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An Effective Double Density Dual-Tree Complex Wavelet Transform Based Denoising for MIMO-OFDM

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Abstract: Nowadays, modern mobile telecommunication systems use multiple input multiple output (MIMO) with orthogonal frequency division multiplexing (OFDM) because of its robustness and huge spectrum efficiency. The most significant issues in MIMO-OFDM are noises occurred during communication and precise channel estimation. In this paper, the double density dual-tree complex wavelet transform (DDDTCWT) based denoising is proposed for eliminating noises occurred over the MIMO-OFDM. The fast independent component analysis using negentropy (FICAN) is used for performing blind channel estimation according to the statistics obtained from the received signal. Therefore, an effective denoising and channel estimation accomplished in the MIMO-OFDM is used to reduce the errors during the transmission. The performance of DDDTCWT-FICAN is analyzed using mean square error (MSE), bit error rate (BER) and symbol error rate (SER). The existing research used to evaluate the efficiency of DDDTCWT-FICAN are pilot-based interpolation (PBI) technique, adaptive optimized fast blind channel estimation (AOFBCE) and discrete fourier transform (DFT) with denoise model based least square (LS) Wiener namely DFT-LS-WIENER. The BER of the DDDTCWT-FICAN for 10 dB of SNR is 0.0053, it is less when compared to the PBI.

Keywords: Blind channel estimation, Denoising, Double density dual-tree complex wavelet transform, Fast independent component analysis using negentropy, Multiple input multiple output, Orthogonal frequency division multiplexing.

1. Introduction

The MIMO can enhance the channel capacity along with the growing needs of communication systems. The diversity technique is applied in MIMO systems for additionally enhancing link reliability [1] [2]. The multipath propagation causes the delay spread and frequency selective fading that creates the Inter Symbol Interference (ISI) during broadband wireless data transfer. The OFDM is recommended as an effective key for overcoming the aforementioned issues. This OFDM has various merits such as simple channel equalization, robustness to interference, immunity to selective fading, and spectrum efficiency [3, 4, 5]. The frequency selective channel is transformed into various autonomous frequency flat sub-channels without any small BER when the OFDM is processed with a huge cyclic prefix [6]. The OFDM is utilized in various applications of wireless communication such as broadband internet access, satellite TV, Mobile and different wireless networks [7].

The integration of MIMO with OFDM is considered a promising broadband wireless access technology because it achieves higher data rates and system capacity without any additional usage of power and bandwidth [8, 9, 10]. MIMO-OFDM is a significant system in wireless standards such as IEEE 802.16 m, 3GPP, and long-term evolution advanced [11]. The performance of MIMO-OFDM is affected, because of the interference that occurred during communication [12]. The channel with higher precision is used to maintain the performances, however, is a challenging task to estimate the channel with higher precision in MIMO-OFDM [13, 14]. There are different channel estimation approaches such as pilot tone and blind/ semi-blind channel estimation are developed in the MIMO-OFDM. The training data obtained from the transmitted signal is used to discover the channel information in channel estimation using pilot tone. The noise signal estimation and sequence training are not required in blind or semi-blind channel estimation [15].

The contributions of this research are concise as follows:

- The noise specifically additive white gaussian noise (AWGN) occurred during the communication through the MIMO-OFDM is eliminated by proposing the DDDTCWT. This research considered quadrature phase shift keying (QPSK) for modulation/demodulation because of its low error probability.
- The channels in the MIMO-OFDM are estimated using FICAN without any pilot sequences which leads to minimizing errors in the received signals.
- Therefore, the combination DDDTCWT based denoising and FICAN-based blind channel estimation minimize the MSE, BER and SER.

The paper is sorted as follows: The related works about error minimization over MIMO-OFDM are provided in section 2. A clear explanation of DDDTCWT-FICAN is provided in section 3. Section 4 offers the outcomes of DDDTCWT-FICAN, then the conclusion is presented in section 5.

2. Related work

The existing works related to the BER minimization in MIMO-OFDM are given in this section.

Nagarajan, and Sophia, S [16] developed multi-level redundant discrete wavelet transform (ML-RDWT) for improving spectral efficiency while accomplishing high-speed data broadcasting in the network. The maximized carrier-to-interference power ratio (CIR) was utilized to avoid the impact of BER, ICI and ISI using the weight parameters optimization based on the red deer algorithm. The ML-RDWT enhanced the spectral performance which does not require any cyclic prefix. A channel estimation was essential for improving the communication performances of MIMO.

Pyla, S [17] investigated the channel estimation, performance of BER, coding approach, and optimal power allocation (OPA) for MIMO-OFDM. The water filling algorithm and singular value decomposition were used to provide the statistics of SNR for an adaptive distribution of power to the channels in OPA. A less amount of channels were chosen for power assignment, when the SNR was less. In comb-type pilot channel estimation, least mean square, minimum mean square error and least squares were used while using the turbo code for improving the performances. The code rate of turbo code was required to be less for an effective BER in the system.

