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An Improved Technique to Reduce ICI in OFDM Systems

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ABSTRACT: Inter Carrier Interference (ICI) caused by the Carrier Frequency Offset (CFO) and Doppler shifts, highly disgrace the performance of OFDM system. For OFDM communication system which is a promising technique for high data rate transmission, the theoretical BER and CIR are difficult to obtain in presence of ICI. The BER of the received signals are very sensitive to Doppler shifts and frequency offsets (reasons of ICI). This paper presents an efficient and improved ICI Self-Cancellation technique. The proposed technique improves the system throughput and reduces the BER. The performance comparison results show that proposed technique has better BER and improved CIR than standard OFDM and existing sc scheme.

KEYWORDS: OFDM, Carrier Frequency Offset (CRO), Inter Carrier Interference (ICI), Bit Error Rate (BER) and Carrier to Interface Ratio (CIR).

I. Introduction

Orthogonal Frequency Division Multiplexing (OFDM) modulation scheme is an emerging trend in the field of wireless communication. OFDM promises at providing high data rate transmission while maintaining spectral efficiency because it is used as Multi Carrier (MC) communication technique [1]. The subcarriers in an OFDM communication system are orthogonal to each other. The orthogonality between subcarriers is maintained so that they do not interfere with each other. The benefit of orthogonality is that this property of OFDM signal subcarriers helps in extracting the original signal at the receiver. But this orthogonality is lost due to multipath fading, phase noise, synchronization errors and Doppler shifts. And hence giving rise to ICI which immediately hampers the performance of OFDM system. Literature has proposed several techniques which reduces the ICI; frequency offset estimation and correction [2], [3] and the frequency offset reduction [4], [5]. This paper focus on the frequency offset reduction technique. In this paper an improved ICI self-cancellation is introduced which is based on an already existing sc scheme, with improved CIR and reduces BER. The BER performance of the proposed method is compared with standard OFDM signal and existing scheme. The rest of the paper described as: in section II OFDM system and ICI effects is described. Section III describes a Review on ICI cancellation schemes. In section IV proposed technique is described. Next in section V simulation results are shown and in section VI conclusions are made.

II. OFDM SYSTEM AND ICI EFFECTS

In an OFDM communication system, the OFDM Symbol can be expressed as:

$$x(n) = \frac{1}{N}\sum_{k=0}^{N-1} X(k) \qquad n = 0,1,2,\ldots..N-1 \tag{1}$$

where N is the total number of subcarriers. *X (k)* denotes the transmission modulated symbol on the subcarrier *k* with *k= 0, 1, 2…N-1*. The received signal after being passed through channel and effected by frequency offset can be written as:

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

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where Ɛ is the normalized frequency offset and w (n) is the Additive White Gaussian Noise (AWGN) introduced in the channel.
At the reception, after FFT block the received signal on subcarriers k suffers frequency offset can be written as:

$$Y(k) = \sum_{n=0}^{N-1} y(n)\, e^{-j2\pi nk/N} \qquad k = 0,1 \ldots . N-1$$

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

W(*k*) is the FFT of *w(n)*, and *S*(*l*-*k*) are the complex coefficients for the ICI components in the received signal. The first term in the right hand side of Eq. 3 represents the desired carrier component. The second term in the same equation is the ICI component and the third term is AWGN. The ICI components are the interfering signals transmitted on subcarriers other than the k^{th} subcarrier. These coefficients are given by:

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

Carrier–to-Interface Ratio (CIR) is the ratio of the signal power to the power in the interference components and act as ICI level indicator. The desired signal is transmitted on subcarrier "0" is considered, then, the CIR of Normal OFDM systems is simplified as:

$$CIR = \frac{E[|C(k)|^2]}{E[|ICI(k)|^2]} = \frac{E[|X(k)|^2]\, E[|S(0)|^2]}{E[|X(l)|^2].\sum_{\substack{l=0 \\ l\neq k}}^{N-1}|S(l-k)|^2} = \frac{|S(0)|^2}{\sum_{l=1}^{N-1}|S(l)|^2} \tag{5}$$

CIR is a function of N and Ɛ. The frequency offset Ɛ and large value of N are both responsible for CIR.

