A New Data Conjugate ICI Self Cancellation for OFDM System

Abhijeet Bishnu
Department of Electronics and Telecommunication, SGSITS, Indore-452003, India
abhijeet.bishnu87@gmail.com

Anjana Jain
Department of Electronics and Telecommunication, SGSITS, Indore-452003, India
jain.anjana@gmail.com

Anurag Shrivastava
Department Of Electronics And Telecommunication, SGSITS, Indore-452003, India
Ashrivastava827@Gmail.Com

Abstract-The available frequency spectrum is scarce, so for high data rate services bandwidth utilization must be efficient. It should be characterized by significantly enhancing the spectral efficiency in order to increases the speed of operation and network capacity. Hence OFDM has been proposed which provides high spectral efficiency and robustness against multi-path interference. The main limitation of OFDM which restricts its performance is inter carrier interference (ICI). ICI occurs because of loss of orthogonality between sub carriers. The main causes of orthogonality lost are Doppler shift and carrier frequency offset (CFO). In this paper, a new data conjugate ICI self cancellation method is proposed for OFDM system. The proposed method is compared with weighted conjugate transformation WCT) ICI self cancellation method in terms of CIR and BER. The simulations are performed in AWGN channel under BPSK and QPSK digital modulation. Convolution coding of code rate 2/3 is also applied. The results and simulations show that the proposed method is better than the WCT method with and without convolution coding. Also results show that the proposed method is robust against frequency.

Keywords- OFDM, ICI, CFO, Data conjugate, Self cancellation

I. Introduction

In OFDM, a high-data rate channel is divided into N number of low data-rate sub channels and each sub channel is modulated in different sub-carrier. By doing so each sub channel experiences a flat-fading and hence equalization at the receiver is simple. So it provides high spectral efficiency and robustness against multi-path interference.

Currently, OFDM is being used in many wireless communication systems, such as Wireless Local Area Network (WLAN) systems, HIPERLAN2 (High Performance Local Area Network), Digital Video Broadcasting (DVB) systems, Worldwide Interoperability for Microwave Access (WiMAX). In OFDM, sub channels are orthogonal to each other, but due to frequency offset causes from frequency drift between oscillator of transceiver or Doppler frequency, orthogonality is lost which causes ICI. So the frequency offset is the main disadvantage of OFDM system performance.

The performance of OFDM is maintained by removing ICI. In literature various methods are given to mitigate ICI, such as frequency-domain equalization [1], time-domain windowing [2], self-cancellation [3]-[7], frequency offset estimation and correction technique [8]-[9], correlative coding [10] and so on. The self-cancellation (SC) method is not very complex and easy way to cancel ICI compared to other methods. Several SC methods are presented, such as data-conversion [3], symmetric data-conversion [4], weighted data-conversion [4]- [5], data-conjugate [6] and weighted conjugate transformation (WCT) [7].

In this paper, we present a new data conjugate ICI self cancellation and compared with WCT [7] in terms of CIR and BER because in [7] the results show that the WCT method outperforms the other existing methods. Our simulation results show that, the new data conjugate method is better than the WCT method.

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II. System Description and ICI Analysis

Description of discrete-time baseband OFDM system is followed the same procedure as given in [7] and shown in fig. 1. Firstly a stream of input serial bit is converted into parallel by S/P, then mapped into symbols using BPSK modulation, then perform IFFT on N-parallel subcarriers and transmitted after adding cyclic prefix and converted to serial data. The addition of cyclic prefix is used to cancel inter-symbol interference (ISI). At the receiver side, the cyclic prefix is removed from received data after S/P, and then performs FFT, remapped into bits and back to serial data using P/S. In OFDM system, the time-domain transmitted signal is given as:

$$x(n) = \frac{1}{N}\sum_{k=0}^{N-1} X(k)e^{j2\pi nk/N} \quad (1)$$

where $x(n)$ denotes the n^{th} sample of sample of transmitted signal, $X(k)$ denotes the modulated symbol for the k^{th} subcarrier (k=0,1,....,N) and N is number of subcarrier. The received signal in time-domain is given as:

$$y(n) = x(n)e^{\frac{j2\pi n\epsilon}{N}} + w(n) \quad (2)$$

ε(ΔfT_s) is the normalised frequency offset, Δf is the Doppler frequency shift, T_s is symbol duration and $w(n)$ is AWGN introduced in the channel.

