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Assessment of Secured Voice Frequency Signal Transmission in Dual Polarized DWT Aided MIMO SC-FDMA Wireless Communication System

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Abstract: In this paper, we have emphasized the BER performance of dual polarized DWT aided MIMO SC-FDMA wireless communication system. The simulated system under investigation with 4 × 4 antenna configuration implements various types of channel coding(LDPC& Turbo) and signal detection (MMSE-SIC, BLUE, ZF & OSIC) techniques. On considering transmission of secured voice frequency signal in a hostile fading channel under MATLAB based simulative study, it is observable that the simulated system shows satisfactory performance in retrieving transmitted audio signal under scenario of implementing Turbo channel coding, MMSE-SIC signal detection and 8-QAM digital modulation schemes.

Keywords: SC-FDMA, Dual Polarized Antennas, DWT, Signal to Noise Ratio, Channel Coding and Signal Detection

1. Introduction

Multiple input multiple output (MIMO) techniques utilize multiple antenna elements at the transmitter and the receiver to improve communication link quality and/or communication capacity. A MIMO system can provide two types of gain such as spatial diversity gain and spatial multiplexing gain. The spatial diversity improves the reliability of communication in fading channels and the spatial multiplexing increases the capacity by sending multiple streams of data in parallel through multiple spatial channels.

Single Carrier Frequency Division Multiple Access (SC-FDMA) is a novel method of radio transmission under consideration for deployment in cellular systems[1].It has been known from literature review that over the past time, several cellular technologies have been surfaced with commercial deployment of the long term evolution (LTE) and its successor of LTE-advanced (LTE-A) networks. The LTE-A networks use MIMO SC-FDMA for uplink transmissions. The SC-FDMA signals have inherently lower peak-to-average power ratio (PAPR) than the OFDMA signals. In comparison to OFDMA, the SC-FDMA significantly reduces the envelope fluctuations in the transmitted waveform [2].In 2012, Umaria and et. al., made performance comparison study for FFT based OFDM system and DWT based OFDM system using different wavelet families and found that the DWT based OFDM system is better than FFT based OFDM system with regards to the bit error rate (BER) performance[3]. In Fifth generation (5G), millimetre wave (mmWave) multiple-input multiple output (MIMO) wireless communication systems are being preferred to provide the throughput enhancements needed to meet up the expected demands for mobile data. The dual-polarized antenna systems are expected to be incorporated in mmWave systems [4].The present study represents SC FDMA system performance on secured audio signal transmission under implementation of dual polarization antenna configuration, Haar's based discrete wave transformation (DWT) schemes and various channel coding and signal detection schemes.

2. Signal Processing Techniques

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

2.1. Turbo Coding

Turbo code is systematic code with its coding rate is of ⅓ formed by concatenating in parallel two recursive systematic convolutional (RSC) codes separated by an interleaver. In such coding scheme, the encoder produces three code bits. One is the message bit treated as systematic bit and the other two are the parity bits generated by the two RSC encoders. The code may also be punctured to obtain a coding rate of 1/2. Puncturing operates only on the parity sequences; the systematic bits are not touched. In maximum a posteriori (MAP) turbo decoding, the transmitted message bits are retrieved iteratively through computation of their log likelihood ratio (LLR). Let $\overline{C} = C_0, C_1, C_2 \ldots\ldots C_{N-1}$ be a coded sequence produced by the rate ½ RSC encoder and $\bar{r} = r_0, r_1, r_2 \ldots\ldots r_{N-1}$ be the noisy received sequence where the codeword is $c_k = (c_k^{(1)} \quad c_k^{(2)})$ with the first bit being the message bit and the second bit being the punctured parity bit. The corresponding received word is $r_k = (r_k^{(1)} \quad r_k^{(2)})$

