A New Data Conjugate ICI Self Cancellation for OFDM System

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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

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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.

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:

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

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

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

$\varepsilon(\Delta f T_s)$ is the normalized frequency offset, where Δf is the Doppler frequency shift, T_s is the symbol duration, and $w(n)$ is the additive white Gaussian noise (AWGN) introduced in the channel.

The received signal at the kth subcarrier is given as:

$$Y(k) = \sum_{l=0}^{N-1} y(n) e^{-\frac{j2\pi kn}{N}} = X(k)S(0) + \sum_{\substack{l=0 \\ l \neq k}}^{N-1} X(l)S(l-k) + W(k) \quad (3)$$

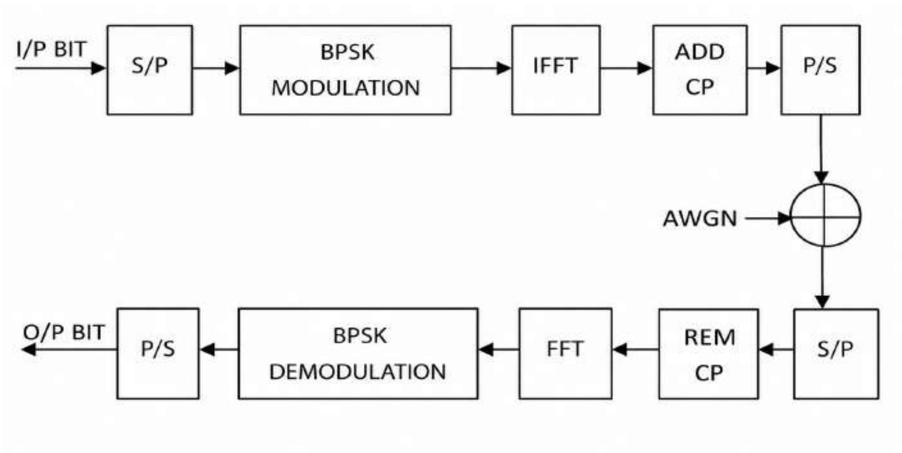

Figure 1. Block Diagram Of Baseband OFDM System

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

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

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:

$$CIR = \frac{E[|X(k)|^2] \cdot E[|S(0)|^2]}{E[|X(l)|^2] \cdot \sum_{l=0, l\neq k}^{N-1} |S(l-k)|^2} = \frac{|S(0)|^2}{\sum_{l=1}^{N-1} |S(l)|^2} \quad (5)$$

Different Methods of ICI Self Cancellation

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

Data-Conversion Scheme

This scheme is based on the data symbol allocation of

$$X'(k) = X(k), \qquad X'(k+1) = -X(k), \quad (k = 0, 2, \ldots, N-2).$$

The desired signal is recovered at the receiver as

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

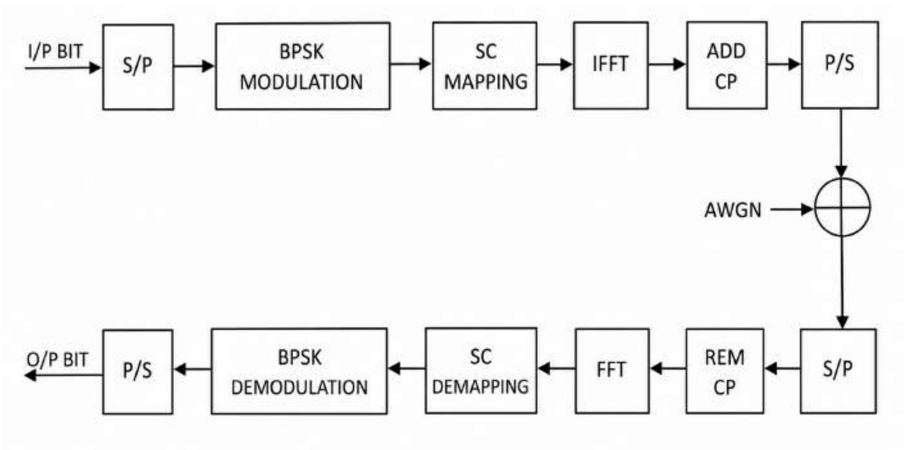

Figure 2. BER Comparison of New Data Conjugate and WCT Under BPSK Modulation for $\varepsilon = 0.25$

where X'(k) is the transmitted data symbol at kth subcarrier after SC mapping, Y;(k) is the 2kth 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:

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

Symmetric Data-Conversion Scheme

This scheme is based on the data symbol allocation of

$$X'(k) = X(k), \qquad X'(N-k-1) = -X(k),$$

where $k = 0, 2, 4, \ldots, N-2$.

The desired signal is recovered at the receiver as:

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

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

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

Real Constant Weighted Data-Conversion Scheme

This scheme is based on the data symbol allocation of

$$X'(k) = X(k), \qquad X'(k+1) = -\mu X(k), \quad (k = 0, 2, 4, \ldots, N-2),$$

where μ is a real constant in the interval $[0, 1]$. The desired signal is recovered at the receiver as:

$$Z(k) = \frac{1}{2}\left(Y'(k) - \mu Y'(k+1)\right) \tag{10}$$

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

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

Plural Weighted Data-Conversion Scheme

This scheme is based on the data symbol allocation of

$$X'(k) = X(k), \quad X'(k+1) = wX(k),$$

where $k = 0, 2, 4, \ldots, N-2$. The desired signal is recovered at the receiver as:

$$Z(k) = \frac{1}{2}\left(Y'(k) - e^{j\theta} Y'(k+1)\right) \tag{12}$$

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

$$CIR = \frac{|S(0) - e^{j\theta} S(-1)|^2}{\sum_{l=2,even}^{N-2} |S(l) - e^{j\theta} S(l-1)|^2} \tag{13}$$

3.5 Data-Conjugate Scheme This scheme is based on the data symbol allocation of

$$X'(k) = X(k), \qquad X'(k+1) = -X^*(k),$$

where $k = 0, 2, 4, \ldots, N-2$.

The desired signal is recovered at the receiver as:

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

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

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

3.6 Weighted Conjugate Transformation

This scheme is based on the data symbol allocation of

$$X'(k) = X(k), \qquad X'(k+1) = e^{j\pi/2}X^*(k),$$

where $k = 0, 2, 4, \ldots, N-2$.

The desired signal is recovered at the receiver as:

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

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

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

New Data Conjugate SC Method

The proposed method is a modification of the WCT scheme. 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 the WCT, using the conjugate of the modulated data within the kth subcarrier. Thus, in the proposed method, the data symbols are allocated as

$$X'(k) = X(k), \qquad X'(k+1) = e^{-j\pi/2}X^*(k), \tag{1}$$

where

$$k = 0, 2, 4, \ldots, N-2.$$

Simulation results demonstrate that the proposed method outperforms the conventional WCT scheme.

The received signal within the kth and $(k+1)$th subcarriers is given as:

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

and

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

respectively. The desired signal is recovered as:

$$
\begin{aligned}
Z(k) &= \frac{1}{2}\left(Y'(k) - e^{\frac{j\pi}{2}} Y'^{*}(k+1)\right) \\
&= \frac{1}{2}\sum_{l=0,even}^{N-2}\Big(X(l)[S(l-k)+S^{*}(l-k)] \\
&\quad + X^{*}(l)\big[e^{-\frac{j\pi}{2}}S(l+1-k) - e^{\frac{j\pi}{2}}S^{*}(l-k-1)\big]\Big) + W'(k) \\
&= \frac{1}{2}\Big(X(k)[S(0)+S^{*}(0)] + X^{*}(k)\big[e^{-\frac{j\pi}{2}}S(1) - e^{\frac{j\pi}{2}}S^{*}(-1)\big] \\
&\quad + \sum_{l=2,even}^{N-2} X(l)[S(l-k)+S^{*}(l-k)] \\
&\quad + X^{*}(l)\big[e^{-j\pi/2}S(l+1-k) - e^{\frac{j\pi}{2}}S^{*}(l-k-1)\big]\Big) + W'(k)
\end{aligned}
\tag{20}
$$

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:

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

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.