The received signal at the k^{th} subcarrier is given as:

$$Y(k) = \sum_{l=0}^{N-1} y(n)e^{-\frac{j2\pi kn}{N}}$$

$$= X(k)S(0) + \sum_{l=0,l\neq k}^{N-1} X(l)S(l-k) + W(k) \quad (3)$$

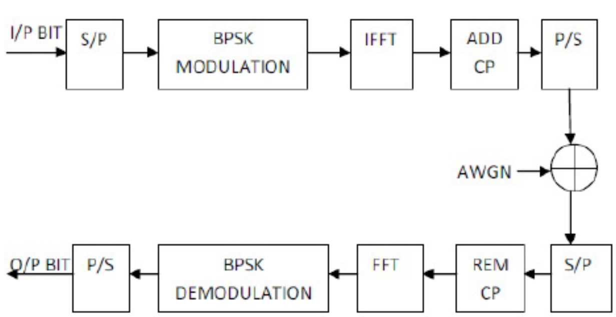

Fig. 1 Block Diagram Of Baseband OFDM System

where $W(k)$ is the FFT of w(n), the first term of eqn.3 is desired signal and second term is interference signal, $S(l-k)$ are the complex coefficients for ICI components in the received signal. The ICI components are the interfering signals other than desired signal. The $S(l-k)$ is given as:

$$S(l-k) = \frac{\sin[\pi(l+\varepsilon-k)]}{N\sin[\frac{\pi(l+\varepsilon-k)}{N}]}e^{[j\pi\left(1-\frac{1}{N}\right)(l+\varepsilon-k)]} \quad (4)$$

The CIR is the ratio of desired signal power to interfering component. The desired signal is transmitted on subcarrier "0" is considered, then the CIR is given by:

$$CIR = \frac{E[|X(k)|^2].E[|S(0)|^2]}{E[X(l)|^2].\sum_{l=0,l\neq k}^{N-1}|S(l-k)|^2}$$

$$= \frac{|S(0)|^2}{\sum_{l=1}^{N-1}|S(l)|^2} \quad (5)$$

III. Different Methods of ICI Self Cancellation

In SC scheme, at transmitter side one data symbol is mapped onto two subcarriers with predefined weighting coefficients. At receiver, the received signal is determined by the difference between the adjacent subcarriers. Fig.2 shows the block diagram of ICI SC OFDM system.

3.1 Data-conversion scheme

This scheme is based on the data symbol allocation of $X'(k) = X(k), X'(k+1) = -X(k)$ $(k = 0,2,\dots,N-2)$. The desired signal is recovered in the receiver as:

$$Z(k) = \frac{1}{2}(Y'(k) - Y'(k+1)) \quad (6)$$

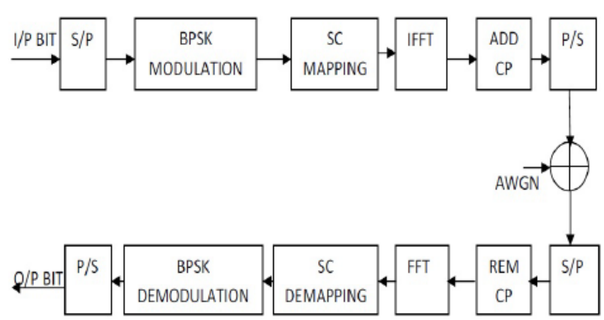

Fig.2 Block Diagram of OFDM System With Self Cancellation

where $X'(k)$ is the transmitted data symbol at k^{th} subcarrier after SC mapping, $Y'(k)$ is the $2k^{th}$ subcarrier data after FFT in the receiver and $Z(k)$ is the desired received signal after SC demapping. The CIR is given by [3] and expressed as:

$$CIR = \frac{|-S(1)+2S(0)-S(-1)|^2}{\sum_{l=2,even}^{N-2}|-S(l-1)+2S(l)-S(l+1)|^2} \quad (7)$$

3.2 Symmetric data-conversion scheme

This scheme is based on data symbol allocation of $X'(k) = X(k)$, $X'(N-k-1) = -X(k)$ (k=0,2,4...,N-2). The desired signal is recovered in the receiver as:

$$Z(k) = \frac{1}{2}(Y'(k) - Y'(N-k-1)) \quad (8)$$

The CIR is given by [4] and expressed as:

$$CIR = \frac{|-S(N-1)+2S(0)-S(1-N)|^2}{\sum_{l=2,even}^{N-2}|-S(N-l-1)+S(l)+S(-1)-S(l-N-1)|^2} \quad (9)$$