The coded bit in 0/1 format is converted to a value of +1/-1. The maximum a posteriori(MAP) decodingis carried out as:

$$c_k^{(1)} = \{\frac{+1, \text{if } P(c_k^{(1)} = +1|\bar{r}) \geq P(c_k^{(1)} = -1|\bar{r})}{-1, \text{if } P(c_k^{(1)} = +1|\bar{r}) < P(c_k^{(1)} = -1|\bar{r})}\} \; (i = 0,1,2,3, N-1) \quad (1)$$

A posteriori log likehood ratio(LLR) of $c_k^{(1)}$ is given by

$$L(c_k^{(1)}) = \ln\left[\frac{P(c_k^{(1)} = +1|\bar{r})}{P(c_k^{(1)} = -1|\bar{r})}\right] \quad (2)$$

The MAP decoding rule in Equation (1) can be written alternatively as:

$$c_k^{(1)} = \text{sign}\left[L(c_k^{(1)}|\bar{r})\right] \quad (3)$$

The magnitude LLR, $\left[L(c_k^{(1)}|\bar{r})\right]$measures the like hood of $c_k^{(1)}$ =+1 or $c_k^{(1)}$ =-1. The LLR can be expressed as a function of the probability $P(c_k^{(1)}|\bar{r})$ as[5]:

$$L(c_k^{(1)}) = \ln\left[\frac{P(c_k^{(1)} = +1|\bar{r})}{P(c_k^{(1)} = -1|\bar{r})}\right] = \left[\frac{P(c_k^{(1)} = +1|\bar{r})}{1 - P(c_k^{(1)} = +1|\bar{r})}\right] \quad (4)$$

2.2. LDPC Coding

In ½.-rated irregular LDPC coding, a code length of 1024 bits is used. Its parity-check matrix [H_{parity}] 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_{parity}] is formed from a concatenation of two matrices [A] and [P]([H_{parity}]=[A]|[P]), each has a dimension of 512 × 512). The columns of the parity-check matrix [H_{parity}] is rearranged to produce a new parity-check matrix [newH]. 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]=[u1u2u3u4…….u512]^{T}and three matrices [P](of [newH]),[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] (5)

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 [6,7].

2.3. Dual Polarized MIMO Channel

A 4× 4 dual polarized MIMO channel $H_\chi \in \mathbb{C}^{4x4}$ is parameterized by a single parameter and can be modeled as:

$$H\chi = X \odot H \quad (6)$$

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

$$X = \begin{bmatrix} 1 & \sqrt{\chi} \\ \sqrt{\chi} & 1 \end{bmatrix} \otimes 1_{2\times 2} \quad (7)$$

The parameter $0 \leq \chi \leq 1$ stands for the inverse of the cross-polar discrimination (XPD), where 1 ≤XPD≤∞. The XPD refers to the physical ability of the antennas to distinguish the orthogonal polarization. In Equation 1, ⊙is theHadamard product of X and H_w. Equation 6 can be written in s a block matrix representation as: [8].

$$H_\chi = \begin{bmatrix} H_{w,11} & \sqrt{\chi}\, H_{w,12} \\ \sqrt{\chi}\, H_{w,21} & H_{w,22} \end{bmatrix} \quad (8)$$

2.4. Best Linear Unbiased Estimation (BLUE)

In BLUE based signal detection scheme, it is assumed that the channel matrix.His deterministic and the covariance matrix Ree (=E{NNT}) 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 Ree is of dimension 4 × 4. The estimated transmitted signal X_{BLUE} using such scheme can be written in terms of Y(Received signal),HχandRee, as[9]:

$$X_{BLUE} = (H\chi T\ R\text{-}1ee\ H\chi)\text{-}1H\chi T\ R\text{-}1eeY \quad (9)$$

