International Journal of Engineering and Advanced Technology (IJEAT)
ISSN: 2249-8958 (Online), Volume-3 Issue-4, April 2014

Performance Analysis of OFDM System Employing an Efficient Scheme of ICI Self- Cancellation

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Abstract— Orthogonal frequency division multiplexing (OFDM) is very sensitive to frequency offset caused by Doppler frequency drift or frequency drift between transmitter and receiver oscillator. This leads to a loss in the orthogonality between sub-carriers and results in inter-carrier-interference (ICI). In this paper we proposed an efficient ICI self-cancellation scheme to reduce ICI in OFDM system and its performance is compared with existing methods of self-cancellation in terms of carrier-to-interference ratio (CIR) and bit-error rate (BER). Simulation result shows that the proposed scheme outperforms the existing schemes.

Index Terms— Inter-carrier-interference (ICI), OFDM, self-cancellation (SC), data-conjugate, data-conversion.

I. INTRODUCTION

OFDM is widely known as the promising communication technique in the broadband wireless communication systems. Currently, OFDM is being used in many wireless communication systems, such as Digital Video Broadcasting (DVB) systems, HIPERLAN2 (High Performance Local Area Network), Worldwide Interoperability for Microwave Access (Wi-Max). In OFDM, a high data rate channel is divided in to many low data rate sub-channels and each sub-channel is modulated in different sub-carriers. Due to this each channel experience a flat-fading and equalization at the receiver is less complex. So it provides high spectral efficiency and robustness to multipath interference. In OFDM sub-channels are orthogonal, but due to frequency offset orthogonality is lost which causes inter-carrier-interference (ICI) and it degrades the performance of OFDM system [1]-[2].

Various schemes have been investigated to mitigate ICI in OFDM system, such as frequency domain equalization [3], time domain windowing [4], pulse-shaping [5], self-cancellation [6]-[11], frequency offset estimation and correction technique [12]-[13] and so on. Among the schemes the ICI self-cancellation is a simple way for ICI reduction. Several self-cancellation schemes have been developed such as data-conversion [6], symmetric data conversion [7], real constant weighted data-conversion [8], plural weighted data-conversion [9], data-conjugate [10], and weighted-conjugate transformation [11].

In this paper we present a theoretical expression of CIR for the proposed scheme and its performance is compared with existing ICI SC schemes in terms of carrier-to-interference ratio (CIR) and bit-error rate (BER). In [11] the results show that the WCT scheme outperforms the other SC schemes. Our simulation result shows that proposed scheme is better than the WCT scheme.

Manuscript published on 30 April 2014.
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II. OFDM SYSTEM DESCRIPTION AND ICI ANALYSIS

Fig.1 illustrates the block diagram of the baseband, discrete time FFT-based OFDM system as given in [11]. Firstly a stream of input serial bit is converted in to parallel by S/P, each parallel bit then mapped in to symbols using MPSK modulation, then the symbols are modulated by IFFT on N-parallel sub-carriers and transmitted after adding cyclic prefix and converted in 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, then perform FFT, de-mapped in to bits and back to serial data using P/S.

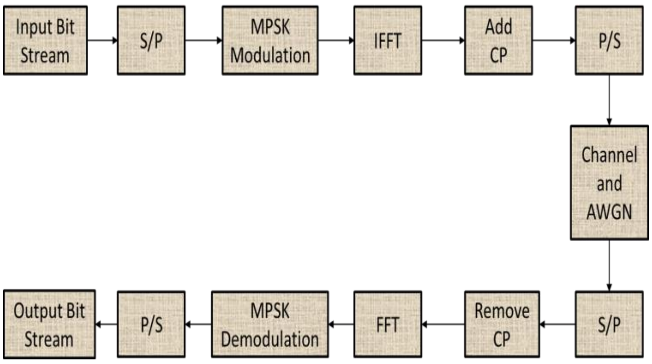

Fig.1. Block diagram of baseband OFDM system

In OFDM system the time domain transmitted signal could be expressed as:

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

where $x(n)$ denotes the n^{th} sample of OFDM transmitted signal, $X(k)$ denotes the modulated symbol for the k^{th} sub-carrier ($k = 0,1,\dots,N-1$) and N is the total number of sub- carriers.