3.3 Real constant weighted data-conversion scheme

This scheme is based on the data symbol allocation of $X'(k) = X(k)$,$X'(k+1) = -\mu X(k)$ (k=0,2,4...,N-2), where μ is a real constant in [0,1]. The desired signal is recovered in the receiver as:

$$Z(k) = \frac{1}{1+\mu}(Y'(k) - Y'(k+1)) \quad (10)$$

The CIR is given by [4] and expressed as:

$$CIR = \frac{|-\mu S(1)+(1+\mu)S(0)-S(1)|^2}{\sum_{l=2,even}^{N-2}|-S(l-1)+(1+\mu)S(l)-\mu S(l+1)|^2} \quad (11)$$

3.4 Plural weighted data-conversion scheme

This scheme is based on the data symbol allocation of $X'(k) = X(k)$, $X'(k+1) = e^{-j\pi/2}X(k)$ (k=0,2,4...,N-2).The desired signal is recovered in the receiver as:

$$\boldsymbol{Z(k) = \frac{1}{2}(Y'(k) - e^{-j\pi/2}Y'(k+1))} \quad (12)$$

The CIR is given by [5] and expressed as:

$$CIR = \frac{\left|2S(0)+e^{-j\pi/2}[S(1)-S(-1)]\right|^2}{\sum_{l=2,even}^{N-2}|2S(l)+e^{-j\pi/2}[S(l+1)-S(l-1)]|^2} \quad (13)$$

3.5 Data-conjugate scheme

This scheme is based on the data symbol allocation of $X'(k) = X(k)$, $X'(k+1) = -X^*(k)$ (k=0,2,4...,N-2). The desired signal is recovered in the receiver as:

$$Z(k) = \frac{1}{2}(Y'(k) - Y'^*(k+1)) \quad (14)$$

The CIR is given by [6] and expressed as:

$$CIR = \frac{|S(0)+S^*(0)|^2 + |S(1)+S^*(-1)|^2}{\sum_{l=2,even}^{N-2}|S(l)+S^*(l)|^2 + |S(l+1)+S^*(l-1)|^2} \quad (15)$$

3.6 Weighted conjugate transformation

This scheme is based on the data symbol allocation of $X'(k) = X(k)$, $X'(k+1) = e^{j\pi/2}X^*(k)$ (k=0,2,4...,N-2).The desired signal is recovered in the receiver as:

$$Z(k) = \frac{1}{2}(Y'(k) - e^{-j\pi/2}Y'^*(k+1)) \quad (16)$$

The CIR of WCT is given by [7] and expressed as:

$$CIR = \frac{|S(0)+S^*(0)|^2 + \left|e^{j\pi/2}S(1) - e^{-j\pi/2}S^*(-1)\right|^2}{\sum_{l=2,even}^{N-2}|S(l)+S^*(l)|^2 + |e^{j\pi/2}S(l+1)+e^{-j\pi/2}S^*(l-1)|^2} \quad (17)$$

IV. New Data Conjugate SC Method

The proposed method is the modification of WCT. In this method the data modulated within the $(k+1)^{th}$ subcarrier is phase rotated by $-\pi/2$, instead of $\pi/2$ as presented in WCT of the conjugate of the modulated data within k^{th} subcarrier. So in proposed method, the data symbol is allocated by $X'(k) = X(k)$, $X'(k+1) = e^{-j\pi/2} X^*(k)$ (k=0,2,4...,N-2). Simulation results show that the proposed method is better than WCT.