2.5. Haar Wavelet Transform

In Wavelet decomposition technique, a discrete signal X(z) is decomposed into coarse approximation a(m) and detail d(m) components using four sets of wavelet filters H_0, H_1, G_0, and G_1. An important property of the wavelet transform is the perfect reconstruction which is the process of rebuilding a decomposed signal into its original transmitted form without deterioration. In Haar wavelet transform, the discrete signalX(z) is decomposed into two components of half the length of original signal. At each decomposition level, the high-pass filter produces the detail component and the low pass filter produces the coarse approximation component. The filtering and decimation process continues until the desired decomposition level is reached. The maximum number of levels depends on the length of the signal. In Haar wavelet transform, the polynomial, P (z) is given by,

$$P(z) = \frac{1}{2}(z+2+z\text{-}1) = \frac{1}{2}(z+1)(1+z\text{-}1) = G0\ (z)\ H0\ (z) \quad (10)$$

the filter $H_0(z)$ and $G_0(z)$ are estimated using the following relation:

$$H0\ (z) = \frac{1}{2}(1+z\text{-}1) \quad (11)$$

$$G0\ (z) = (z+1) \quad (12)$$

The other two filters $H_1(z)$ and $G_1(z)$ are estimated using the following relation:

$$G1(z) = zH0\ (\text{-}z) = \frac{1}{2}z(1\text{-}z\text{-}1) = \frac{1}{2}(z\text{-}1) \quad (13)$$

$$H1(z) = z\text{-}1\ G0\ (\text{-}z) = z\text{-}1(\text{-}z+1) = (z\text{-}1\text{-}1) \quad (14)$$

The approximation and detail coefficients can be expressed as follows [10]:

$$a(m) = \sum_{k=-\infty}^{\infty} x(k)H_0\,(2m-k) \quad (15)$$

$$d(m) = \sum_{k=-\infty}^{\infty} x(k)H_1\,(2m-k) \quad (16)$$

where, m ranges from 1,2,3……. 32 as the total number of samples used in a single block wise processing is 64

2.6. Zero Forcing (ZF)

In Zero-Forcing (ZF) signal detection scheme, the ZF weight matrix is given by

$$W_{ZF} = (H_\chi{}^H H_\chi)^{-1} H_\chi{}^H \quad (17)$$

and the detected desired signal $\tilde{\mathbf{x}}_{\mathbf{ZF}}$ from the transmitting antenna in terms of ZF weight matrix and received signal Y is given by

$$\tilde{X}_{ZF} = W_{ZF}Y \quad (18)$$

2.7. MMSE-SIC

In Minimum mean square error successive interference cancellation (MMSE-SIC) scheme,

The extended channel matrix $\hat{\mathbf{H}}$ and the extended received signal $\hat{\mathbf{Y}}$ in terms of identity and null matrices are given by

$$\hat{\mathbf{H}} = \begin{bmatrix} H_\chi \\ (\sqrt{\sigma^2{}_n})I_{4\times4} \\ \end{bmatrix} \quad (19)$$

$$\hat{Y} = \begin{bmatrix} Y \\ \mathbf{0}_{4\times146445} \end{bmatrix} \quad (20)$$

On QR decomposition of $\hat{\mathbf{H}}$, a 8×8 orthogonal matrix $\hat{\mathbf{Q}}$ and a 8×4upper triangular matrix $\hat{\mathbf{R}}$ are produced. Equation (20) is multiplied with $\hat{\mathbf{Q}}^{\mathrm{T}}$ to provide a modified form of received signal with neglected noise component

$$\hat{\hat{\mathbf{Y}}} = \hat{\mathbf{Q}}^{\mathrm{T}}\,\hat{\mathbf{Y}} = \hat{\mathbf{Q}}^{\mathrm{T}}\hat{\mathbf{H}}\mathbf{X} = \hat{\hat{\mathbf{R}}}\mathbf{X} \quad (21)$$