Chitra, [18] developed the pilot-based interpolation (PBI) approach for joint carrier frequency offset (CFO) and estimation of the channel in MIMO-OFDM. An evaluation of the CFO was accomplished by broadcasting the pilot symbols over each block of MIMO-OFDM and its impact was compensated on the receiver side. The FFT interpolation was used in the estimated channel for identifying the channel response that was used to reduce the residual estimation error as well as it offered the accurate channel evaluation for fast varying Doppler channels. The existence of CFO was created the ICI between the subcarriers of MIMO-OFDM.

Nandi, [19] presented AOFBCE for MIMO-OFDM with space-time block code. The major objective of this AOFBCE was to simultaneously support the many users in the same frequency band using Multi-Carrier Code-Division Multiple Access (MC-CDMA). Here, modified flower pollination was used to tune the hyperparameters. The MC-CDMA based blind channel estimation was accomplished to restrict the ISI. The denoising was required to be incorporated to further minimize the errors in the received signal.

Venkateswarlu and Rao, [20] developed the channel estimation using modified newton's - based improved animal migration optimization (IAMO) in MIMO-OFDM. The IAMO estimated the optimal channel for restricting interference during the data transfer. Moreover, this IAMO was appropriate for higher data rates, but it was concentrated only on estimating the channels.

Palanisamy [21] presented the channel estimation using DFT with denoise model-based LS wiener namely DFT-LS-WIENER. The pulse shaping filter was used for controlling the ISI. The BER of the DFT-LS-WIENER was high, when there was an increment in the pilot frequency.

The issues found from the related work are high error caused by inappropriate code rate and higher pilot frequency. The combination of both the channel

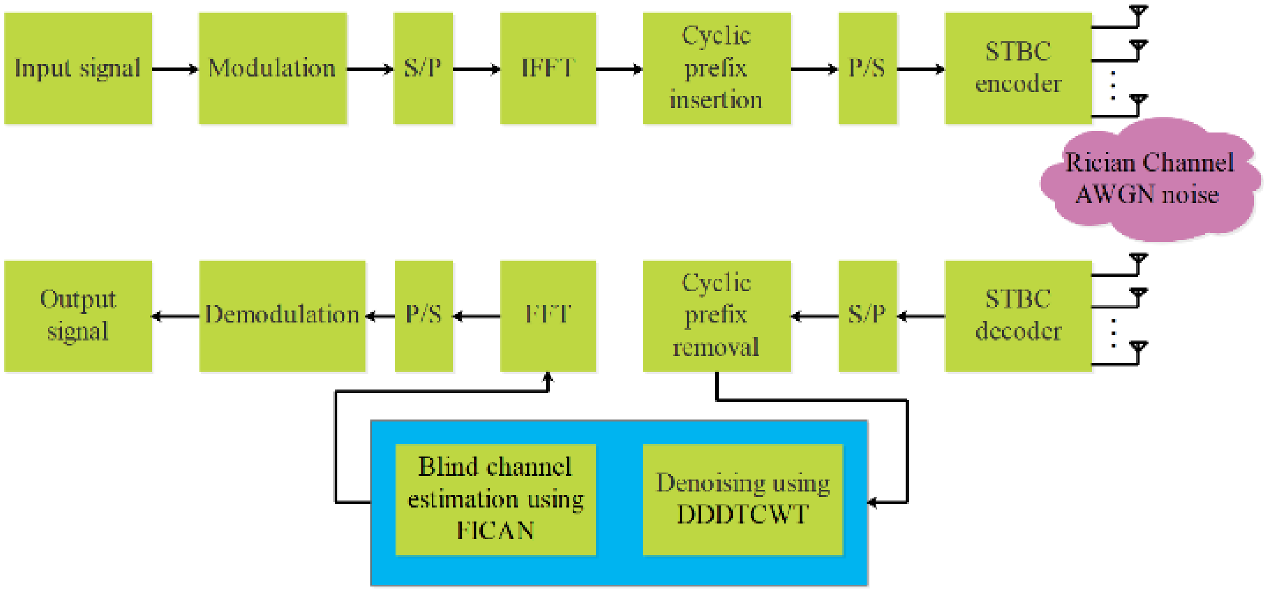

Figure. 1 Block diagram of the DDDTCWT-FICAN method

estimation and denoising is required to be designed for achieving the less error values during the communication. In this research, FICAN based blind channel estimation and DDDTCWT based denoising in MIMO-OFDM. The noises occurred in the communication process is denoised by DDDTCWT. FICAN used to identify channels without any pilot sequences. This channel identification used to avoid the issue related to the pilot contamination which minimizes the errors occurred in the received signal

3. DDDTCWT-FICAN method

In this proposed method, the combination of DDDTCWT and FICAN is used for improving the performances of MIMO-OFDM. The noises that occurred during the data transmission are eliminated by denoising the signals acquired in the receiver. Further, the issues related to the pilot contamination are overcome using the FICAN based blind channel estimation. The block diagram for the DDDTCWT-FICAN method is shown in Fig. 1.