The received signal within k^{th} and $(k+1)^{th}$ subcarrier given as:

$$Y'(k) = \sum_{l=0}^{N-1} X(l)S(l-k) + W(k)$$

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$$= X(0)S(0-k) + e^{-\frac{j\pi}{2}}X^*(0)S(1-k) + \cdots + W(k)$$

$$= \sum_{l=0,even}^{N-2} X(l)S(l-k) + e^{-\frac{j\pi}{2}}X^*(l)S(l+1-k) + W(k) \quad (18)$$

and

$$Y'(k+1) = \sum_{l=0,even}^{N-2} X(l)S(l-k-1) + e^{-\frac{j\pi}{2}}X^*(l)S(l-k) + W(k+1) \quad (19)$$

respectively. The desired signal is recovered as:

$$Z(k) = \frac{1}{2}(Y'(k) - e^{\frac{j\pi}{2}}Y'^*(k+1)$$

$$= \frac{1}{2}\sum_{l=0,even}^{N-2}(X(l)[S(l-k) + S^*(l-k)]$$

$$+X^*(l)[e^{-\frac{j\pi}{2}}S(l+1-k) - e^{\frac{j\pi}{2}}S^*(l-k-1)]) + W'(k)$$

$$= \frac{1}{2}(X(k)[S(0) + S^*(0)] + X^*(k)[e^{-\frac{j\pi}{2}}S(1) - e^{\frac{j\pi}{2}}S^*(-l)] + \sum_{l=0,even}^{N-2}(X(l)[S(l-k) + S^*(l-k)] + X^*(l)\left[e^{-j\pi/2}S(l+1-k) - e^{\frac{j\pi}{2}}S^*(l-k-1)\right]) + W'(k) \quad (20)$$

The first term of eqn. 20 is the desired signal power and the second term is the interfering component. Consider the desired signal is transmitted in "0" subcarrier, then the CIR of proposed method is given by:

$$CIR = \frac{|S(0) + S^*(0)|^2 + \left|e^{-j\pi/2}S(1) - e^{j\pi/2}S^*(-1)\right|^2}{\sum_{l=2,even}^{N-2}|S(l) + S^*(l)|^2 + |e^{-j\pi/2}S(l+1) - e^{j\pi/2}S^*(l-1)|^2} \quad (21)$$

V. Results and Discussion

In this section, we compared the new data conjugate SC method with WCT in terms of CIR and BER for BPSK and QPSK modulation with and without Convolution coding. For simulation purpose we have considered AWGN channel and 128 sub carriers. Fig. 3 shows the comparison of proposed and WCT in terms of CIR. It shows that the CIR is same for both methods.

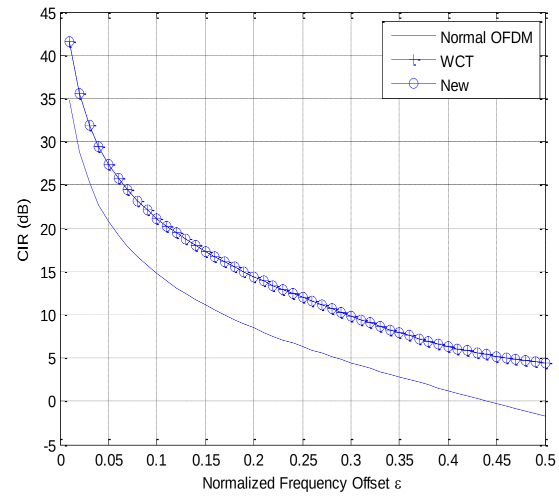

Fig. 3 CIR Comparison of New Data Conjugate And WCT Method

Table I shows the simulation parameter for BER calculation. Fig. 4 shows BER comparison of proposed and WCT method for ε = 0.25 under BPSK modulation. It shows that for the same BER the proposed method required 0.5dB less Eb/No as compared to WCT. Similarly Fig. 5 shows BER comparison for ε = 0.5 under same modulation and it shows that the new method is better than WCT by 2dB Eb/No for same BER.

Table 1: Simulation Parameter

PARAMETER	SPECIFICATION
FFT size	128
Sub carrier spacing	9.765KHz
Useful symbol time	0.1024ms
Guard interval time	0.02048ms
Modulation	BPSK, QPSK
Channel coding	Convolution coding (2/3)
ε	0.25, 0.5