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

$$\hat{\hat{\mathbf{Y}}}[(:,1)] = \begin{bmatrix} \hat{\hat{\mathbf{Y}}}_1 \\ \hat{\hat{\mathbf{Y}}}_2 \\ \hat{\hat{\mathbf{Y}}}_3 \\ \hat{\hat{\mathbf{Y}}}_4 \\ \hat{\hat{\mathbf{Y}}}_5 \\ \hat{\hat{\mathbf{Y}}}_6 \\ \hat{\hat{\mathbf{Y}}}_7 \\ \hat{\hat{\mathbf{Y}}}_8 \end{bmatrix} = \begin{bmatrix} \hat{\hat{\mathbf{R}}}_{1,1} & \hat{\hat{\mathbf{R}}}_{1,2} & \hat{\hat{\mathbf{R}}}_{1,3} & \hat{\hat{\mathbf{R}}}_{1,4} \\ 0 & \hat{\hat{\mathbf{R}}}_{2,2} & \hat{\hat{\mathbf{R}}}_{2,3} & \hat{\hat{\mathbf{R}}}_{2,4} \\ 0 & 0 & \hat{\hat{\mathbf{R}}}_{3,3} & \hat{\hat{\mathbf{R}}}_{3,4} \\ 0 & 0 & 0 & \hat{\hat{\mathbf{R}}}_{4,4} \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \end{bmatrix} \begin{bmatrix} \hat{\hat{\mathbf{X}}}_1 \\ \hat{\hat{\mathbf{X}}}_2 \\ \hat{\hat{\mathbf{X}}}_3 \\ \hat{\hat{\mathbf{X}}}_4 \end{bmatrix} \quad (22)$$

the transmitted signals are detected from equation 22

2.8. Ordered Successive Interference Cancellation (OSIC)

In Ordered successive interference cancellation (OSIC) signal detection scheme, its implementation is performed in four steps. In first step, the first detected signal/data stream $\tilde{\mathbf{x}}_{\mathbf{OSIC-1}}$ and modified form of received signal $\tilde{\mathbf{Y}}_{\mathbf{OSIC-1}}$ can be written as:

$$\tilde{X}_{OSIC-1} = W_{(MMSE(1,:)}Y \quad (23)$$

$$\tilde{Y}_{OSIC-1} = Y - H_{\chi(:,1)}\tilde{X}_{OSIC-1}$$

In second step, the second detected signal/data stream $\tilde{\mathbf{x}}_{\mathbf{OSIC-2}}$ and modified form of received signal $\tilde{\mathbf{Y}}_{\mathbf{OSIC-2}}$ can be written as:

$$\tilde{X}_{OSIC-2} = W_{(MMSE(2,:)}\tilde{Y}_{OSIC-1} \quad (24)$$

$$\tilde{Y}_{OSIC-2} = \tilde{Y}_{OSIC-1} - H_{\chi(:,2)}\tilde{X}_{OSIC-2}$$

In third step, the third detected signal/data stream $\tilde{\mathbf{x}}_{\mathbf{OSIC-3}}$

and modified form of received signal $\tilde{\mathbf{Y}}_{\mathbf{OSIC}-3}$ can be written as:

$$\tilde{X}_{OSIC-3} = W_{(MMSE(3,:)}\tilde{Y}_{OSIC-2} \tag{25}$$

$$\tilde{Y}_{OSIC-3} = \tilde{Y}_{OSIC-2} - H_{\chi(:,3)}\tilde{X}_{OSIC-3}$$

In fourth step, the fourth detected signal/data stream $\tilde{\mathbf{x}}_{\mathbf{OSIC}-4}$ and modified form of received signal $\tilde{\mathbf{Y}}_{\mathbf{OSIC}-4}$ can be written as:

$$\tilde{X}_{OSIC-4} = W_{(MMSE(4,:)}\tilde{Y}_{OSIC-3} \tag{26}$$

$$\tilde{Y}_{OSIC-4} = \tilde{Y}_{OSIC-3} - H_{\chi(:,4)}\tilde{X}_{OSIC-4}$$

where, W(MMSE(1,:),W(MMSE(2,:), W(MMSE(3,:)and W(MMSE(4,:)are the first, second, third and fourth rows of MMSE weight matrix and Hχ(:,1), Hχ(:,2),Hχ(:,3) and Hχ(:,4)are the first, second, third and fourth columns of the dual polarized channel matrix respectively. The detected desired signal $\tilde{\mathbf{x}}_{\mathbf{OSIC}}$ from the transmitting antenna is given by[11-13]

$$\tilde{X}_{OSIC} = \begin{bmatrix} \tilde{X}_{OSIC-1} \\ \tilde{X}_{OSIC-2} \\ \tilde{X}_{OSIC-3} \\ \tilde{X}_{OSIC-4} \end{bmatrix} \tag{27}$$