III. RELATED WORK

The researches at ICI reduction techniques for OFDM systems were begun in very early date. Among all the frequency offset reduction techniques like Frequency Domain Equalization [11], Time Domain Windowing [12], Pulse shaping [13] and ICI Self-Cancellation [4]. ICI SC schemes are chosen to be most appropriate for further study due to its less complexity.

Zhao [4], had proposed the first ICI SC technique which is known as Adjacent Symbol Repetition (ASR). The algorithm of this scheme follows as- repeating the same symbol with opposite polarity on two adjacent subcarriers, *k* and *k+1*, and at receiver, and then combining the received samples. This is expressed as:

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

In [5] author has proposed Symmetric Data Conversion scheme also known as Symmetric Symbol Repetition (SSR) in which each data symbol is mapped onto a pair of non-adjacent subcarrier k and (N-1-k) with opposite polarity. Real Constant Weighted Data Conversion (RCWDC) [6] was based on ASR scheme, where the same symbol is repeated by multiplying it with a constant weight 'μ' [0,1]. The Plural Weighted data conversion scheme (PWDC) [7] is again closely related to ASR. In this scheme, author has phase shifted the repeated adjacent subcarrier by –π/2. While these techniques are very effective in reducing the ICI on signal, but the OFDM signal still undergoes the same phase rotation as a conventional OFDM. The other technique known as Data conjugate scheme was proposed by Ryu [8]. In this scheme the adjacent symbol is mapped as the negative conjugate of the previously mapped symbol. It is represented as:

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

Weighted Conjugated Transformation (WCT) scheme [9] depends on two previous explained schemes PWDC and Data conjugate scheme in which adjacent symbol is modulated as the conjugate of previously modulated symbol and is

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phase rotated by π/2. Another technique [10] which is improved version of WCT scheme, repeats the same symbol by rotating phase –π/2 of the conjugate of the previously modulated subcarrier.

IV. SYSTEM MODEL

A simplified block diagram of the proposed OFDM system with New ICI Self-Cancellation scheme is shown in Figure 1. The simulation block diagram of the proposed system can be obtained by simply appending "ICI cancelling modulation" and "ICI cancelling demodulation" blocks. The high-speed information data pass through the serial to parallel converter and become parallel data streams of N/2 branch. At the time of reception again converted back into serial data. Output bits and Input bits are then compared by XOR operation and BER is obtained.

