} & h_{43I} & h_{44I} \end{bmatrix} \begin{bmatrix} x_{1I} \\ x_{2I} \\ x_{3I} \\ x_{4I} \end{bmatrix} + \begin{bmatrix} n_{1R} \\ n_{2R} \\ n_{3R} \\ n_{4R} \end{bmatrix} =$$

$$\begin{bmatrix} h_{11R} & h_{12R} & h_{13R} & h_{14R} & -h_{11I} & -h_{12I} & -h_{13I} & -h_{14I} \\ h_{21R} & h_{22R} & h_{23R} & h_{24R} & -h_{21I} & -h_{22I} & -h_{23I} & -h_{24I} \\ h_{31R} & h_{32R} & h_{33R} & h_{34R} & -h_{31I} & -h_{32I} & -h_{33I} & -h_{34I} \\ h_{41R} & h_{42R} & h_{43R} & h_{44R} & -h_{41I} & -h_{42I} & -h_{43I} & -h_{44I} \end{bmatrix} \begin{bmatrix} x_{1R} \\ x_{2R} \\ x_{3R} \\ x_{4R} \\ x_{1I} \\ x_{2I} \\ x_{3I} \\ x_{4I} \end{bmatrix} + \begin{bmatrix} n_{1R} \\ n_{2R} \\ n_{3R} \\ n_{4R} \end{bmatrix} \qquad \textbf{(12(a))}$$

and

$$\begin{bmatrix} y_{1I} \\ y_{2I} \\ y_{3I} \\ y_{4I} \end{bmatrix} = \begin{bmatrix} h_{11I} & h_{12I} & h_{13I} & h_{14I} & h_{11R} & h_{12R} & h_{13R} & h_{14R} \\ h_{21I} & h_{22I} & h_{23I} & h_{24I} & h_{21R} & h_{22R} & h_{23R} & h_{24R} \\ h_{31I} & h_{32I} & h_{33I} & h_{34I} & h_{31R} & h_{32R} & h_{33R} & h_{34R} \\ h_{41I} & h_{42I} & h_{43I} & h_{44I} & h_{41R} & h_{42R} & h_{43R} & h_{44R} \end{bmatrix} \begin{bmatrix} x_{1R} \\ x_{2R} \\ x_{3R} \\ x_{4R} \\ x_{1I} \\ x_{2I} \\ x_{3I} \\ x_{4I} \end{bmatrix} + \begin{bmatrix} n_{1I} \\ n_{2I} \\ n_{3I} \\ n_{4I} \end{bmatrix} \qquad \textbf{(12(b))}$$

The Equations **(12(a))** and **(12(b))** can be combined to yield the following expression:

$$\begin{bmatrix} y_{1R} \\ y_{2R} \\ y_{3R} \\ y_{4R} \\ y_{1I} \\ y_{2I} \\ y_{3I} \\ y_{4I} \end{bmatrix} = \begin{bmatrix} h_{11R} & h_{12R} & h_{13R} & h_{14R} & -h_{11I} & -h_{12I} & -h_{13I} & -h_{14I} \\ h_{21R} & h_{22R} & h_{23R} & h_{24R} & -h_{21I} & -h_{22I} & -h_{23I} & -h_{24I} \\ h_{31R} & h_{32R} & h_{33R} & h_{34R} & -h_{31I} & -h_{32I} & -h_{33I} & -h_{34I} \\ h_{41R} & h_{42R} & h_{43R} & h_{44R} & -h_{41I} & -h_{42I} & -h_{43I} & -h_{44I} \\ h_{11I} & h_{12I} & h_{13I} & h_{14I} & h_{11R} & h_{12R} & h_{13R} & h_{14R} \\ h_{21I} & h_{22I} & h_{23I} & h_{24I} & h_{21R} & h_{22R} & h_{23R} & h_{24R} \\ h_{31I} & h_{32I} & h_{33I} & h_{34I} & h_{31R} & h_{32R} & h_{33R} & h_{34R} \\ h_{41I} & h_{42I} & h_{43I} & h_{44I} & h_{41R} & h_{42R} & h_{43R} & h_{44R} \end{bmatrix} \begin{bmatrix} x_{1R} \\ x_{2R} \\ x_{3R} \\ x_{4R} \\ x_{1I} \\ x_{2I} \\ x_{3I} \\ x_{4I} \end{bmatrix} + \begin{bmatrix} n_{1R} \\ n_{2R} \\ n_{3R} \\ n_{4R} \\ n_{1I} \\ n_{2I} \\ n_{3I} \\ n_{4I} \end{bmatrix} \qquad \textbf{(13)}$$