The received signal in time domain is given by:

$$y(n) = x(n)\ e^{j2\pi n\varepsilon/N} + \omega(n) \quad (2)$$

where ε denotes the normalized frequency offset and is given by $\Delta f . NT_s$. Δf is the Doppler frequency drift and T_s is sub-carrier symbol period, $\omega(n)$ is additive white Gaussian noise (AWGN) introduced in the channel.

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The effect of this frequency offset on the received symbol stream can be understood by considering the received symbol $Y(k)$ on the k^{th} sub-carrier.

$$Y(k) \;=\; X(k)S(0) + \sum_{\substack{l=0\\ l\neq k}}^{N-1} X(l)S(l-k) + W(k) \qquad (3)$$

where $W(k)$ is the FFT of the $\omega(n)$, the first term in right hand side of eqn. 3 is desired signal and second term is interference signal. $S(l-k)$ are the complex coefficients for the ICI components in the received signal. The ICI components are the interfering signals transmitted on sub-carrier other than the k^{th} sub-carrier.
The $S(l-k)$ can be expressed as:

$$S(l-k) = \frac{sin[\pi(l+\varepsilon-k)]}{Nsin\,[\pi(l+\varepsilon-k)/N]} exp\,[j\pi(1-1/N)(l+\varepsilon-k)] \qquad (4)$$

The carrier-to-interference ratio (CIR) is the ratio of the signal power to the power in the interference components. It serves as a good indication of signal quality. The derivation assumes that the standard transmitted data has zero mean and the symbols transmitted on the different sub-carriers are statistically independent. The desired signal is transmitted on sub-carrier "0" is considered, then the CIR of standard OFDM system [6] is simplified as:

$$CIR = \frac{|S(k)|^2}{\sum_{\substack{l=0\\ l\neq k}}^{N-1} |S(l-k)|^2} = \frac{|S(0)|^2}{\sum_{l=1}^{N-1} |S(l)|^2} \qquad (5)$$

III. DIFFERENT ICI SELF-CANCELLATION SCHEMES

It is seen that the difference of ICI coefficients between two consecutive sub-carrier $S(l-k)$ and $S(l+1-k)$ is very small. Hence the idea of self-cancellation is generated. The main idea is to modulate one data symbol on to group of sub-carriers with predefined weighting coefficients. By doing so, the ICI signals generated within a group can be self-cancelled each other [6]. Thus it is called self-cancellation scheme. Fig.2 shows the block diagram of typical ICI self-cancellation scheme.

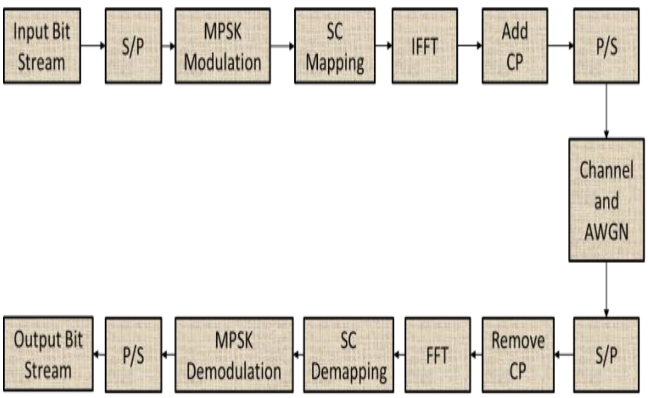

Fig.2. Block diagram of ICI SC OFDM system

A. Data-conversion scheme

This scheme is based on the data symbol allocation of $X'(k) = X(k),\;\; X'(k+1) = -X(k),\;\; (k = 0,2,\ldots,N-2)$.

The final recovered signal is as follows:

$$Y''(k) = \tfrac{1}{2}[Y'(k) - Y'(k+1)] \qquad (6)$$

The CIR of data-conversion is given by [6] and expressed as:

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

B. Symmetric data-conversion scheme

This scheme is based on the data symbol allocation of $X'(k) = X(k), X'(N-1-k) = -X(k), (k = 0,1,\ldots,\frac{N}{2}-1)$. The final recovered signal is as follows:

$$Y''(k) = \tfrac{1}{2}[Y'(k) - Y'(N-1-k)] \qquad (8)$$

The CIR of symmetric data-conversion (SDC) is given by [7] and expressed as:

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

C. Real constant weighted data-conversion scheme

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

$$Y''(k) = \frac{1}{1+\mu}[Y'(k) - Y'(k+1)] \qquad (10)$$

The CIR of real constant weighted data-conversion scheme (RCWDC) is given by [8] and expressed as:

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

D. Plural weighted data-conversion scheme

This scheme is based on the data symbol allocation of $X'(k) = X(k),\;\; X'(k+1) = e^{-j\frac{\pi}{2}}X(k), (k = 0,2,\ldots,N-2)$. The final recovered signal is as follows:

$$Y''(k) = \tfrac{1}{2}\left[Y'(k) - e^{-j\frac{\pi}{2}}Y'(k+1)\right] \qquad (12)$$

The CIR of plural weighted data-conversion scheme (PWDC) is given by [9] and expressed as:

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

E. Data-conjugate scheme

This scheme is based on the data symbol allocation of $X'(k) = X(k),\;\; X'(k+1) = -X^*(k), (k = 0,2,\ldots,N-2)$. The final recovered signal is as follows:

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

The CIR of data-conjugate is given by [10] and expressed as:

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

F. Weighted conjugate transformation

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

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

The CIR of weighted conjugate transformation (WCT) is given by [11] and expressed as:

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

IV. PROPOSED ICI SELF-CANCELLATION SCHEME

It is noticed that conjugate decreases BER [10] and symmetric conversion increases CIR [7]. Hence by combining these two factors, an efficient scheme has been proposed which provides better ICI reduction. The proposed scheme is based on the symbol allocation of $X'(k) = X(k)$, $X'(N-1-k) = e^{j\frac{\pi}{2}}X^{*}(k)$, $(k = 0,1,\dots,\frac{N}{2}-1)$. It means that the data modulated within the $(N-1-k)^{th}$ sub-carrier is the rotated phase $\frac{\pi}{2}$ of the conjugate of the modulated data within k^{th} sub-carrier.

The received signal within k^{th} and $(N-1-k)^{th}$ sub-carrier is given as:

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

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

The final signal is recovered as follows:

$$Y''(k) = \frac{1}{2}\left[Y'(k) - e^{-j\frac{\pi}{2}}Y'^{*}(N-1-k)\right] \quad (20)$$

$$\begin{aligned} Y''(k) &= \frac{1}{2}\sum_{l=0}^{\frac{N}{2}-1}[X(l)\{S(l-k)+S^{*}(k-l)\} + X^{*}(l) \{e^{j\frac{\pi}{2}}S(N-1-l-k) - e^{-j\frac{\pi}{2}}S^{*}(l-N+1+k)\}] + W'(k) \\ &= \frac{1}{2}[X(k)\{S(0)+S^{*}(0)\} + X^{*}(k)\{e^{j\frac{\pi}{2}}S(N-1) - e^{-j\frac{\pi}{2}}S^{*}(1-N)\} + \sum_{\substack{l=0 \\ l\neq k}}^{\frac{N}{2}-1} X(l)\{S(l-k)+S^{*}(k-l)\} + X^{*}(l)\{e^{j\frac{\pi}{2}}S(N-1-l-k) - e^{-j\frac{\pi}{2}}S^{*}(l-N+1+k)\}] + W'(k) \end{aligned} \quad (21)$$

The first term in the right hand side of eqn. 21 is the desired signal power and second term is the interfering component.

In this paper, the desired signal is transmitted on sub-carrier "0" is considered, so the CIR of proposed self-cancellation scheme is given as:

$$CIR = \frac{|S(0)+S^{*}(0)|^2 + |e^{j\frac{\pi}{2}}S(N-1) - e^{-j\frac{\pi}{2}}S^{*}(1-N)|^2}{\sum_{l=1}^{\frac{N}{2}-1}[|S(l)+S^{*}(-l)|^2 + |e^{j\frac{\pi}{2}}S(N-1-l) - e^{-j\frac{\pi}{2}}S^{*}(l-N+1)|^2]} \quad (22)$$

V. SIMULATION RESULTS

The proposed scheme is compared with existing self-cancellation schemes in terms of CIR and BER. The simulation parameters for the proposed scheme are shown in Table I.

TABLE I
SIMULATION PARAMETERS

PARAMETER	SPECIFICATION
FFT size	256
Sub-carriers	256
Modulation	QPSK
Channel	AWGN
Frequency offset	0.15, 0.2
OFDM symbols for one loop	5000

The CIR of proposed scheme and different self- cancellation schemes are shown in Fig. 3 for normalized frequency offset 0.05 < ε < 0.2. It can be seen that proposed scheme provides significant CIR improvement over WCT, data-conjugate, standard OFDM and PWDC.