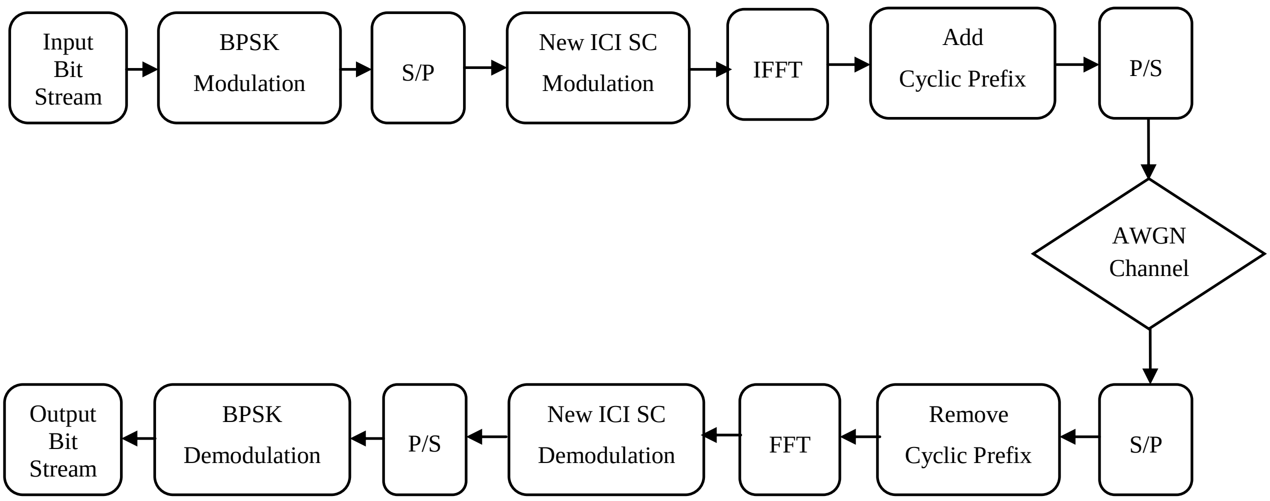

Fig. 1 Block Diagram of ICI SC based OFDM system

A. *Description of the System Model:*

Aim of the system model is to minimize the effect of ICI on OFDM symbols by ICI modulation and ICI demodulation processes, without increasing the system complexity while maintaining bandwidth efficiency. The system model consist an OFDM transreceiver that works in following steps.

Step 1: Input Binary Bit Stream and BPSK Modulation.
Step 2: Serial to Parallel Conversion
Step 3: ICI SC Modulation
Step 4: IFFT
Step 5: Add CP
Step 6: Parallel to Serial Conversion
Step 7: Up Conversion to AWGN Channel:
Step 8: Serial to Parallel Conversion
Step 9: Remove CP
Step 10: FFT
Step 11: ICI SC Demodulation.
Step 12: Parallel to Serial Conversion.
Step 13: BPSK Demodulation and output data in binary form

B. *Design Considerations:*

- Input bits are in binary form and serial sequence.
- BPSK modulation is used as ICI SC scheme provides better results at small alphabet size.
- For ICI Cancellation process constant weight '*w*' value is [0,1].
- Fast Fourier Transformation (FFT) size is taken as 256.

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- Number of subcarrier used is also N=256.
- Cyclic Prefix (CP) value is taken as 12.
- Number of OFDM symbols are 1000.
- Additive White Gaussian Noise (AWGN) Channel is used for transmission of OFDM symbols.
- Frequency Offset value is: Ɛ = 0 - 0.5.

V. PROPOSED TECHNIQUE

The proposed scheme , the data modulated within the $(k+1)th$ subcarrier is phase rotated by –π/2, of the conjugate of the modulated data within kth subcarrier, same as that of the Improved WCT scheme and multiplied by a constant weight $'w'(0, 1)$ as in Real Constant WDC scheme.
The new data allocation scheme can be represented as:

$$X'(k) = X(k),$$

$$X'(k+1) = we^{-j\frac{\pi}{2}}X^*(k) \qquad \text{(k = 0, 2, 4 ..... N − 2)}$$

The received signal within kth subcarrier from Eq. 3

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

$$= X(0)S(0-k) + w\,e^{-j\frac{\pi}{2}}X^*(0)S(1-k) + \;\dots\dots Wk$$

$$= \sum_{\substack{l=0,\\ l=even}}^{N-2} X(l)S(l-k) + we^{-j\frac{\pi}{2}}X^*(l)S(l+1-k) + Wk \tag{6}$$

And similarly, the received signal in $(k+1)^{th}$ subcarrier:

$$Y'(k+1) = \sum_{\substack{l=0\\ l=even}}^{N-2} X(l)S(l-k-1) + we^{-j\frac{\pi}{2}}X^*(l)S(l-k) + W(k+1) \tag{7}$$

ICI coefficient is denoted as:

$$S'(l-k) = S(l-k) - S(l+1-k)$$

The desired signal is recovered from above two Eq. 6 and 7 as follows:

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

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

$$= \frac{1}{2}\{X(k)[S(0) + S^*(0)] + \; X^*(l)\left[S(1)we^{-j\frac{\pi}{2}} - we^{-j\frac{\pi}{2}}S^*(-1)\right] + \sum_{\substack{l=0,\\ l\neq k}} X(l)[\,S(l-k) + S^*(l-k)] + X^*(l)[S(l-k+1) \dots\dots + Wk$$