Neglecting noise term in Equation **(13)**, the detected desired signal from the transmitting antenna $\bar{x}$ in their real and imaginary component forms can be obtained using the following relation:

$$\bar{x} = (\bar{H}_{\chi}{}^{H}\bar{H}_{\chi})^{-1}\bar{H}_{\chi}{}^{H}\bar{y} \qquad \textbf{(14)}$$

where, $\bar{H}_{\chi}$ is the modified channel matrix of Equation (13) and $\bar{y}$ is the received signal in their real and imaginary component forms.

III. System Description

The block diagram of the simulated MGSTC BLAST spatial multiplexing scheme aided dual polarized OFDM system is shown in Figure 1. It is assumed that a single user is transmitting his/her data utilizing all allocated subcarriers during the time of several OFDM symbols and the OFDM symbols assigned are adaptively changed in each frame. A segment of digitally recorded audio signal is processed for analysis. The sampled analog values of audio signal are converted into corresponding integer values under consideration of 65536 quantization levels. The extracted binary bits in 0/1 format are encrypted and channel encoded using LDPC and Turbo scheme and then are digitally modulated using 16-QAM and 16-PSK. The digitally modulated symbols are fed into Spatial demultiplexing section using multi-group space-time coding for production of four data series to be transmitted from antenna after executing various processing steps(Serial to parallel conversion, OFDM modulation, Cyclic prefixing and parallel to serial conversion).In receiving section, all the transmitted signals are detected with linear signal detection schemes and the detected signals are subsequently sent up to the serial–to–parallel (S/P) converter and after that they are processed with cyclic prefix removing scheme, then fed into OFDM demodulator which performs FFT operation on each OFDM block. The FFT operated OFDM block are undergone from parallel–to–serial conversion and fed into Multi-group space-time decoding section. The multiplexed complex symbols are digitally demodulated, channel decoded and decrypted to recover the transmitted data.