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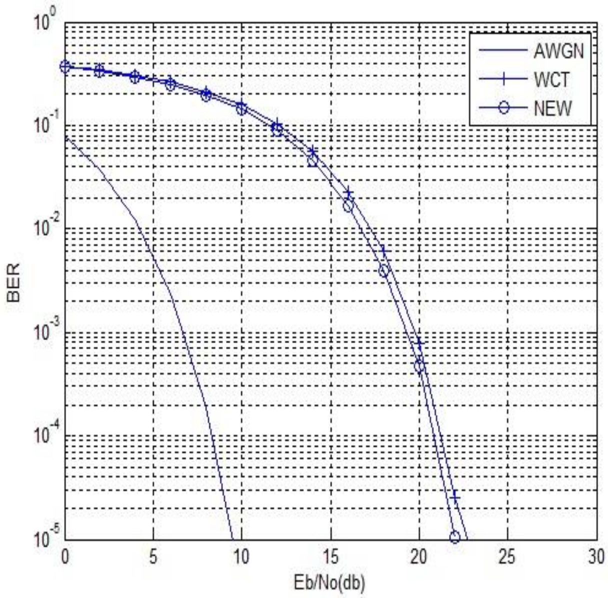

Fig. 4 BER Comparison of New Data Conjugate And WCT Under BPSK Modulation For E = 0.25

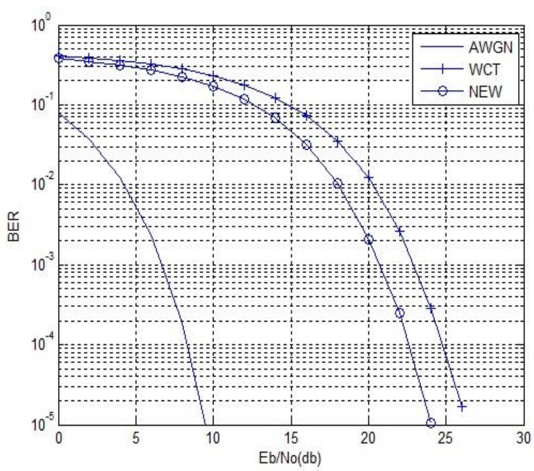

Fig. 5 BER comparison of new data conjugate and WCT under BPSK modulation for ε = 0.5

Table II: Eb/No Required For BER Of 10^{-3} Under BPSK

Methods	**With coding**		**Without coding**	
	ε = 0.25	ε = 0.5	ε = 0.25	ε = 0.5
WCT	16.5dB	20dB	20dB	23dB
NEW SC	16dB	17.2dB	19dB	21dB

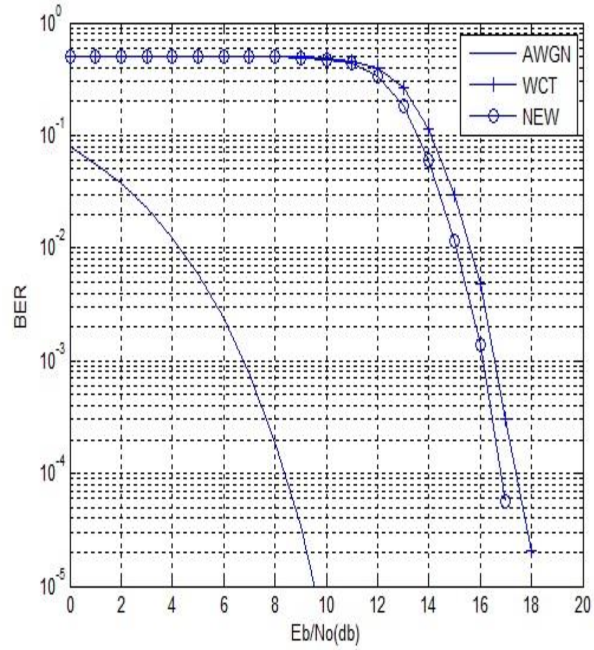

Fig. 6 BER Comparison Of New Data Conjugate And WCT Under BPSK Modulation For E = 0.25 With Convolution Coding

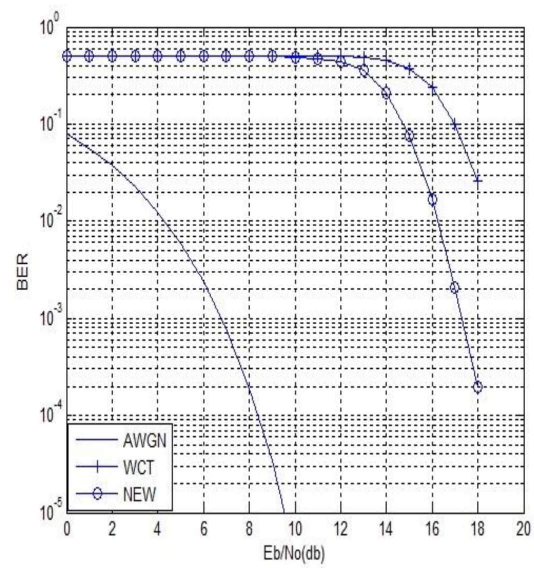

Fig. 7 BER Comparison of New Data Conjugate And WCT Under BPSK Modulation For E = 0.5 With Convolution Coding