Table I shows the simulation parameters used for BER calculation. Figure 4 presents the BER comparison between the proposed method and the WCT method for $\varepsilon = 0.25$ under BPSK modulation. It can be observed that, for the same BER, the proposed method requires $0.5\,\mathrm{dB}$ lower E_b/N_0 than the WCT method. Similarly, Figure 5 shows the BER comparison for $\varepsilon = 0.5$ under the same modulation scheme. The results indicate that the proposed method outperforms the WCT method by approximately $2\,\mathrm{dB}$ in terms of the required E_b/N_0 to achieve the same BER.

Table 1. Simulation Parameters

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

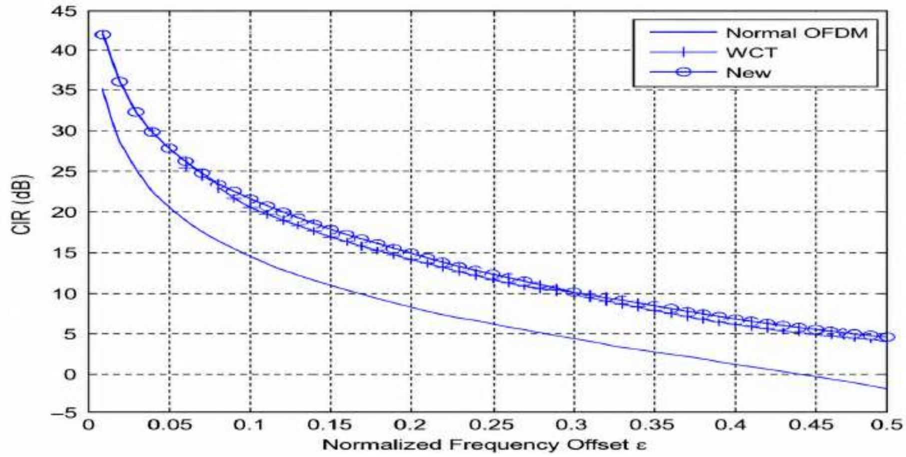

Figure 3. CIR Comparison of New Data Conjugate And WCT Method

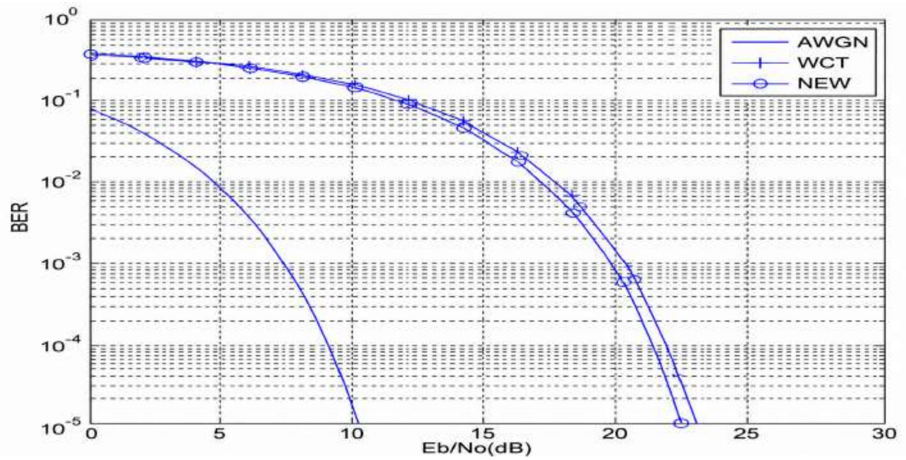

Figure 4. BER Comparison of the Proposed New Data Conjugate Scheme and WCT Under BPSK Modulation for $\varepsilon = 0.25$