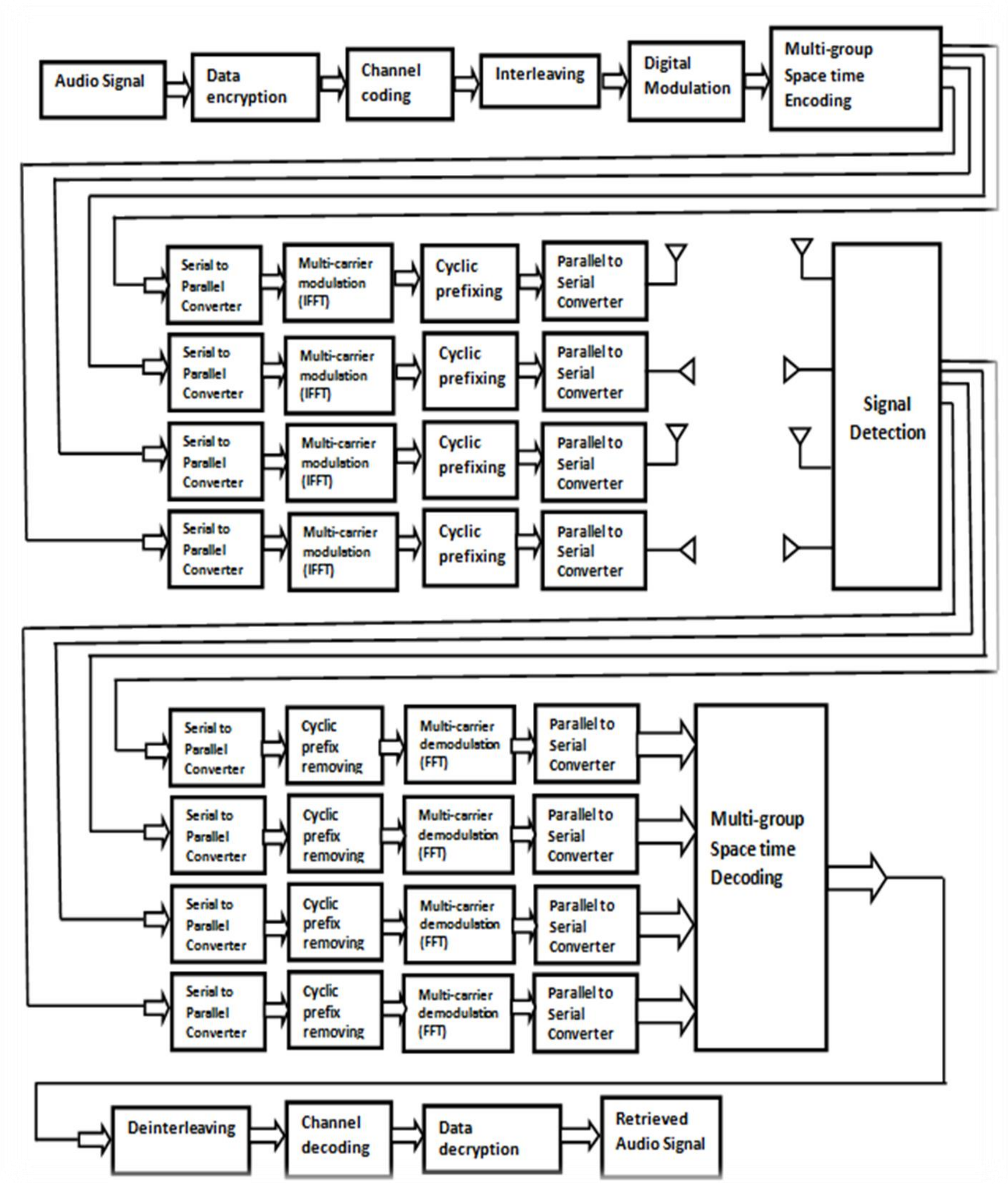

Figure 1: MGSTC BLAST spatial multiplexing scheme aided dual polarized OFDM system on secure voice frequency signal transmission

IV. Result and Discussion

In this section, we have presented a series of simulation results to illustrate the significant impact of system performance in terms of BER in a MGSTC BLAST spatial multiplexing scheme aided dual polarized OFDM system with simulation parameters tabulated in Table 1.

Table 1: Summary of the Simulated Model Parameters

Data type	**Audio Signal**
No. of samples	32768
Sampling Frequency(Hz)	12000
No of binary bits for a single sample	16
Antenna configuration	4-by-4
Spatial multiplexing	Multi-group space time(MGST)
Channel Coding	LDPC and Turbo
Data Modulation	16-PSK,16-QAM
IFFT/FFT size	1024
Signal detection Scheme	MMSE-SIC,BLUE, MMSE and SD
Channel	AWGN and Rayleigh fading
Signal to noise ratio, SNR	0 to 5 dB

The graphical illustrations presented in Figure 2 through Figure 4 show system performance comparison (Bit error rate (BER) Vs SNR values). In all cases, the system performance is well defined under scenario of implementing MMSE-SIC, BLUE & MMSE-SIC signal detection, 16-QAM & 16-PSK digital modulation and LDPC & TURBO channel coding schemes in MGSTC BLAST spatial multiplexing scheme aided dual polarized OFDM system. It is quit obvious from the presented figures that the simulated system shows comparatively better performance in Turbo channel coding over a significant region of SNR values.

In Figure 2 for MMSE signal detection scheme, the estimated BER values are 0.3755 and 0.2122 in a typically assumed SNR value of 1dB for LDPC channel coding with16-PSK digital modulation as compared to TURBO channel coding with16-QAM digital modulation which is indicative of a system performance improvement of 2.47dB.

In Figure 3 for MMSE-SIC signal detection scheme, it is observable that the system shows satisfactory performance in QAM with LDPC channel coding and worst performance in 16-PSK with TURBO. Under such case, the estimated BER values at 1 dB SNR values are found to be of 0.1227 and 0.3493 which ratifies a 4.54 dB system performance improvement.

In Figure 4 for BLUE signal detection scheme, the estimated BER values are 0.3766 and 0.3251 in a typically assumed SNR value of 1dB for LDPC channel coding with 16-PSK digital modulation as compared to TURBO channel coding with 16-QAM digital modulation which is indicative of a system performance improvement of 0.64dB.