The corresponding ICI coefficients then become:

$$S''(l-k) = -S(l-k+1) + 2S(l-k) - S(l-k-1) \tag{8}$$

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The magnitude of $S"(l-k)$ has less value than *S' (l-k)* and *S (l-k)*.
The impacts of ICI power on OFDM systems can be evaluated by computing the CIR. Assuming the transmitted data have zero mean and are statistically independent and consider the desired signal is transmitted in "0" subcarrier. By using Eq. (5), the CIR of proposed scheme is derived as follows:

$$CIR = \frac{|S(0) + S^{*}(0)|^2 + \left|we^{-j\frac{\pi}{2}}S(1) - we^{j\frac{\pi}{2}}S^{*}(-1)\right|^2}{\sum_{\substack{l=2,\\ even}}^{N-2}\left[|S(l) + S^{*}(l)|^2 + \left|e^{-j\frac{\pi}{2}}S(l+1) - e^{j\frac{\pi}{2}}S^{*}(l-1)\right|^2\right]} \tag{9}$$

The CIR obtained from the above derived formula is represented in figure 4.

VI. Simulation Results

The simulation is done to evaluate the performance of proposed technique. The proposed technique is implemented with MATLAB. OFDM symbols of same size are transmitted over the AWGN channel. The simulation parameters are the total number of subcarriers N=256, OFDM symbols are 1000 with FFT size 256, the normalized frequency offset Ɛ = 0-0.5, Cyclic prefix value is 12 and BPSK modulation is used. Based on the transmitted *X (k)* and received value *Z (k)*, the Bit Error Rate is calculated and a graph is plotted which compares the BER of this proposed scheme with the existing scheme and Standard OFDM. The BER graph is shown in figure 2.

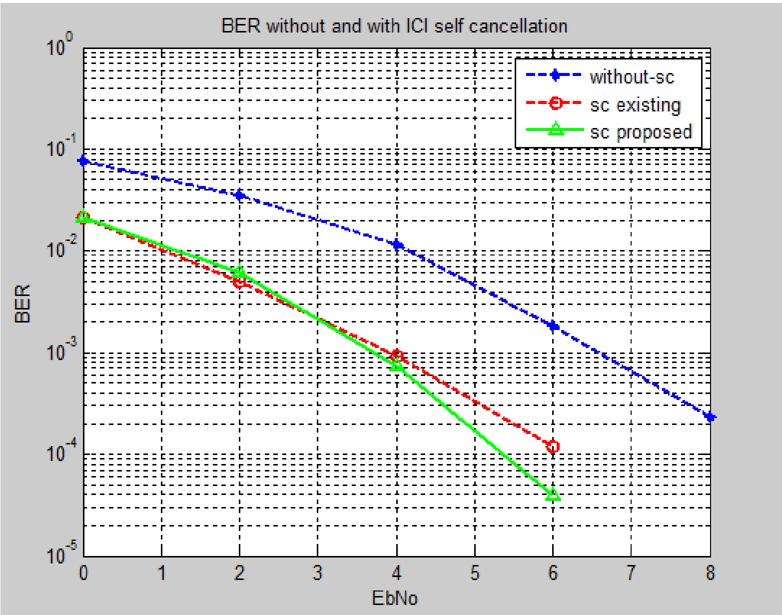

Fig. 2: BER performance graph among standard OFDM signal, existing sc scheme and proposed sc scheme.

From the figure we observe that as the value of SNR increases BPSK BER curve leans downward which indicates reduction in bit error rate .The graph depicts the comparison between proposed scheme and existing scheme. Initially proposed scheme has BER little greater than the existing one. But as the SNR (EbNo) value increases, proposed scheme shows better results. BER of proposed scheme is less as compared to existing scheme and standard OFDM system.

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A theoretically expression for Carrier to Interface Ratio (CIR) is also derived. CIR is the ICI level indicator. The comparison of Standard OFDM CIR and ICI theory is shown in figure 3. The standard CIR curve is obtained by taking N=64 and Ɛ=0.2. By varying these factors different CIR curves can be obtained. As CIR is the function of N and frequency offset Ɛ.