The steps processed in the communication through MIMO-OFDM are mentioned as follows:

1. At first, the input signals are randomly generated and these input signals are modulated using QPSK. The QPSK effectively modulates the signals, because of its enhanced noise immunity and low error probability. Next these modulated signals are applied to the serial to parallel (S/P) operation and then inverse fast fourier transform (IFFT) takes place over the converted signals.
2. The IFFT converts the time domain signals to the frequency domain and a cyclic prefix is included in those signals. Next, Parallel to serial (P/S) is again applied over those signals and it is encoded using space time block coding (STBC).
3. The encoded signals are transmitted using numerous antennas through the Rician fading channel under AWGN constraint.
4. After receiving the signals, again it is processed with STBC decoder, S/P conversion, and cyclic prefix removal. The noises that occurred due to the AWGN is minimized by using DDDTCWT. Additionally, the FICAN is used to perform precise channel estimation without pilot sequences.
5. Next, the remaining processes such as FFT, P/S conversion, and demodulation are performed to obtain the source signal.

A detailed explanation of the MIMO-OFDM model, DDDTCWT and FICAN are given in the following sections.

3.1 MIMO-OFDM and blind source separation model

This section shows the mathematical explanation of the MIMO-OFDM and Blind Source Separation (BSS) models. The output samples from the MIMO system (x) are expressed in Eq. (1).

$$x = As_t + n_t \tag{1}$$

Where the channel matrix is represented as A; the unknown source signal sample in time t is represented as $s_t = [s_1, \dots, s_{N_t}]_t^T$, T denotes vector transpose; receiver noise is denoted as n_t and the unknown mixing matrix is denoted as $A^{N_t \times N_r} = [a_1, \dots, a_{N_r}]^T$; the number of transmitting and receiving antennas is represented as N_t and N_r respectively. This representation for a mixing issue in BSS is identical to the MIMO channel representation. The matrix A denotes the channel coefficients and additive channel noise is denoted as n_t whereas the elements of A either vector or scalar. The channel condition of BSS with MIMO-OFDM of this research doesn't contain the time delays or signal reflections, therefore, the scalar form of a is considered in MIMO-OFDM-BSS. The consistency of the data transmission is enhanced using the STBC encoder and decoder in the transmitter and receiver of MIMO-OFDM.

The channel matrix dimension of MIMO-OFDM is $\mathbb{R}^{N_t \times N_r}$, this proposed work is primarily concentrated on the overdetermined systems. The Rician fading channel is considered for this MIMO-BSS with AWGN. The overdetermined systems represented that the observations in the receivers are higher than the signals which are available on the transmitter side. Further, the DDCWT is used for denoising followed by the Fast ICA with Negentropy (FICAN) is used to accomplish the blind channel estimation. The FICAN is utilized to enhance the input SNR of the continuous BSS stage and minimize the dimensionality channel matrix. The BSS is applied to the square $N_t \times N_t$ as well as divides the matrix into independent components approximately the source signals.

The main objective of BSS is to discover the separation matrix $W \in \mathbb{R}^{N_t \times N_r}$, therefore the output (u_t) is expressed as shown in Eq. (2).

$$u_t = P s_t + W n_t \tag{2}$$

Where the permutation matrix is denoted as P.

3.2 Denoising using DDDTCWT

The proposed DDDTCWT is used to denoise the signal received from the transmitter. The structure of DDDTCWT is formulated from 4 wavelets and 2 scaling operations. Here, one scaling and two wavelets are utilized for real and imaginary values of complex wavelets respectively. The filter banks used in this DDDTCWT are dual and primary. The decomposition of high and low pass filters of dual and primary filter banks is denoted as $H_1(z)$& $H_2(z)$ and $H_0(z)$ are respectively. Eq. (3) and Eq. (4) shows the wavelet and scaling operations of the primary filter respectively.

$$\psi_{hi}(t) = 2 \sum_M h_i[M]\, \phi_h(2t - M) \text{ for } i = 1,2,..\text{M} \tag{3}$$

$$\phi_h(t) = 2 \sum_M h_0[M]\, \phi_h(2t - M) \tag{4}$$

Where, the impulse response of $H_0(z)$ and $H_i(z)$ are $h_0[M]$ and $h_i[M]$ respectively, transform $z = e^{j\omega}$, imaginary unit is j, frequency is ω and difference scale is denoted as M. The wavelet and scaling operations are equally defined for both the primary and dual filter banks which are implemented as the sub-bands of the upper and lower filter are taken as real and imaginary portions of transformation. The real part's wavelets are required to be wavelet's Hilbert transform linked with the imaginary part. Hence the DDDTCWT denoised the transmitted signal x and develops the output as dx.

