BER Analysis of ICI Self Cancellation Schemes for OFDM Based Wireless Systems

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Abstract— the consistently rising demand for very high rate data transmission over wireless mediums requires ingenious usage of electromagnetic resources considering constraints like power consumption, spectrum efficiency, robustness against multipath propagation and implementation complexity. Orthogonal frequency division multiplexing (OFDM) is a propitious technique for next generation wireless communication systems. Nevertheless it suffers from Inter-Carrier Interference (ICI) due to its susceptibility to the frequency offset caused by frequency difference between local oscillator of transmitter and receiver or due to Doppler shift. This paper epitomize self-cancellation techniques to mitigate ICI effect for OFDM based wireless systems. The performances of ICI self-cancellation schemes have been in terms of the bit error rate (BER). Simulation results exhibit ICI self-cancellation Scheme that outperforms other existing self-cancellation methods and robustness to large frequency offset.

Keywords— Orthogonal Frequency Division Multiplexing (OFDM), Inter-Carrier Interference (ICI), Self-Cancellation (SC), Bit Error Ratio (BER).

I. Introduction

The expansion in number of mobile users urges for wireless technologies that can deliver data at high speeds in a spectrally decisive manner. However, aiding such high data rates with sufficient robustness to radio channel impairments requires prudent selection of techniques. Orthogonal frequency division multiplexing (OFDM) is a multicarrier multiplexing technique, in which data is transmitted through several parallel frequency sub channels at a lower rate. It has been standardized in many wireless applications such as Digital Video Broadcasting (DVB), Digital Audio Broadcasting (DAB), High Performance Wireless Local Area Network (HIPERLAN), IEEE 802.11 (Wi-Fi), and IEEE 802.16 (WiMAX 1) and has also been used for wired applications as in the Asynchronous Digital Subscriber Line (ADSL) and power-line communications [1,2]. One of the main reasons to use OFDM is to increase the robustness against frequency selective fading or narrowband interference. As every technique has its flaws, this technique also has drawback of being sensitive towards frequency mismatch. This paper has been organized in way that Section II describes the basic description and issues of OFDM system followed by the system description and interference analysis and Mathematical description of methods available for mitigation of ICI has been given in Section III followed by simulation results in Section IV. The conclusion of paper has been given in Section V.

II. Orthogonal Frequency Division Multiplexing

OFDM is a peculiar case of multi-carrier modulation. The principle of OFDM is to divide a single high-data rate stream into a number of lower rate streams that are transmitted simultaneously over some narrower sub channels which are orthogonal to each other. Henceforth it is not only a modulation technique but a multiplexing technique too. The merits of this technique that make it a preferred choice over other modulation techniques are its high spectral efficiency, easier implementation of FFT, lower receiver complexity, robustness for high-data rate transmission over multipath fading channel, high flexibility for link adaptation are few advantages to list. However, it has two basic disadvantages: 1) higher peak to average power ratio (PAPR) as compared single carrier signal [3]. 2) Sensitivity to phase noise, timing and frequency offsets that introduces ICI into the system. The carrier frequency offset is caused by the mismatch of frequencies between the oscillators at the transmitter and receiver, or from the Doppler spread due to the relative motion between the transmitter and receiver. The phase noise arises mainly due to imperfections of the local oscillator in the transceiver. The timing offset arises due to the multipath delay spread and because of it not only inter-symbol interference, but ICI also occurs. However, ICI induced by phase noise and timing offset can completely be compensated or corrected. But the occurrence of frequency offset due to the Doppler spread or frequency shift resulting in ICI is random, henceforth only its impact can be mitigated. Many different ICI mitigation schemes have been extensively explored to combat the Inter-Carrier Interference in OFDM systems, including frequency-domain equalization [8], time-domain windowing [9], and the ICI self-cancellation (SC) scheme[10]-[17], frequency offset estimation and compensation techniques[18] and so on. Among the schemes, the ICI self-cancellation scheme is a simple method for ICI reduction. It is a two-stage technique that uses redundant modulation to suppress ICI with ease for OFDM. This paper investigates several the self-cancellation techniques to mitigate ICI for OFDM systems. The fundamental idea is to modulate the input data symbol onto a group of subcarriers with predefined coefficients such that the generated interference signals within that group cancel each other, consequently called self-cancellation. In this mitigation technique, the bandwidth efficiency becomes half, which is the drawback of this technique but this drawback can be compensated by using large size alphabets or by increasing no. of subcarriers.