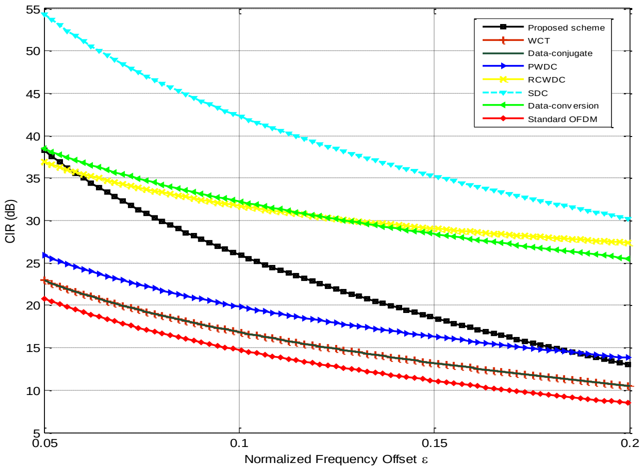

Fig.3. CIR of proposed and different ICI self-cancellation schemes

Fig. 4-5, show the BER comparison of proposed self-cancellation scheme with existing self-cancellation schemes for QPSK modulation techniques with different value of frequency offset. It can be seen that proposed scheme provides better BER performance compared to existing self-cancellation schemes. In Fig. 4, it can be seen that WCT outperforms the existing SC schemes and proposed scheme is better than the WCT scheme, it offers 3dB SNR gain over WCT at BER of 10^{-4} for frequency offset value $\varepsilon = 0.15$.

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In Fig. 5, proposed scheme offers 1dB SNR gain over WCT at BER 10^{-2} for frequency offset value $\varepsilon = 0.2$.

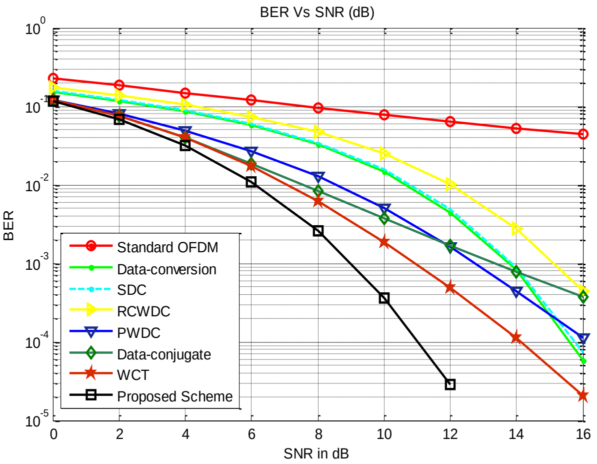

Fig.4. BER versus SNR for $\varepsilon = 0.15$

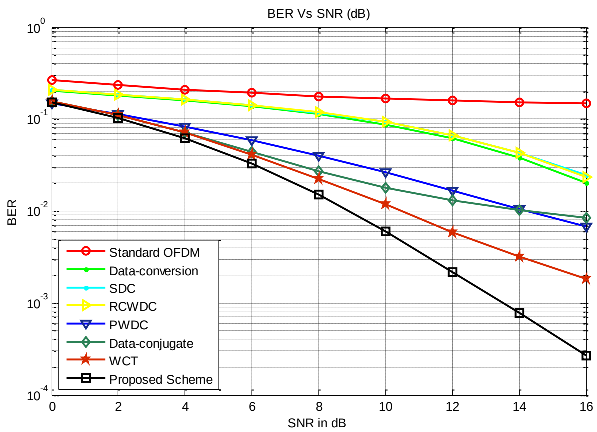

Fig.5. BER versus SNR for $\varepsilon = 0.2$

VI. CONCLUSION

In this paper, an efficient ICI self-cancellation scheme is proposed to mitigate the effect of ICI caused by frequency offset in OFDM system. The proposed scheme provides significant CIR improvement over standard OFDM, WCT, data-conjugate and PWDC which has been studied theoretically and by simulations. Also proposed scheme gives better BER performance as compared to existing self-cancellation schemes. Although the bandwidth efficiency of proposed scheme is reduced, because as only half of the sub-carrier is used for transmitted data, it can be solved by increasing the number of sub-carrier or using larger signal alphabet size.

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