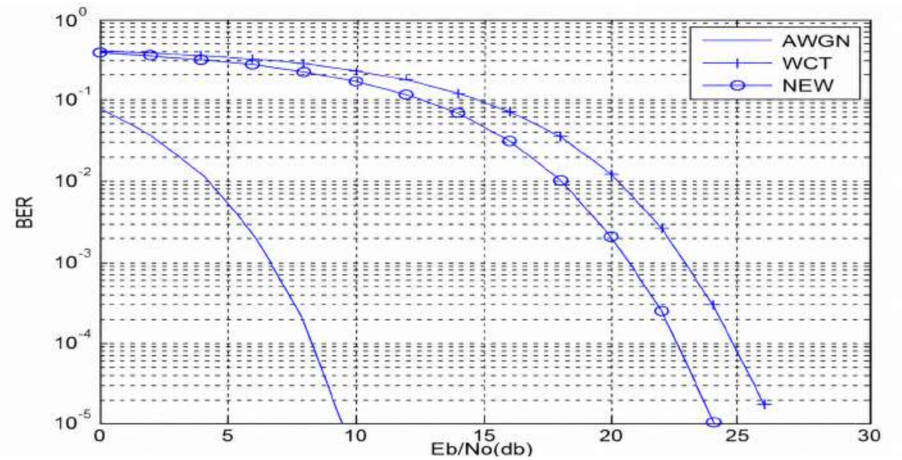

Figure 5. BER Comparison of the Proposed New Data Conjugate Scheme and WCT Under BPSK Modulation for $\varepsilon = 0.5$

Table 2. E_b/N_0 Required for BER of 10^{-3} Under BPSK

Methods	With coding		Without coding	
	$\varepsilon = 0.25$	$\varepsilon = 0.5$	$\varepsilon = 0.25$	$\varepsilon = 0.5$
WCT	16.5 dB	20 dB	20 dB	23 dB
NEW SC	16 dB	17.2 dB	19 dB	21 dB

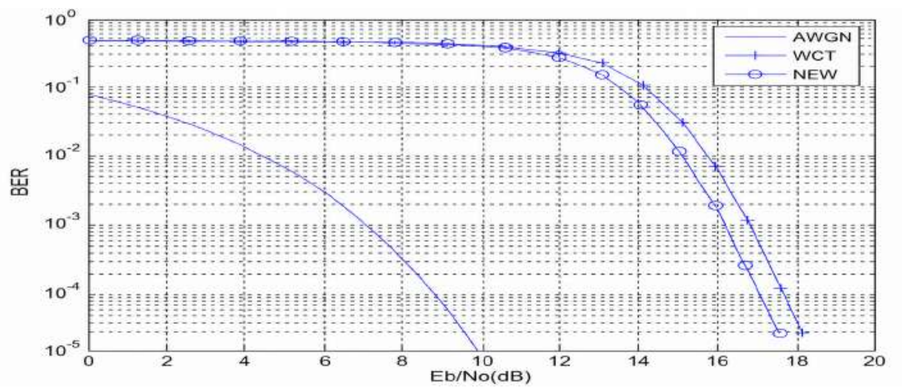

Figure 6. BER Comparison of New Data Conjugate and WCT Under BPSK Modulation for $\varepsilon = 0.25$ with Convolution Coding