3.2 FICAN based blind channel estimation

The reconstruction of the original independent source is can't be directly obtained from the mixed signal. Hence, the BSS approaches are unsupervised learning approaches that develop objective functions according to some prior information. From the various BSS approaches, ICA is chosen because of its powerful approach to processing the signal and perform data analysis. The ICA utilizes multidimensional data for discovering the statistical independence and non-Gauss intrinsic values for BSS. Further, the fast ICA is developed according to the non-Gaussian maximization principle that is utilized to improve the negative entropy of the system. Subsequently, the negentropy is incorporated in the Fast ICA which obtains the linear transformation of a random variable that doesn't alters its negentropy value. The developed FICAN is a fast method used to divide the required signal from the mixed source signal and it is having three important features. 1) The non-Gaussian maxima $W^T dx$ is discovered by using the fixed-point iteration theory; 2) A huge amount of sampling points of monitored variable x is processed by using the Newton iteration method; 3) The objective function for optimization uses the value of maximal negative entropy.

Eq. (5) denotes the approximation of negative entropy (J_G).

$$J_G(W) = \left[E\{G(W^t \overline{dx})\} - E\{G(v)\}\right]^2 \tag{5}$$

Where, the calculation of mean is denoted as $E[.]$; the nonlinear function is denoted as $G(.)$,whitened mixing matrix is denoted as $\overline{dx}$ and is chosen as $G_1(y) = \tanh(y)$; the output variable with zero mean and unit variance is denoted as $W^t\overline{dx}$; time period is denoted as t; the Gaussian random variable is denoted as $v = \overline{dx}(t)$. The y used to compute the G represents the decomposition which is expressed in Eq. (6).

$$y = W\overline{dx} \tag{6}$$

Where, $\overline{dx}$ is whitened mixing matrix which is expressed in Eq. (7).

$$\overline{dx} = Qx(t) \tag{7}$$

Where, the whitening matrix of the observed signal is denoted as Q. The objective function is expressed in Eq. (8).

$$J(W_i) = E\left[G\left(W^T\overline{dx}\right)\right] + \gamma(\|W\|^2 - 1) \tag{8}$$

Where the lagrangian multiplier is denoted as γ.

The iterative process according to the newton method is expressed in Eq. (9) and Eq. (10).

$$W_i(k+1) = E\left[G\overline{dx}(W_i(k)^T)\overline{dx}\right] - E\left[G(W_i(k)^T)\overline{dx}\right]dx_i(k) \tag{9}$$

$$W_i^*(k+1) = \frac{W_i(k+1)}{\|W_i(k+1)\|} \tag{10}$$

The directional selectivity and shift invariance property of DDDTCWT is used for accomplishing effective denoising in MIMO-OFDM. Further, the issues related to the pilot contamination is avoided using the FICAN. Hence, the DDDTCWT and FICAN are used to minimize the error between the transmitter and receivers of MIMO-OFDM.

4. Simulation results and discussion

In this section, the performance of the DDDTCWT-FICAN method is evaluated using MATLAB R2018a software. Here, the system is operated with an i5 processor and 6GB RAM. The DDDTCWT-FICAN is used to perform an effective denoising and channel estimation for MIMO-OFDM. Here, 4 antennas are used on the transmitter side and 2 antennas are used on receiver side. The simulation parameters considered for this DDDTCWT-FICAN method are given in Table 1.

Table 1. Simulation parameters

Parameter	Value
Modulation type	QPSK
Number of transmitting antennas	4
Number of receiving antennas	2
Subcarriers number	128 & 256
Number of frames	10,000

The performance of the DDDTCWT-FICAN method is analyzed by means of MSE, BER and SER. The DDDTCWT-FICAN is evaluated for three different scenarios which are specified as follows:

- Scenario 1: Number of subcarriers=128 with various channel estimation approaches.
- Scenario 2: Number of subcarriers=128 with various modulation approaches.
- Scenario 3: Number of subcarriers=256 with different channels.

The different channel estimation considered in scenario 1 is least square (LS), minimum mean-square error (MMSE) along with communication without any denoising and channel estimation namely OFDM and theoretical values. Subsequently, the different modulations considered for scenario 2 are phase shift keying (PSK) and binary phase shift keying (BPSK) approaches. The different channel considered for scenario 3 is Rayleigh channel.