III. System Description And ICI Analysis

Figure1 displays a typical discrete-time base-band equivalent OFDM system model. As shown, a stream of input bit stream is first mapped into symbols using BPSK modulation. The symbols are modulated by IFFT on N-parallel subcarriers after the serial-to-parallel (S/P) conversion. With cyclic prefix (CP) addition, the OFDM symbols are serialized using parallel to serial (P/S) conversion and sent to the channel. At the receiver side, the received symbols are retrieved by S/P conversion, CP subtraction, FFT transformation, P/S conversion and are demapped with corresponding scheme to obtain the desired original bit stream.

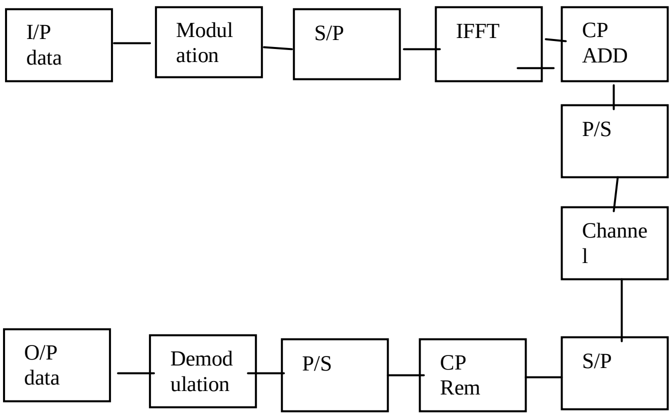

Fig. 1 OFDM Transceiver

In OFDM systems, the transmitted signal in time domain can be expressed as:

$$x(n) = \frac{1}{N}\sum_{k=0}^{N-1} X(k) e^{j\frac{2\pi kn}{N}} \qquad (1)$$

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

$$y(n) = x(n) e^{j\frac{2\pi n \in}{N}} + w(n) \qquad (2)$$

Where $\in$ is the normalized frequency offset given by $\in \; = \Delta f . NTs$ in which Δf is the frequency difference which is either due to difference in the local oscillator carrier frequencies of transmitter and receiver of due to Doppler shift and T_s is the subcarrier frequency and w(n) is the Additive White Gaussian Noise introduced in the channel. The effect of this frequency offset on the received symbolstream can be understood by considering the received symbol Y (k) on the kth subcarrier. The received signal at subcarrierindex kcan be expressed as

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

Where k = 0, 1… N-1 and X (k) S (0) is the desired signal and $\sum_{l=0\; l\neq k}^{N-1} X(l)S(l-k)$ is the ICI component of received OFDM signal.

ICI component S (l-k) can be given as:

$$S(l-k) = \frac{\sin(\pi(l+\epsilon-k))}{N\sin(\pi(l+\epsilon-k)/N)} \exp(j\pi\left(1-1N l+\epsilon-k\right)$$
(4)

To analyse this ICI component, simulation is done with N = 16 for 0.05, 0.15 and 0.30 values of offset. As displayed in fig 2, the marker of blue asterisk denotes ICI component at offset value 0.05, Red Cross denotes it for offset value 0.15 and black circle depicts it for offset value 0.30.

The carrier-to-interference ratio (CIR) is the ratio of thesignal power to the power in the interference components. Itserves as a good indication of signal quality in the absence ofnoise. The desired signal is transmitted on subcarrier "0" isconsidered, then, the CIR of Normal OFDM systems issimplified as

$$CIR = \frac{E[|C(k)|^2]}{E[|ICI(k)|^2]} = \frac{|S(0)|^2}{\sum_{l=1}^{N-1} |S(l)|^2} \qquad (5)$$

It has been analysed that CIR of OFDM systems depends on normalized frequency offset $\in$ for subcarriers $N \geq 8$.

IV. ICI Self Cancellation Schemes

The scheme works in two very simple steps. At the transmitter side, one data symbol is modulated onto a group of adjacent subcarriers with a group of weighting coefficients. The weighting coefficients are designed so that the ICI caused by the channel frequency errors can be minimized. At the receiver side, by linearly combining the received signals on these subcarriers with proposed coefficients, the residual ICI contained in the received signals can then be further reduced. Various schemes implemented having different weighting coefficients have been described below:-

A. Data Conversion Scheme

In the data-conversion self-cancellation scheme [10] for ICI mitigation, data symbol allocation is as

$$X'(k) = X(k)$$
$$X'(k+1) = -X(k)$$

Where k =0,2,….,N-2 in consecutive subcarriers to deal with the ICI. The received signal *Y* (*k*) is determined by the difference between the adjacent subcarriers. This self-cancellation scheme relies on the fact that the realand imaginary parts of the ICI coefficients change gradually with respect to the subcarrier index k. Therefore, the difference between consecutive ICI coefficients $S(l-k) - S(l-k+1)$ is very small. Then the resultant data sequence is used for making symbol decision can be represented