3. System Description

The simulateddual polarized DWT aided MIMO SC-FDMA wireless communication system is depicted in Figure 1.In such system, a segment of audio signal is processed primarily for generating binary bit stream and subsequently encrypted[14]. The encrypted binary data are channel coded and.digitally modulated and are spatially demultiplexed to produce four data stream. Each data stream is rearranged into blocks with each block consisting of 64 symbols. A 64 point discrete wavelet transformation (DWT) algorithm is applied to each block to produce details and approximate coefficients. These coefficients are concatenated block wise, spatially mapped into a block of data symbols, serial to parallel converted with 2048 parallel data symbols and are transformed with inverse discrete wavelet transformation(IDWT), cyclically prefixed,parallel to serially converted and transmitted from four dual polarized antennas. In receiving end, the transmitted signals are detected using various signal detection techniques. The detected signals are processed with subsequent cyclic prefix removing, 64 point DWT transformed with its output coefficients concatenation, inverse discrete wavelet transformed(IDWT), spatially multiplexed, digitally demodulated, deinterleaved, channel decoded and decrypted to recover transmitted audio signal.

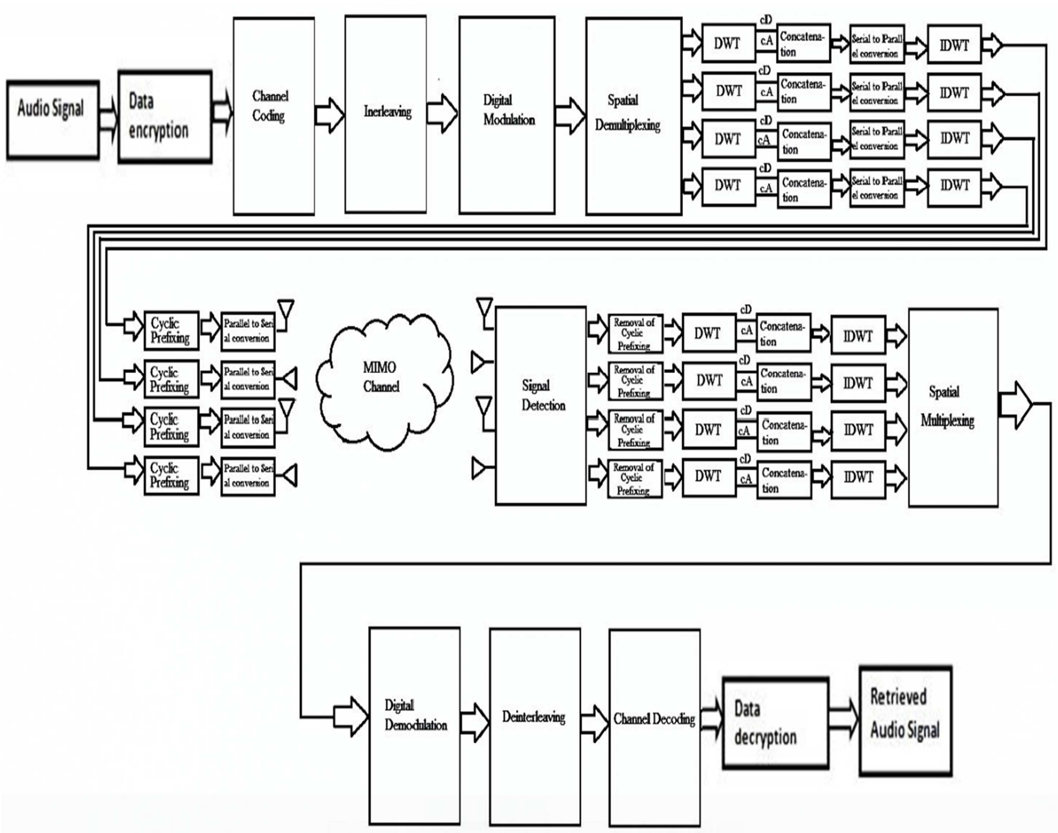

