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A New Hybrid ICI-SC Scheme for OFDM Systems

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Abstract: Orthogonal Frequency Division Multiplexing (OFDM) is an optimum technique for 4G broadband multimedia wireless systems. OFDM suffers from the effect of frequency offset caused by mobility which disturbs the orthogonality between subcarriers and results in Inter Carrier Interference (ICI). ICI leads to system performance impairments. Many ICI cancellation methods have been proposed to cancel or reduce the effect of ICI. This paper presents a new ICI Self-Cancellation scheme (Hybrid Self-Cancellation) by combining two techniques. In proposed scheme, the Real Constant Weighted Data Conversion (RCWDC) Scheme and Improved Weighted Conjugate Transformation (IWCT) Scheme are put together which will minimizes the effect of ICI on adjacent subcarriers. In terms of BER and CIR, the Hybrid scheme gives better results compared to that existing Self Cancellation scheme.

Keywords: OFDM, ICI-SC, RCWDC, IWCT, BER and CIR.

1. INTRODUCTION

Orthogonal Frequency Division Multiplexing is an excellent multiplexing technique in the broadband wireless communication system. OFDM is a Multicarrier Communication (MC) technique provides high data rate transmission in which available bandwidth is divided into many carriers each one is modulated by a low rate data stream [1]. OFDM system has high spectral efficiency due to overlapping of subcarrier spectra which is termed as Orthogonality. But the orthogonality is hampered by the Frequency Offset. Frequency offsets occurs due to the mismatch between transmitter and receiver Local Oscillator (LO) frequency and hence give rise to the Inter Carrier Interference (ICI). This undesired ICI disgrace the performance of the OFDM Systems. Therefore OFDM requires an accurate and efficient ICI reduction procedure which completely cancels the effect of ICI on the adjacent subcarrier.

Several techniques for reducing ICI has been proposed in literature including frequency-domain equalization [2], time-domain windowing [3], self-cancellation [4]-[9], frequency offset estimation and correction technique [10]-[11], correlative coding [12] etc. ICI Self-Cancellation is a very simple way to remove ICI in OFDM system. It needs not to estimate Frequency offsets. It is very useful to combat the fast fading channel due to Doppler Spread and fit to simple low-speed OFDM Systems. This paper focused on the further development of ICI Self-Cancellation technique. Various ICI self-cancellation schemes has been developed till now are such as data-conversion [4], symmetric data-conversion [5], constant weighted data conversion [5]-[6], data-conjugate [7], weighted conjugate transformation [8] and improved weighted conjugate transformation [9].

In the proposed scheme, a new data allocation method is employed which is the blend of two existing self cancellation schemes such as Real Constant Weighted data conversion (RCWDC) and Improved Weighted Conjugate Transformation (IWCT). A theoretical expression of CIR for proposed scheme is derived and its performance is compared with the existing IWCT scheme in terms of CIR and BER. In [9] the results show that the IWCT scheme outperforms the other SC scheme. This paper simulation result shows that proposed scheme is better than IWCT scheme

2. ICI ANALYSIS IN OFDM SYSTEM

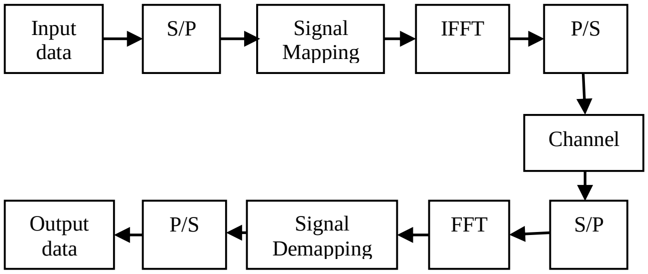

Figure 1: Block Diagram of Baseband OFDM System

In an OFDM System, as shown in figure 1 the input bit stream is multiplexed into N symbol stream and then each symbol stream is used to modulate parallel, synchronous sub carriers. These modulated N symbol streams are mapped to bits of an IFFT. These IFFT bits correspond to the orthogonal subcarriers in OFDM.

Therefore, the OFDM symbol can be expressed as:

$$x(n) = \frac{1}{N}\sum_{k=0}^{N-1} X(k) \qquad (1)$$

$$n = 0,1,2,\ldots\ldots N-1$$

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:

$$y(n) = x(n)e^{\frac{j2\pi n\mathcal{E}}{N}} + w(n) \qquad (2)$$

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:

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

$$= \underbrace{X(k)S(0)}_{C(k)} + \sum_{\substack{l=0\\ l\neq k}}^{N-1} \underbrace{X(l)S(l-k)}_{ICI(k)} + W(k) \qquad (3)$$

where *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 Eq. 3 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:

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

Carrier–to-Interface Ratio (CIR) is used as the ICI level indication. The CIR is the ratio of the signal power to the power in the interference components. It serves as a good indication of signal quality in the absence of noise. The desired signal is transmitted on subcarrier “0” is considered, then, the CIR of Normal OFDM systems is simplified as:

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

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

CIR is a function of N and Ɛ. The frequency offset Ɛ and large value of N are both responsible for CIR. The theoretical curve calculated by Eq. 5 will be shown in Figure.3.