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

According to the definition of CIR, the CIR of data conversion scheme can be represented as:

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

(7)

B. Symmetric Data Conversion Scheme

In symmetric data-conversion scheme [13], subcarrier signal is mapped in the form of

$$X'(k) = X(k)$$
$$X'(N-k-1) = -X(k).$$

The desired signal is recovered as follows,

$$Y''(K) = \frac{1}{2}\left[Y'(K) - Y'(N-K-1)\right]$$
(8)

The CIR of the symmetric data-conversion (SDC) scheme is:

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

C. Real Constant Weighted Data Conversion Scheme

In real constant weighted data-conversion scheme [12], subcarrier signal is mapped in the form of

$$X'(k) = X(k)$$
$$X'(k+1) = -\mu X$$

Where µis a real constant in [0,1]. Then the desired data sequence is used for making symbol decision can be represented as:

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

The CIR of the real constant weighted data-conversion (RCWDC) scheme can be represented as:

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

(11)

D. Plural Weighted Data Conversion Scheme

This ICI SC scheme is proposed in [15] with the data allocation

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

The receivedsignal can be derived as:

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

Hence, the CIR of Plural weighted data-conversion (PWDC)
Scheme is given by:

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

(13)

E. Data Conjugate Scheme

In the data-conjugate scheme [16], subcarrier signals aremapped in the form of

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

The final recovered signal is as follows,

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

The CIR of the scheme is given by:

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

F. Weighted Conjugate Transformation Scheme

In the weighted conjugate transformation scheme [7], subcarrier signals are demapped in the form of

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

The final recovered signal is as follows,

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

The CIR of the WCT scheme is given by:

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

(17)

G. Rotated Weighted Conjugate Transformation Scheme

In the RWCT scheme [17], subcarrier signals are demapped in the form of

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

The final recovered signal is as follows,

$$Y''(k) = \frac{1}{2}\left[Y'(k) - Y'^*(k+1)e^{j\pi/2}\right] \quad (18)$$

The CIR of the scheme is given by:

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

(19)

V. SIMULATION RESULTS

A simulation is conducted to evaluate performance of system for input parameters given in Table 1.

TABLE I
INPUT PARAMETERS FOR SIMULATIONS

Input Parameters	
Parameters	**Values**
Bandwidth	10 MHz
Modulation	BPSK
No. of Bits	51200
No. of Symbols	50
Data Sub-Carriers	1024
Subcarrier Frequency	10.94 KHz
Cyclic Prefix	256
OFDM Symbol Length	1280
Symbol Time	91.4 µ sec
FFT Size	1024
SNR (dB)	0:1:10
Offset ϵ	0.1, 0.2, 0.3
Channel	AWGN channel
Noise	AWGN

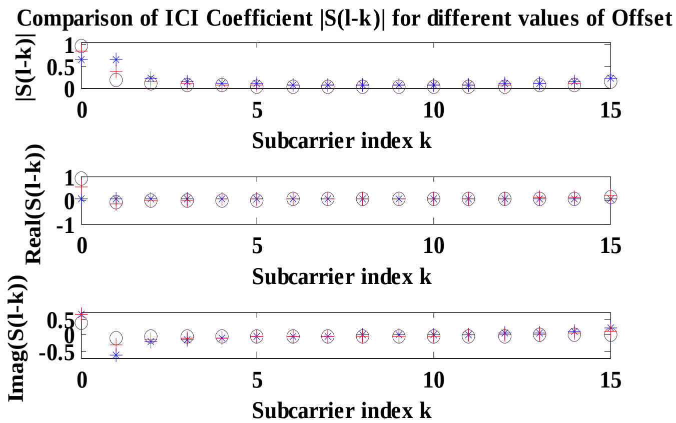

Fig. 2 Components of ICI Coefficient at offset values 0.05, 0.15, and 0.30

Figure 2 depicts that for a larger value of offset, the weight of the desired signal component, S(0) decreases, while the weights of the ICI components increases , also it has been analysed that the adjacent carrier has the maximum contribution to the ICI which is the fact is used in the ICI self-cancellation.