In Figure 5 for SD signal detection scheme, it is observable that the system shows satisfactory performance in QAM with LDPC channel coding and worst performance in 16-QAM with TURBO. Under such case, the estimated BER values at 1 dB SNR values are found to be of 0.3183 and 0.4954 which ratifies a 1.92 dB system performance improvement.

In Figure 6, the transmitted and retrieved audio signals at Signal to Noise power (SNR) ratio of 5 dB have been shown which are found to have great resemblance with each other. In perspective of spectral decomposition, the transmitted and retrieved audio signals are also found to have identical frequency components (Figure 7).

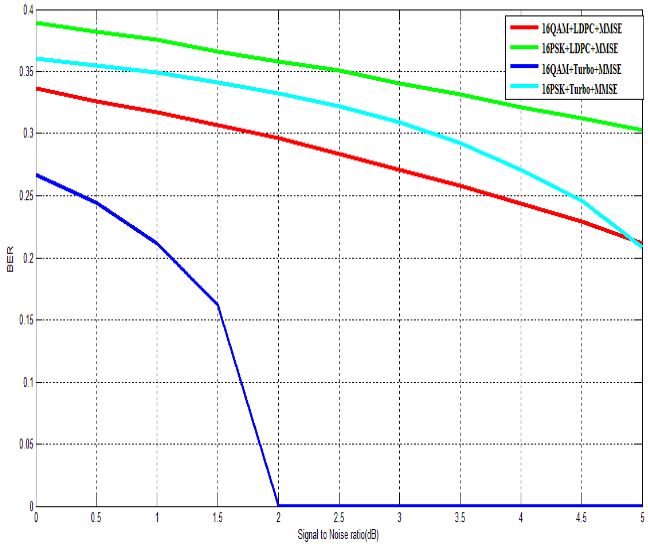

Figure 2: BER performance of MGSTC BLAST spatial multiplexing scheme aided dual polarized OFDM system using MMSE signal detection technique

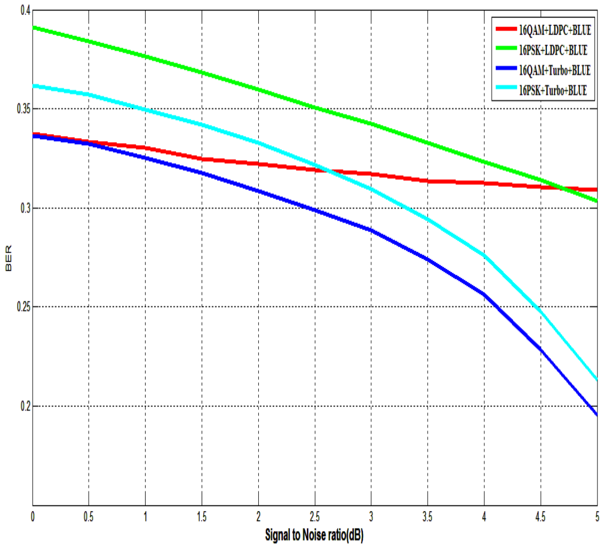

Figure 4: BER performance of MGSTC BLAST spatial multiplexing scheme aided dual polarized OFDM system using BLUE signal detection technique

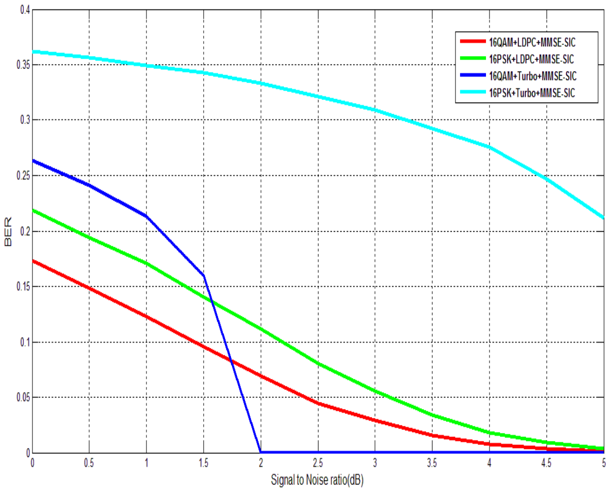

Figure 3: BER performance of MGSTC BLAST spatial multiplexing scheme aided dual polarized OFDM system using MMSE-SIC signal detection technique