Fig. 6 and 7 show the BER comparison under BPSK modulation for ε = 0.25 and 0.5 respectively using convolution coding of code rate 2/3. Table II shows the required Eb/No for BER of 10^{-3} with and without channel coding. From Table II, it shows that by applying channel coding WCT and new method required 3dB and 3.5dB less Eb/No for same BER.

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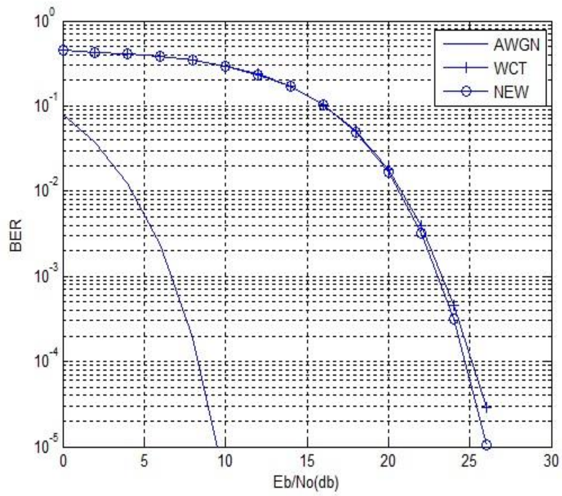

Fig. 8 BER Comparison of New Data Conjugate And WCT Under QPSK Modulation For E = 0.25

Fig. 8 shows BER comparison of proposed and WCT method for ε = 0.25 under QPSK modulation. It shows that for the same BER the proposed method required 0.1dB less Eb/No as compared to WCT. Similarly Fig. 9 shows BER comparison for ε = 0.5 under same modulation and it shows that the new method is better than WCT by 0.5dB Eb/No for same BER.

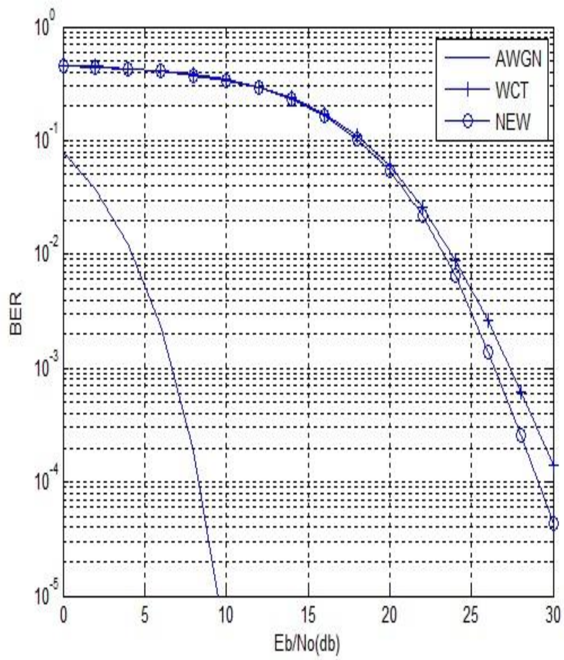

Fig. 9 BER comparison of new data conjugate and WCT under QPSK modulation for ε = 0.5

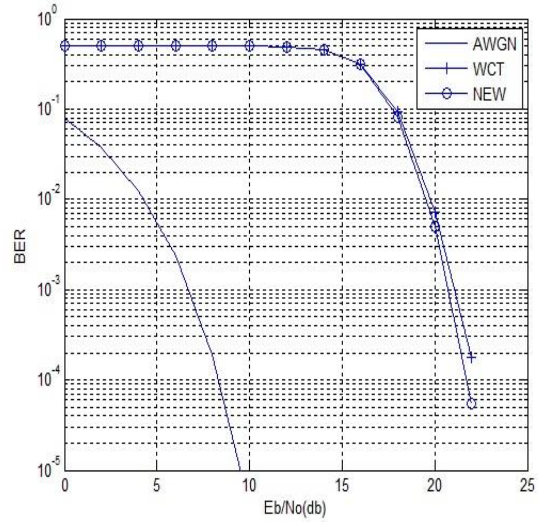

Fig. 10 BER Comparison Of New Data Conjugate And WCT Under QPSK Modulation For E = 0.25 With Convolution Coding