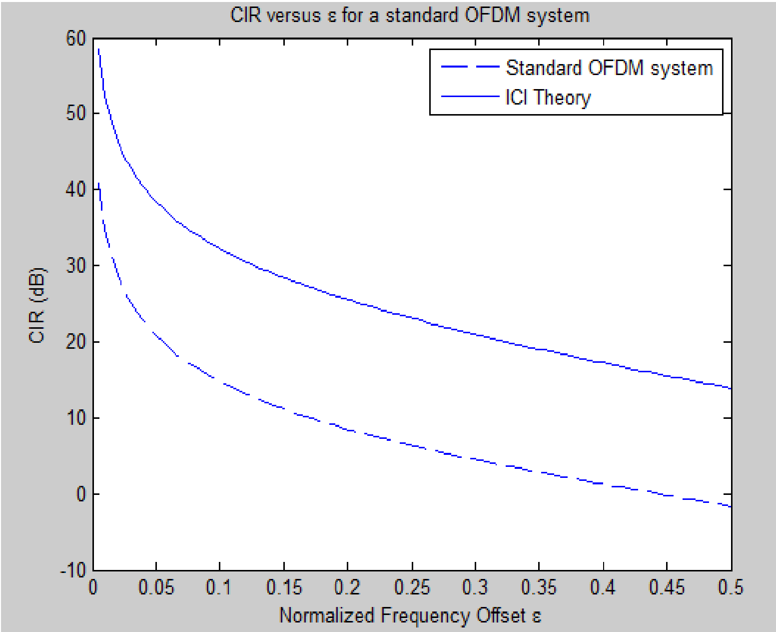

Fig. 3.CIR verses Ɛ for a standard OFDM system and ICI theory

Another comparison of CIR of proposed scheme, existing scheme, ICI theory and standard OFDM is also made in figure 4. The figure shows that the CIR of the proposed scheme is almost same as that of the existing scheme, except some values of frequency offset (Ɛ=0.4 - 0.7). As the frequency offset value Ɛ increases CIR of the proposed scheme goes much better than the standard OFDM and finally touches the ICI theory curve line.

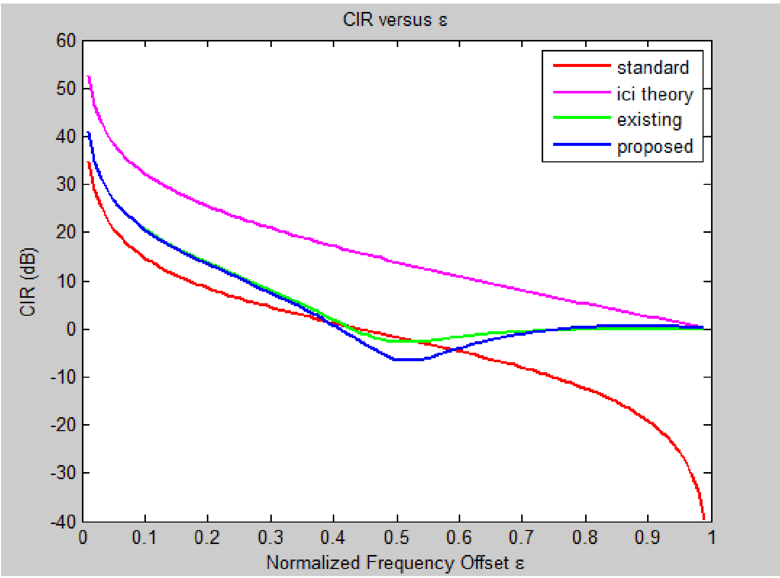

Fig. 4. CIR comparison of standard OFDM system, ICI theory, existing sc and proposed sc scheme

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VII. CONCLUSION AND FUTURE WORK

In this paper, ICI Self-Cancellation techniques is opted and studied for eliminating the effect of ICI caused by frequency offsets in OFDM systems. This paper proposes a new ICI-SC scheme which provides immunity to Inter Carrier Interference (ICI). The simulation results suggest that the proposed scheme gives better BER performance than the existing scheme in AWGN channel. The proposed scheme provides better CIR than standard OFDM which has been studied theoretically and by simulations. It can be concluded that with the proposed scheme the need of channel equalization can be eliminated without increasing the system complexity. The number of subcarriers can be increased to increase the bandwidth efficiency of the system. The OFDM system with proposed ICI self cancellation scheme performs better than the standard OFDM system and the OFDM system using existing ICI self cancellation scheme.

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