Figure 1. *Block diagram of dual polarized DWT aided MIMO SC-FDMAwireless communication system.*

4. Results and Discussion

In this section, we present a series of simulation results using MATLAB R2014ato illustrate the significant impact of various channel and signal detection techniques on dual polarized DWT aided MIMO SC-FDMA system performance in terms of BER based on the parameters given in Table 1. It is assumed that the channel state information (CSI) of the dual polarized MIMO fading channel is available at the receiver and the fading process is approximately constant during the whole audio signal transmission.

Table 1. *Summary of the Simulated Model Parameters.*

Parameters	Types
Data type	Audio signal
No. of samples	32768
Sampling Frequency(Hz)	12000
No of binary bits for a single sample	16
Total number of binary bits from audio samples	524288
Digital modulation	8PSK and 8QAM
Signal detection	BLUE, MMSE-SIC,ZF and OSIC
Channel coding	Turbo and LDPC
Antenna configuration	4 × 4
Value of inverse of the cross-polar discrimination (XPD)	0.85
SNR	0-10 dB
Channel	AWGN and Rayleigh

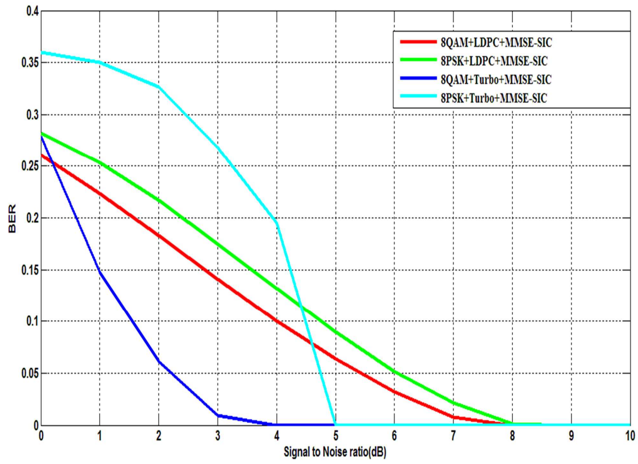

Figure 2. *BER performance of Dual Polarized DWT aided MIMO SC-FDMA Wireless Communication systemusing MMSE-SIC signal detection technique.*

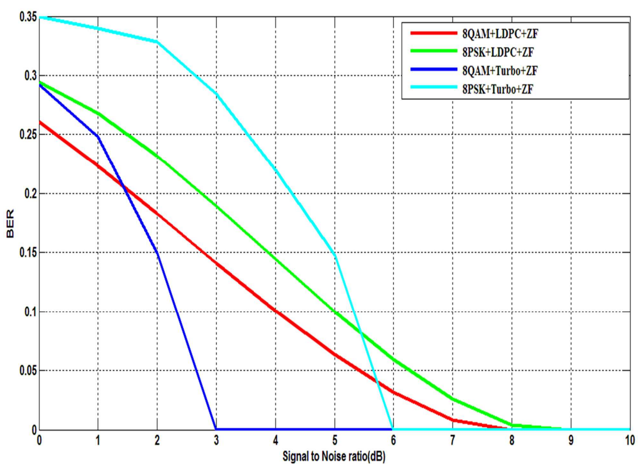

Figure 3. *BER performance of Dual Polarized DWT aided MIMO SC-FDMA Wireless Communication systemusing ZF signal detection technique.*