3. RELATED WORK

There are various ICI Self-Cancellation schemes. The two schemes which are related to this paper are explained below:

I. Real Constant Weighted Data Conversion Scheme (CWDC)

This ICI SC scheme for OFDM systems have been proposed in [5] in which subcarrier signals are allocated in the form of *X’(k) = X(k), X’(k+1) = -μX(k),* where μ is a real constant in [0,1]. Then the received signal can be represented as:

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

$$= \frac{1}{1+\mu}\Bigg\{ X(k)[\,(1+\mu)S(0) - \mu S(1) - S(-1)]$$

$$+ \sum_{\substack{l=0\\ l=EVEN\\ l\neq k}}^{N-2} X(l)\,[(1+\mu)S(l) - \mu S(l-k-1)$$

$$- \mu S(l-k+1)]\Bigg\} + W'(k)$$

The CIR of this scheme can be expressed as:

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

The data conversion scheme has better CIR performance in OFDM than data conjugate scheme with frequency offset as mentioned in [13].

II. Improved Weighted Conjugate Transformation Scheme (IWCT)

This scheme [9] is the modification of the already existing Weighted Conjugate Transformation (WCT) scheme. In this method the data modulated within the $(k+1)^{th}$subcarrier is phase rotated by −π/2, instead of π/2 as presented in WCT of the conjugate of the modulated data within k^{th}subcarrier. This scheme is based on data symbol allocation of *X’(k)= X(k), X’(k+1)=* $e^{-\frac{J\pi}{2}}X^*(k)$ $(k = 0,2,4\ldots.N-2)$.

The desired signal is recovered in receiver as:

$$Y(\text{k})=1/2\ (\text{Y}(k) - e^{\frac{J\pi}{2}}Y^*(k+1)) \qquad (8)$$

The CIR of this scheme can be expressed as:

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

The Data Conjugate method has best BER performance compared with data conversion method in the [14] AWGN channe

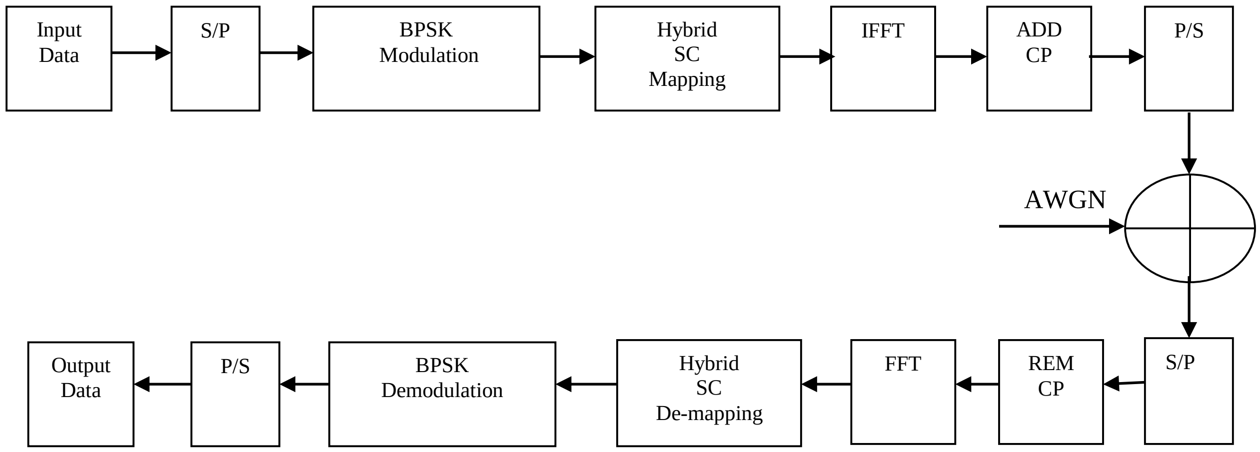

Figure 2: Block Diagram of Hybrid ICI SC OFDM System

4. HYBRID ICI SELF-CANCELLATION SYSTEM MODEL

The ICI self-cancellation scheme is a very simple way for abolishing the effect of ICI in OFDM. The difference between the ICI co-efficient of two consecutive sub-carriers are very small and negligible. This makes the basis of ICI self cancellation method. The process of this method [4] is to modulate one data symbol onto a group of subcarriers with predefined weighting coefficients. One data symbol is not modulated in to one sub-carrier, rather at least in to two consecutive sub-carriers. If the data symbol *'a' is* modulated in to the 1st sub-carrier then *'-a'* is modulated in to the 2nd sub-carrier. Hence the ICI generated between the two sub-carriers almost mutually cancels each other. This method is suitable for multipath fading channels, as here no channel estimation is required. The self-cancellation (SC) method is not very complex and is an easy way to cancel ICI compared to other methods. Because the scheme needn't to estimate frequency offsets. Figure 2 represents the proposed block diagram of a Hybrid ICI Self-Cancellation OFDM system.