4.1 Performance analysis of DDDTCWT-FICAN for scenario 1

This section shows the performance evaluation of DDDTCWT-FICAN for different channel estimation techniques. Fig. 2, Fig. 3 and Fig. 4 show the performance comparison of MSE, BER and SER for DDDTCWT-FICAN with LS, MMSE, OFDM and theoretical. From the figures, it is concluded that the DDDTCWT-FICAN achieves less MSE, BER and SER than the LS, MMSE, OFDM and theoretical calculation. The accuracy between the transmitted and received signals of the DDDTCWT-FICAN is improved by avoiding the issues related to pilot contamination using the FICAN. The negentropy used in the FICAN obtains linear transformation which doesn’t alter the value of entropy, hence the errors are minimized while transmitting the signals.

4.2 Performance analysis of DDDTCWT-FICAN for scenario 2

The different modulation techniques such as PSK and BPSK are used to evaluate the performance of QPSK used in the DDDTCWT-FICAN are PSK and

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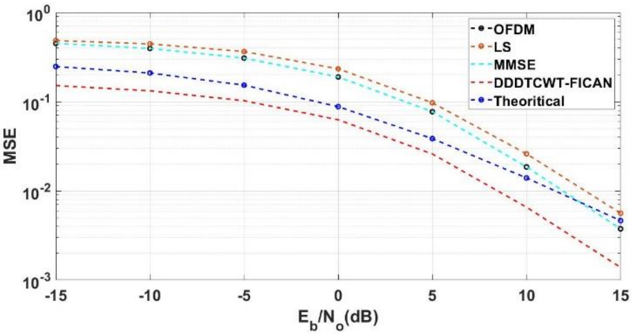

Figure. 2 MSE analysis for DDDTCWT-FICAN with various channel estimation techniques

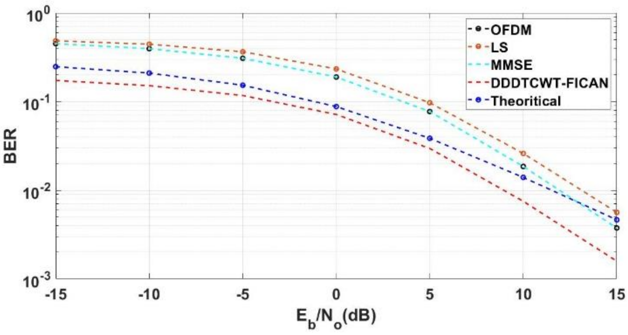

Figure. 3 BER analysis for DDDTCWT-FICAN with various channel estimation techniques

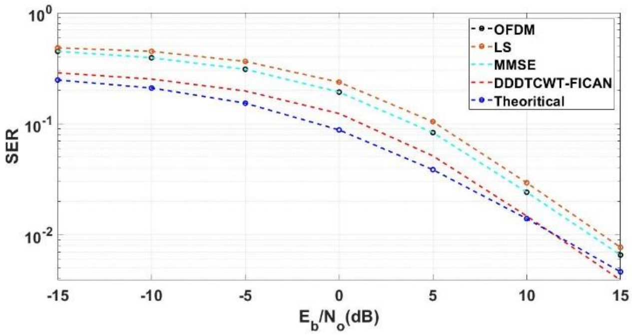

Figure. 4 SER analysis for DDDTCWT-FICAN with various channel estimation techniques

BPSK. Further, the OFDM and theoretical are also included in the evaluation. The performance comparison of MSE, BER and SER for DDDTCWT-FICAN is shown in Fig. 5, Fig. 6 and Fig. 7. The MSE, BER and SER of DDDTCWT-FICAN with QPSK is less when compared to the PSK, BPSK, OFDM and theoretical. The QPSK used in DDDTCWT-FICAN achieves less error because of its enhanced noise immunity and low error probability.

4.3 Performance analysis of DDDTCWT-FICAN for scenario 3

This section shows the performance evaluation of DDDTCWT-FICAN for a different channel. The Rician channel used with the DDDTCWT-FICAN is