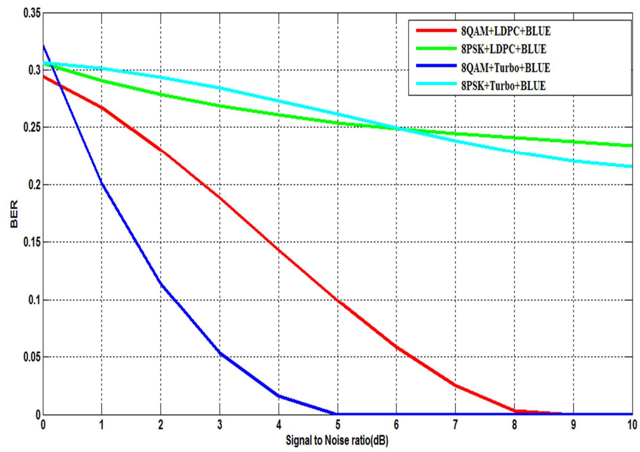

Figure 4. *BER performance of Dual Polarized DWT aided MIMO SC-FDMA Wireless Communication systemusing BLUE signal detection technique.*

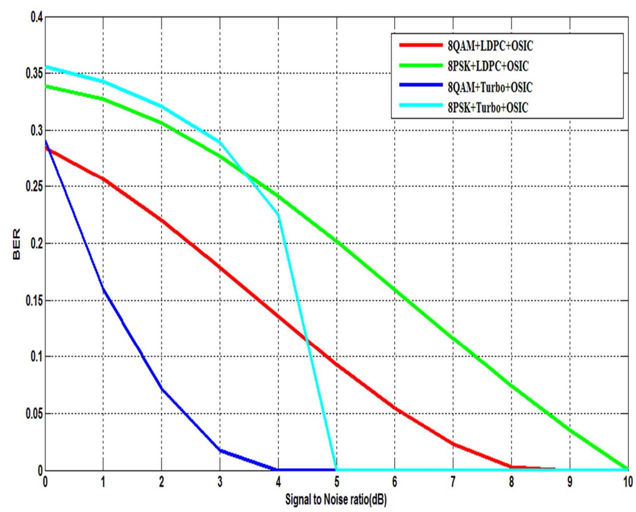

Figure 5. *BER performance of Dual Polarized DWT aided MIMO SC-FDMA Wireless Communication systemusing OSIC signal detection technique.*

The graphical illustrations presented in Figure 2 through Figure 5 show system performance comparison with implementation of MMSE-SIC, ZF, BLUE and OSIC based signal detection schemes under various digital modulations and channel coding schemes. In all cases, the system outperforms in 8QAM and shows worst performance in 8PSK digital modulations. The BER performance difference is quite obvious in lower SNR areas and the system's BER declines with increase in SNR values. In Figure 2, it is noticeable that for a typically assumed SNR value of 2 dB and MMSE-SIC signal detection, the estimated BER values are 0.0128 and 0.2263 in case of Turbo channel coding with 8-QAM and Turbo coding with 8-PSK which is indicative of a system performance improvement of 7.27dB.

In Figure 3, it is observable that for a SNR value of 2 dB and ZF signal detection, the estimated BER values are 0.1495 and 0.3280 in case of Turbo channel coding with 8-QAM and Turbo coding with 8-PSK which is indicative of a system performance improvement of 3.41dB. At 5% BER, SNR gains of 2.7,2.9 and 3.6 dB are achieved in case of 8-QAM with Turbo in comparison with 8-QAM with LDPC, 8-PSK with Turbo and 8-PSK with LDPC respectively.

In Figure 4, it is noticeable that for a SNR value of 2 dB and BLUE signal detection, the estimated BER values are 0.1139 and 0.2939 in case of Turbo channel coding with 8-QAM and Turbo coding with 8-PSK which is indicative of a system performance improvement of 4.11dB.