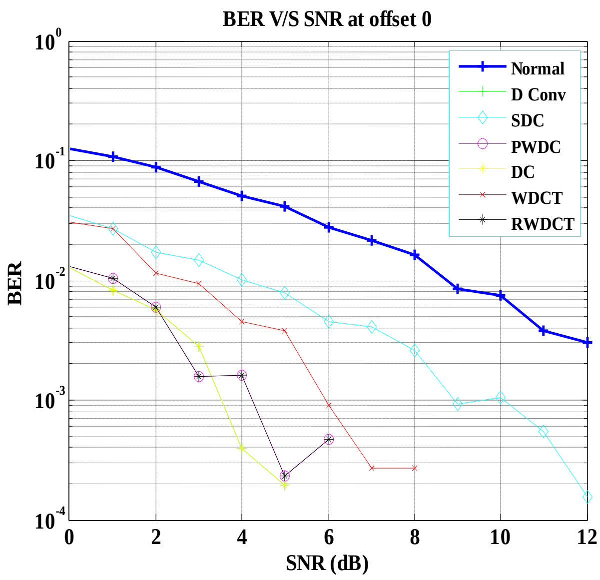

Fig. 3 BER v/s SNR for system with 0 offset

In Figure 3, it can be clearly seen that with BPSK modulation for Channel Bandwidth of 10 MHz and subcarrier 1024, BER of 10^{-4}can be achieved for both lower and higher values of SNR in case there is no offset in the system. But as the offset gets introduced either due to frequency difference or due to Doppler shift system's performance starts deteriorating in terms of BER of the system.

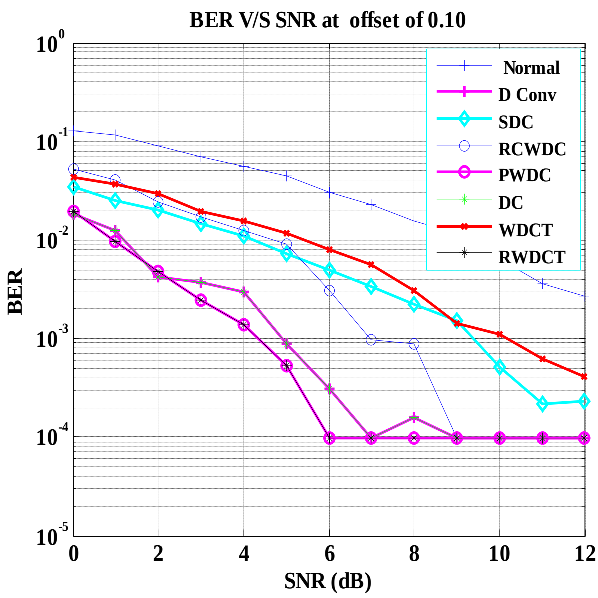

Fig. 4 BER v/s SNR for system with 0.1 offset

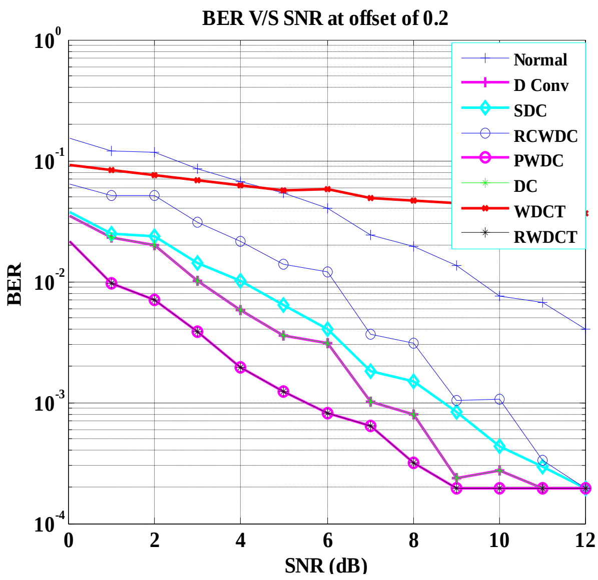

Fig. 5 BER v/s SNR for system with 0.2 offset

It can be seen in figure 4 and figure 5 that BER of RWCT outperforms other self-cancellation schemes for lower as well as higher values of SNR. Compared with other schemes, the RWCT scheme is less sensitive to theNormalized frequency offset and outperforms other SC
Schemes for even larger values of offset.

VI. Conclusion

This paper analyses the ICI self-cancellation schemes to mitigate the effect of ICI caused by normalised frequency offset in OFDMSystems. Although the bandwidth efficiency of the scheme is reduced byhalf due to the redundant symbols, it can be overcome byincreasing the number of subcarriers or using larger signal alphabet size and it is less complex as compared to the otherfrequency offset estimation and correction schemes. Simulation results shows thatBER of RWCT outperforms other self-cancellation schemes for lower as well as higher values of SNR. Compared with other schemes, the RWCT scheme is less sensitive to the Normalized frequency offset and outperforms other SCSchemes for even larger values of offset.

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