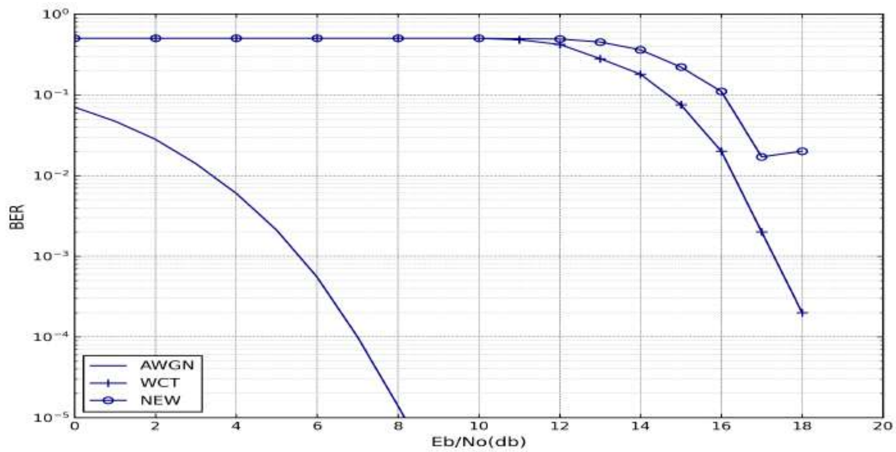

Figure 7. BER Comparison of New Data Conjugate and WCT Under BPSK Modulation for $\varepsilon = 0.5$ with Convolution Coding

Fig. 6 and 7 show the BER comparison under BPSK modulation for $\varepsilon = 0.25$ and $\varepsilon = 0.5$, respectively, using convolution coding of code rate $2/3$. Table II shows the required E_b/N_0 for BER of 10^{-3} with and without channel coding. From Table II, it shows that by applying channel coding, the WCT and new method required $3\,\mathrm{dB}$ and $3.5\,\mathrm{dB}$ less E_b/N_0, respectively, for the same BER.

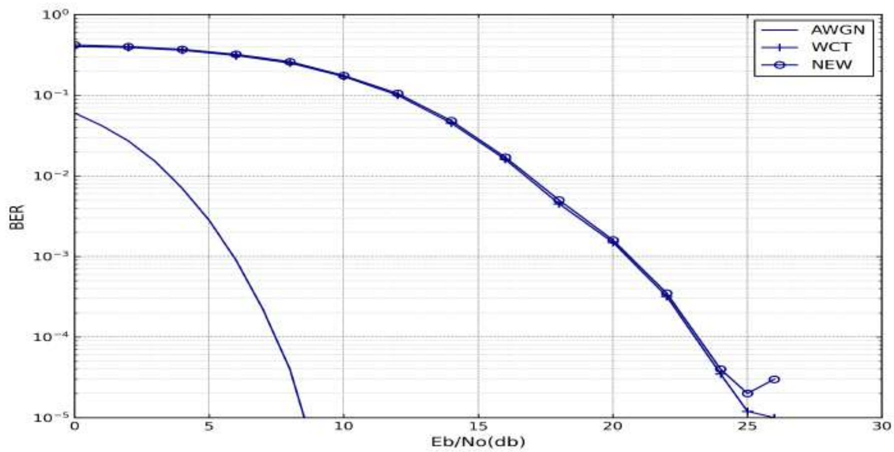

Figure 8. BER Comparison of New Data Conjugate And WCT Under QPSK Modulation For $\varepsilon = 0.25$

Fig.8 shows BER comparison of proposed and WCT method for $\varepsilon = 0.25$ under QPSK modulation. It shows that for the same BER the proposed method required $0.1\,\mathrm{dB}$ less E_b/N_0 as compared to WCT.

Similarly Fig.9 shows BER comparison for $\varepsilon = 0.5$ under same modulation and it shows that the new method is better than WCT by $0.5\,\mathrm{dB}$ E_b/N_0 for same BER..