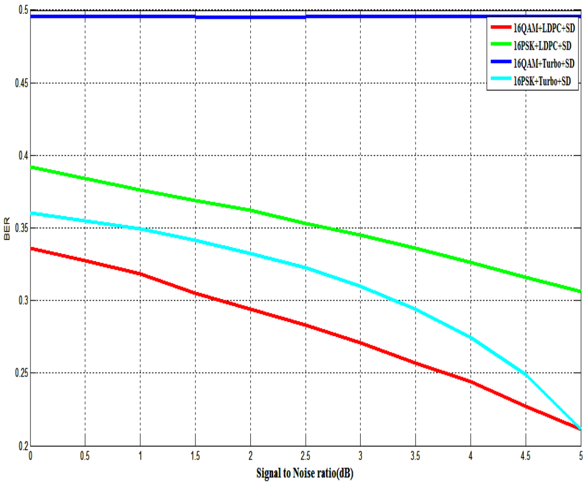

Figure 5: BER performance of MGSTC BLAST spatial multiplexing scheme aided dual polarized OFDM system using SD signal detection technique

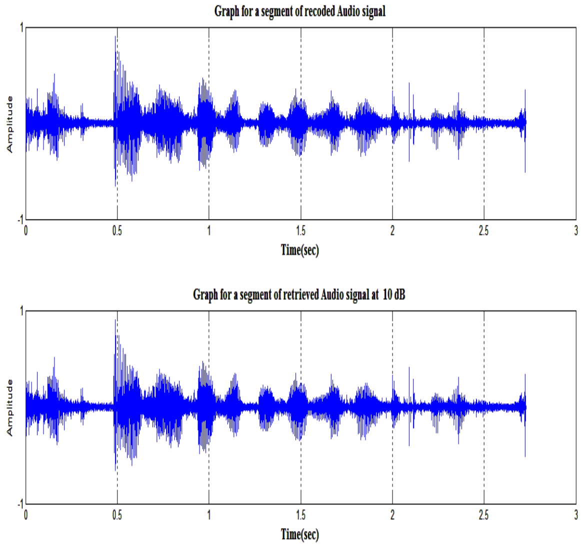

Figure 6: Transmitted and Retrieved audio signals at Signal to Noise power (SNR) ratio of 5 dB
Under implementation of Turbo channel coding, 16-QAM digital modulation and MMSE-SIC Signal detection technique.

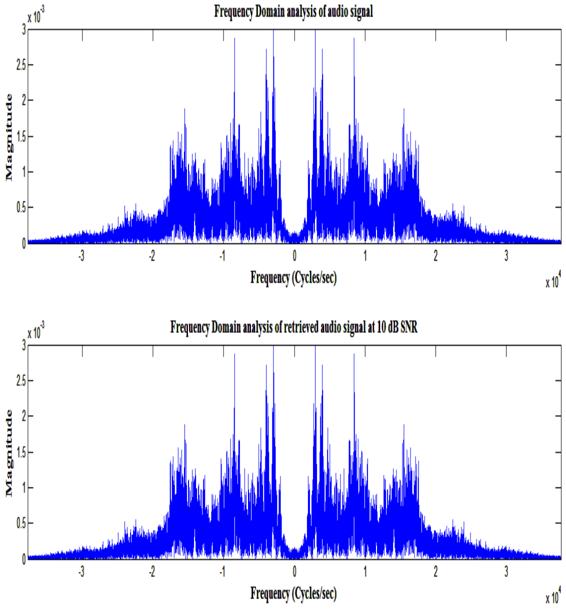

Figure 7: Spectral analysis of Transmitted and Retrieved audio signals at Signal to Noise power (SNR) ratio of 5 dB
Under implementation of Turbo channel coding, 16-QAM digital modulation and MMSE-SIC Signal detection technique.

V. Conclusions

In this paper, various digital signals processing technique oriented Channel Equalization schemes have been implemented merely to observe critically the quality of the transmitted audio signal in a noisy channel. Simulation results indicate that the MMSE-SIC signal detection technique is very much effective in significant reduction of distortion inferred from the time varying channel.
However, Based on the simulation results, it can be concluded that the system is very much robust and effective in retrieving audio signal under utilization of Turbo channel coding 16-QAM digital modulation and MMSE-SIC signal detection technique.

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