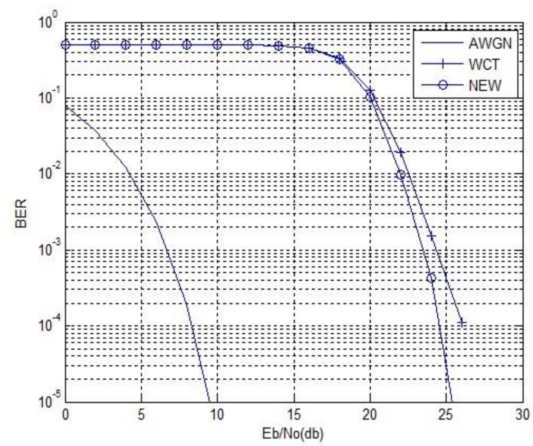

Fig. **11** BER Comparison Of New Data Conjugate And WCT Under QPSK Modulation For E = 0.5 With Convolution Coding

Fig. 10 and 11 show the BER comparison under QPSK modulation for ε = 0.25 and 0.5 respectively using convolution coding of code rate 2/3. Table III shows the required Eb/No for BER of 10^{-3} with and without channel coding.

Table III: Eb/No Required For BER Of 10^{-3} Under QPSK

Methods	**With coding**		**Without coding**	
	ε = 0.25	ε = 0.5	ε=0.25	ε= 0.5
WCT	21.4dB	24.8dB	22.6dB	27.5dB
NEW SC	21dB	24dB	22.5dB	26.5dB

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From Table III, it shows that by applying channel coding WCT and new method required 1.5dB and 2dB less Eb/No for same BER.

VI. Conclusion

In this paper, a new data conjugate ICI self cancellation method is proposed and compared with WCT. The CIR comparison is same for both methods but in terms of BER proposed method outperforms the WCT under BPSK and QPSK with and without channel coding. Also from Table III, new method required 4dB more Eb/No as compared to WCT which required 5dB more Eb/No as normalized frequency offset increases. It shows that the new method is robust against frequency offset as compared to WCT.

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Abhijeet Bishnu was born on 2nd Sep 1987 in India. He received B.E. degree in Electronics and Communication Engineering from Technocrat Institute of Technology, Bhopal, India in 2010. He is currently studying M.E. degree in Electronics and Telecommunication Engineering from S.G.S.I.T.S. Indore, India. His research interests include OFDM system and Multi-carrier systems.

Dr. (Mrs.) Anjana Jain was born on 2nd Feb 1967 in India. She received B.E. degree (1989) in Electronics and Telecommunication from M.A.C.T., Bhopal, India and M.E. degree (1996) in Electrical engineering from Shri G.S. Institute of Technology and Science, Indore, India in 1996. She did PhD in May 2013. She has teaching experience of 21 years and currently Associate professor in the Department of Electronics and Telecommunication in Shri G.S. Institute of Technology and Science, India. She has published papers in National and International Journals, Conferences and Workshops organised by IEEE, IETE, ISTE and IE. Her research interest arein Characterisation of Mobile Radio Channel, Reliability and Availability computation of Fading Channels and its Modelling. Mrs. Jain is member of IEEE, TWAWS, IACSIT, IETE, ISTE, IE (I). She received Nokia Award for her paper presented in AINA, PAEWN 2007.

Mr. Anurag Shrivastava was born on 27th Aug 1976 in India. He received B.E degree (2000) in Electronics and Communication Engineering from SVITS Indore, India and M.Tech degree in Communication engineering from IIT Bombay, India in 2009. He has registered for PhD from IIT Bombay. He has teaching experience of 11 years and currently Assistant professor in the Department of Electronics and Telecommunication in Shri G.S. Institute of Technology and Science, India. He has published many papers in National and International

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Journal and Conferences. His research interest in embedded systems, Signal processing and Telecommunication networking. He is member of IETE, IE and ISTE.

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