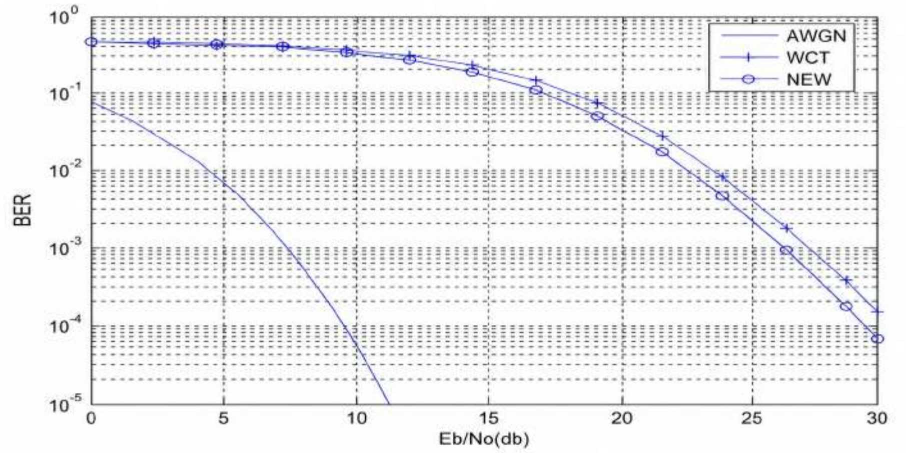

Figure 9. BER comparison of new data conjugate and WCT under QPSK modulation for $\varepsilon = 0.25$

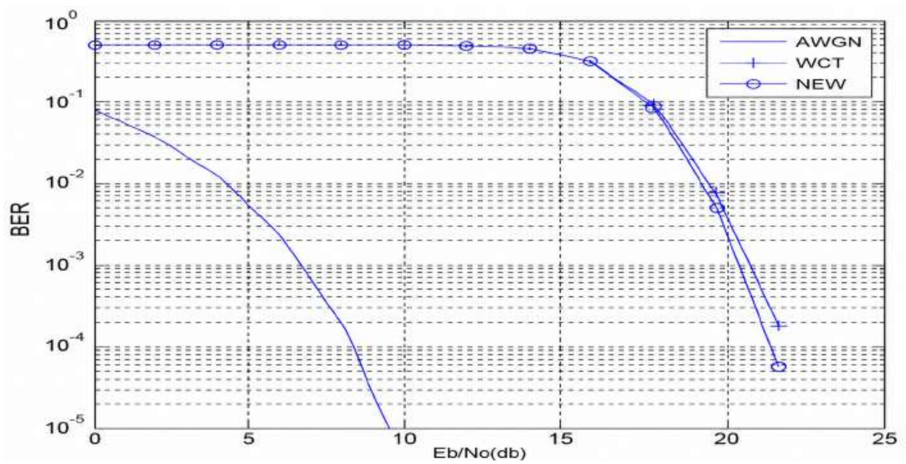

Figure 10. BER Comparison Of New Data Conjugate And WCT Under QPSK Modulation For $\varepsilon = 0.25$ With Convolution Coding

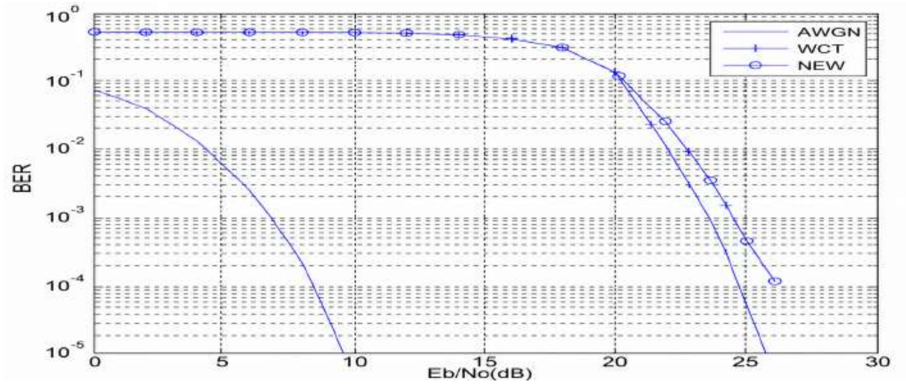

Figure 11. BER Comparison Of New Data Conjugate And WCT Under QPSK Modulation for $\varepsilon = 0.25$ With Convolution Coding

Table 3. E_b/N_0 Required for BER of 10^{-3} Under QPSK

Methods	With coding		Without coding	
	$\varepsilon = 0.25$	$\varepsilon = 0.5$	$\varepsilon = 0.25$	$\varepsilon = 0.5$
WCT	21.4 dB	24.8 dB	22.6 dB	27.5 dB
NEW SC	21 dB	24 dB	22.5 dB	26.5 dB

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

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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