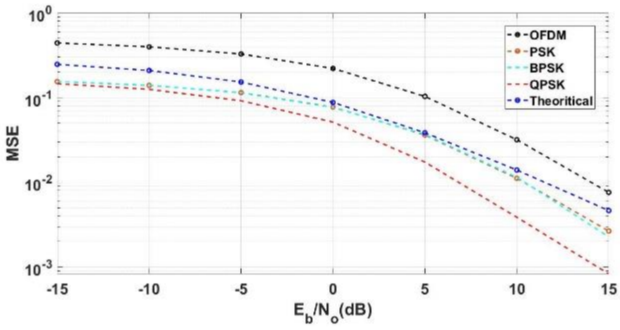

Figure. 5 MSE analysis for DDDTCWT-FICAN with various modulation techniques

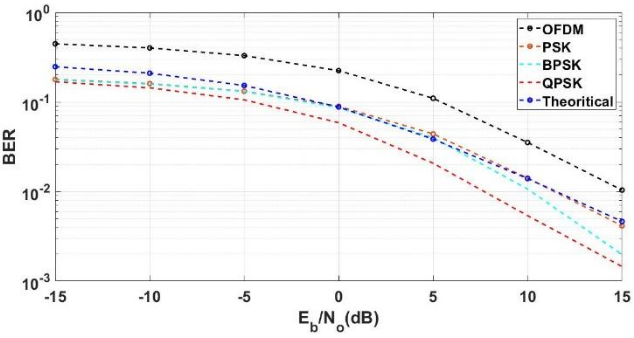

Figure. 6 BER analysis for DDDTCWT-FICAN with various modulation techniques

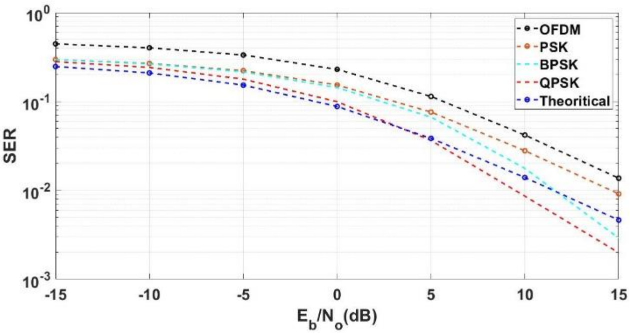

Figure. 7 SER analysis for DDDTCWT-FICAN with various modulation techniques

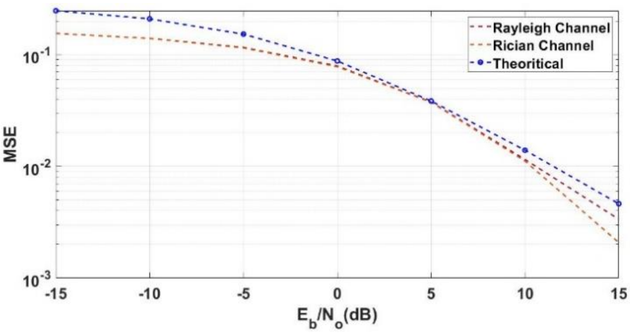

Figure. 8 MSE analysis for DDDTCWT-FICAN with various channels

compared with the Rayleigh channel. Fig. 8, Fig. 9, and Fig. 10 shows the performance comparison of MSE, BER and SER for the Rician channel used in

Table 2. Comparative analysis of PBI and DDDTCWT-FICAN

Metrics	Methods	Signal to Noise Ratio in dB			
		3 (dB)	5 (dB)	10 (dB)	15 (dB)
BER	PBI [18]	0.0501	0.0316	0.0158	0.0032
	DDDTCWT-FICAN	0.0316	0.0207	0.0053	0.0014

Table 3. Comparative analysis of AOFBCE and DDDTCWT-FICAN

Metrics	Methods	Signal to Noise Ratio in dB			
		3 (dB)	5 (dB)	10 (dB)	15 (dB)
MSE	AOFBCE [19]	7.9432	6.1659	2.8183	NA
	DDDTCWT-FICAN	0.0277	0.0181	0.0047	0.0012
SER	AOFBCE [19]	794.3282	616.5950	165.9586	15.8489
	DDDTCWT-FICAN	0.0590	0.0364	0.0086	0.0019

Table 4. Comparative analysis of DFT-LS-WIENER and DDDTCWT-FICAN

Metrics	Methods	Signal to Noise Ratio in dB		
		6 (dB)	9 (dB)	12 (dB)
BER	DFT-LS-WIENER [21]	0.010104	0.002036	0.000367
	DDDTCWT-FICAN	0.002340	0.000193	0.0000122
MSE	DFT-LS-WIENER [21]	0.003916	0.001961	0.000987
	DDDTCWT-FICAN	0.001561	0.000134	0.000014