In Figure 5, it is observable that for a SNR value of 2 dB and OSIC signal detection, the estimated BER values are 0.0717 and 0.3207 in case of Turbo channel coding with 8-QAM and Turbo coding with 8-PSK which is indicative of a system performance improvement of 6.51dB. At 5% BER, SNR gains of 2.4, 3.7 and 6.3 dB are achieved in case of 8-QAM with Turbo in comparison with 8-PSK with Turbo, 8-QAM with LDPC and 8-PSK with LDPC respectively.

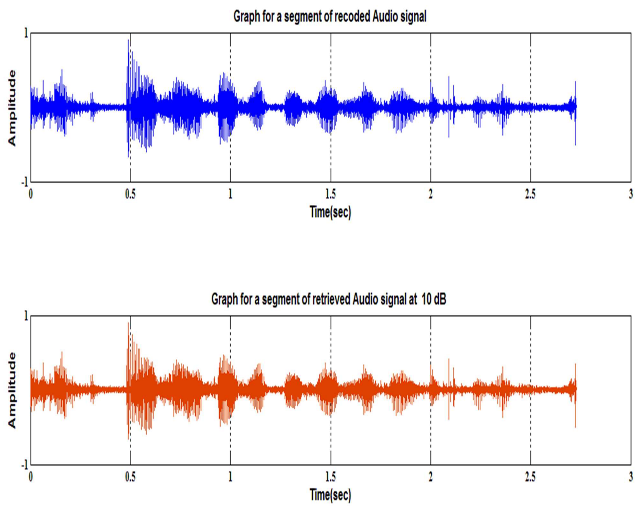

Figure 6. Transmitted and Retrieved audio signals at SNR value of 8 dB under implementation of Turbo channel coding, 8-QAM digital modulation and MMSE-SIC signal detection technique.

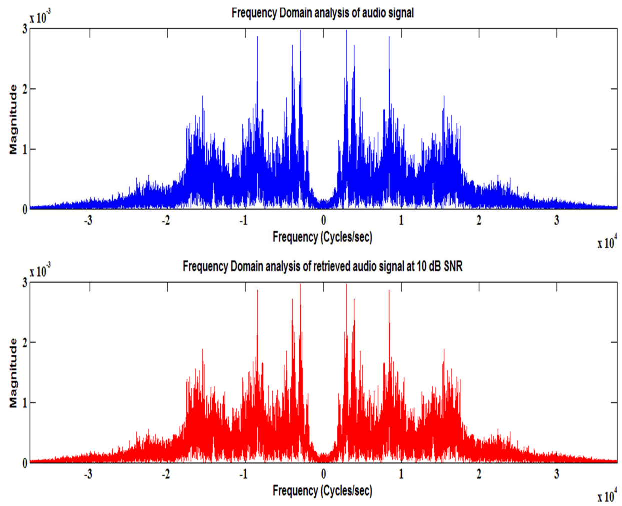

Figure 7. Spectral analysis of Transmitted and Retrieved audio signals at SNR value of 8 dB under implementation of Turbo channel coding, 8-QAM digital modulation and MMSE-SIC signal detection technique.

In Figure 6, the transmitted and retrieved audio signals at SNR value of 8 dB have been presented which are found to have great resemblance with each other. In perspective of spectral representation, the amplitude of different significant frequency components fortransmitted and retrieved audio signals are shown in Figure 7. It is noticeable that a unique spectral response is achieved in case of both transmitted and received audio signals.

5. Conclusions

In this paper, the performance of dual polarized DWT aided MIMO SC FDMA wireless communication system has been investigated on secured audio signal transmission using 8QAM and 8PSK digital modulations, various types of channel coding and signal detection techniques. The simulation results show that the implementation of Turbo channel coding, MMSE-SIC signal detection and 8QAM digital modulation schemes ratifies the robustness of dual polarized DWT aided MIMO SC-FDMA wireless communication system in retrieving audio signal transmitted over noisy and Rayleigh fading channels.

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Biography

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