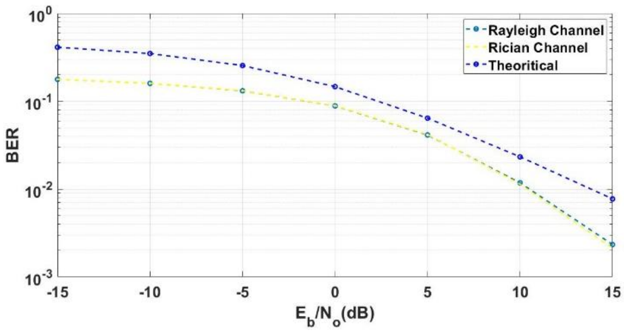

Figure. 9 BER analysis for DDDTCWT-FICAN with various channels

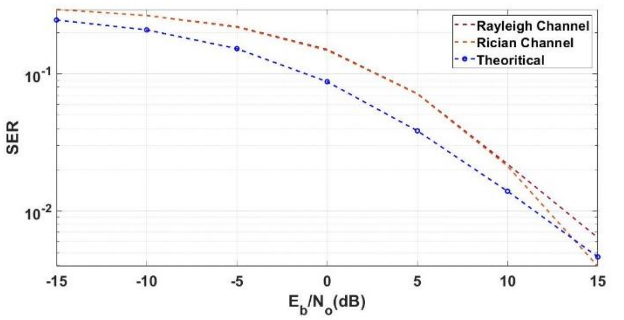

Figure. 10 SER analysis for DDDTCWT-FICAN with various channels

the DDDTCWT-FICAN with Rayleigh channel and theoretical. From the figures, it is concluded that the DDDTCWT-FICAN achieves less MSE, BER and SER than the Rayleigh channel and theoretical calculation. The errors that occurred during the communication over the MIMO-OFDM are minimized by denoising the received signals using the DDDTCWT. The directional selectivity and shift invariance property of DDDTCWT is used to perform effective denoising through the signals transmitted over the MIMO-OFDM.

4.4 Comparative analysis

This section shows the comparative analysis of DDDTCWT-FICAN with existing research such as PBI [18], AOFBCE [19] and DFT-LS-WIENER [21]. The comparison is done by means of BER, MSE and SER. Tables 2, 3 and 4 shows the comparative analysis of DDDTCWT-FICAN with PBI [18], AOFBCE [19] and DFT-LS-WIENER [21]. From Tables 2, 3 and 4, it is known that the DDDTCWT-FICAN achieves better results because of its effective denoising and effective channel estimation. The following strategies are used to minimize the error values: The blind channel estimation using FICAN helps to overcome the issues related to the pilot contamination. Further, a directional selectivity and shift invariance property of DDDTCWT helps to perform an effective denoising in MIMO-OFDM.

5. Conclusion

The combination of effective denoising and blind channel estimation is required to enhance the performances of MIMO-OFDM. In this paper, the DDDTCWT based effective denoising is proposed for minimizing the noises occurred while transmitting the signals. Subsequently, the FICAN based blind channel estimation is done for discovering the channel without any pilot sequences. The developed channel estimation using FICAN avoids the issue related to the pilot contamination. Therefore, it minimizes the errors occurred in the received signal which is useful in communication systems. From the results, it is concluded that the DDDTCWT-FICAN outperforms well than the PBI, AOFBCE and DFT-LS-WIENER. The BER of the DDDTCWT-FICAN for 10 dB of SNR is 0.0053, it is less when compared to the PBI. In the future, the BER minimization of MIMO-OFDM can be analyzed with different fading channels.

Notation

Parameter	Description
x	Output samples
A	Channel matrix
t	Time
s	Source signal
N_t	Number of transmitting antennas
N_r	Number of receiving antennas
T	Vector transpose
$\mathbb{R}$	Channel matrix dimension of MIMO-OFDM
W	Separation matrix
P	Permutation matrix
u_t	Output with BSS
$H_1(z)\& H_2(z)$	High filters of dual filter banks
$H_0(z)$	Low pass filters of primary filter banks
$h_0[M]$	Impulse response of $H_0(z)$
$h_i[M]$	Impulse response of $H_i(z)$
j	Imaginary unit
ω	Frequency
M	Difference scale
J_G	Negative entropy
$E[.]$	Mean
$G(.)$	Nonlinear function
$\overline{dx}$	Whitened mixing matrix
Q	Whitening matrix
v	Gaussian random variable
y	Decomposition
γ	Lagrangian multiplier

Conflicts of interest

The authors declare no conflict of interest

Author contributions

For this research work all authors' have equally contributed in Conceptualization, methodology, validation, resources, writing—original draft preparation, writing—review and editing.

References

[1] X. Zhang, M. Zhou, and C. Wang, "Time-varying sparse channel estimation based on adaptive average and MSE optimal threshold in STBC MIMO-OFDM systems", *IEEE Access*, Vol. 8, pp. 177874-177895, 2020.

[2] M. Rakshit, S. Bhattacharjee, J. Sanyal, and A. Chakrabarti, "Hybrid turbo coding PTS with enhanced switching algorithm employing de to carry out reduction in PAPR in AUL-based MIMO-OFDM", *Arabian Journal for Science and Engineering*, Vol. 45, No. 3, pp. 1821-1839, 2020.

[3] M. Shamsesalehi, Y. Attarizi, and R. Rajabi, "Power allocation and subchannel pairing for BER minimization in MIMO-OFDM AF relay systems", *Annals of Telecommunications*, Vol. 75, Nos. 5-6, pp. 175-184, 2020.

[4] Q. Wu, X. Zhou, C. Wang, and H. Cao, "Variable pilot assisted channel estimation in MIMO-OFDM system with STBC and different modulation modes", *EURASIP Journal on Wireless Communications and Networking*, Vol. 2022, p. 45, 2022.

[5] S. Jothi and A. Chandrasekar, "An efficient modified dragonfly optimization based mimo-ofdm for enhancing qos in wireless multimedia communication", *Wireless Personal Communications*, Vol. 122, No. 2, pp. 1043-1065, 2022.

[6] C. Venkateswarlu and N. V. Rao, "An Efficient MAPSO Model for Interference Cancellation and Optimal Channel Estimation in MIMO-OFDM System", *Wireless Personal Communications*, Vol. 128, No. 1, pp. 283-307, 2023.

[7] K. Nageswaran, M. Selvan, and M. Gandhi, "A Hybrid Transform for Reduction of Peak to Average Power Ratio in OFDM System", *Wireless Personal Communications*, Vol. 118, No. 4, pp. 3187-3197, 2021.

[8] H. Kasban, S. Hashima, S. Nassar, E. M. Mohamed, and M. A. M. E. Bendary, "Performance enhancing of MIMO-OFDM system utilizing different interleaving techniques with rate-less fountain raptor code", *IET Communications*, Vol. 16, No. 20, 2022.

[9] P. De, "Reduced-Rank Filtering-Based Semiblind MIMO-OFDM Sparse Channel Estimation", *IEEE Systems Journal*, Vol. 15, No. 1, pp. 1036-1047, 2021.

[10] M. Vijayalakshmi and K. R. Reddy, "An effective hybrid approach for PAPR reduction in MIMO-OFDM", *Analog Integrated Circuits*

and Signal Processing, Vol. 102, No. 1, pp. 145-153, 2020.

[11] Y. Yuan, B. Zhang, and J. L. Yu, "Subspace Channel Identification for Multiuser MIMO STBC-OFDM Systems", *Circuits, Systems, and Signal Processing*, Vol. 38, No. 9, pp. 4115-4140, 2019.

[12] R. Bhandari and S. Jadhav, "Novel spectral efficient technique for MIMO-OFDM channel estimation with reference to PAPR and BER analysis", *Wireless Personal Communications*, Vol. 104, No. 4, pp. 1227-1242, 2019.

[13] S. N. Raut and R. M. Jalnekar, "Taylor-Based Least Square Estimation in MIMO-OFDM Systems for Multimedia Applications", *Wireless Personal Communications*, Vol. 120, No. 1, pp. 609-631, 2021.

[14] S. Dhanasekaran, S. Palanisamy, F. Hajjej, O. I. Khalaf, G. M. Abdulsahib, and S. Ramalingam, "Discrete Fourier Transform with Denoise Model Based Least Square Wiener Channel Estimator for Channel Estimation in MIMO-OFDM", *Entropy*, Vol. 24, No. 11, p. 1601, 2022.

[15] P. Saxena, S. B. Patel, and J. K. Bhalani, "MIMO Semi-blind Channel Estimation by using Tikhonov Regularized MMSE and MAP Algorithms with Householder Transformation based QR Decomposition", *Radioelectronics and Communications Systems*, Vol. 64, No. 4, pp. 165-173, 2021.

[16] K. Nagarajan and S. Sophia, "Multilevel Redundant Discrete Wavelet Transform (ML-RDWT) and optimal Red Deer algorithm (ORDA) centred approach to mitigate the effect of ICI, BER and CIR in a MIMO-OFDM System", *Wireless Personal Communications*, Vol. 122, No. 4, pp. 3347-3370, 2022.

[17] S. Pyla, "Capacity and BER performance improvement in integrated MIMO-OFDM system using optimal power allocation, channel estimation, and turbo coding", *International Journal of Communication Systems*, Vol. 34, No. 14, p. e4915, 2021.

[18] S. Chitra, S. Ramesh, R. Vijay, G. Jegan, and T. S. Lawrence, "Joint CFO and channel estimation using pilot aided interpolation for high performance MIMO-OFDM", *International Journal of Electronics*, 2022.

[19] S. Nandi, N. N. Pathak, and A. Nandi, "A novel adaptive optimized fast blind channel estimation for cyclic prefix assisted space–time block coded MIMO-OFDM systems", *Wireless Personal Communications*, Vol. 115, No. 2, pp. 1317-1333, 2020.

[20] C. Venkateswarlu and N. V. Rao, "Optimal channel estimation and interference cancellation in MIMO-OFDM system using MN-based improved AMO model", *The Journal of Supercomputing*, Vol. 78, No. 3, pp. 3402-3424, 2022.

[21] S. Palanisamy, F. Hajjej, O. I. Khalaf, and G. M. Abdulsahib, "Discrete Fourier Transform with Denoise Model Based Least Square Wiener Channel Estimator for Channel Estimation in MIMO-OFDM", *Entropy*, Vol. 24, No. 11, p.1601, 2022.