Comparison with the conventional OFDM system the transceiver of proposed model appends only few circuits, including: Hybrid SC Mapper, Hybrid SC De-Mapper, Cyclic Prefix adder and Cyclic Prefix subtractor. As shown, a high data rate stream of serial input bits are first converted into low data rate parallel output bits. The Input bit stream is binary data. The parallel data streams are mapped into symbols using BPSK modulation. The modulated data, to suppress the effect of ICI in OFDM symbol is the feed to Hybrid SC mapping block. In this block, new data allocation schemes will be employed which is the combination of two above discussed SC schemes. ICI modulation takes place at this step. ICI coefficients can be found at this step. Two adjacent symbols are produced here. These symbols are modulated by IFFT on N-parallel subcarriers so that each subcarrier is assigned with a specific frequency. The frequencies are selected so that they are orthogonal in nature. At this same step the frequency domain OFDM symbols are converted to time domain symbols. With cyclic prefix (CP) addition, the OFDM symbols are serialized using parallel-to serial (P/S) conversion. A number of frames can be regarded as one OFDM signal. These OFDM symbols constitute a frame and sent down to the channel. Channel used here is AWGN channel. At the receiver side, the received symbols are retrieved by S/P conversion, CP subtraction, FFT transformation, Hybrid SC De-mapping, P/S conversion and demodulation with corresponding scheme to obtain the desired original bit stream. The time domain OFDM symbols are converted back into frequency domain at FFT block. ICI effect is further removed by ICI demodulation performed in Hybrid SC De-mapping block. Here ICI cancellation modulation and ICI cancellation demodulation together known as Hybrid Self Cancellation Scheme. And finally the desired signal is obtained at the output with zero ICI.

5. PROPOSED HYBRID SCHEME

The proposed scheme is the blend of two above explained schemes Real Constant Weighted Data Conversion (RCWDC) scheme and Improved Weighted Conjugate transformation (IWCT) scheme. In this scheme, the data modulated within the $(k+1)^{th}$ subcarrier is phase rotated by –π/2, of the conjugate of the modulated data within k^{th} subcarrier, same as that of the Improved WCT scheme and multiplied by a constant weight $'w'(0, 1)$.

Therefore, new data allocation scheme can be represented as:

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

$$X'(k+1) = w\, e^{-j\frac{\pi}{2}} X^*(k) \qquad (\mathrm{k} = 0,2,4 \ldots\ldots \mathrm{N}-2)$$

The received signal within k^{th} subcarrier from Eq. 3

$$Y'(k) = \sum_{l=0}^{N-1} X(l)S(l-k) + Wk$$
$$= X(0)S(0-k) + w\,e^{-j\frac{\pi}{2}}X^*(0)S(1-k) + \ldots\ldots Wk$$
$$= \sum_{\substack{l=0,\\ l=even}}^{N-2} X(l)S(l-k) + we^{-j\frac{\pi}{2}}X^*(l)S(l+1-k)$$
$$+ Wk \qquad (10)$$

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

$$Y'(k+1) = \sum_{\substack{l=0,\\ l=even}}^{N-2} X(l)S(l-k-1) + we^{-j\frac{\pi}{2}}X^*(l)\,S(l-k)$$
$$+ W(k+1) \qquad (11)$$

ICI coefficient is denoted as:

$$S'(l-k) = S(l-k) - S(l+1-k) \qquad (12)$$

The desired signal is recovered from above two Eq. (10) and (11) as follows:

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

$$= \frac{1}{2}\{X(k)[S(0) + S^*(0)] + X^*(l)\,[S(1)we^{-j\frac{\pi}{2}} - we^{-j\frac{\pi}{2}}S^*$$
(-1)]+
$$\sum_{\substack{l=0,\\ l\neq k}} X(l)[\,S(l-k) + S^*(l-k)] + X^*(l)[S(l-k+1) \ldots$$
$$+ Wk \qquad (13)$$

The corresponding ICI coefficients then become:

$$S''(l-k) = -S(l-k+1) + 2S(l-k) - S(l-k-!) \qquad (14)$$

The magnitude of $S''(l-k)$ has less value than *S' (l-k)* and *S (l-k)* as shown in figure 1

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=

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

6. SIMULATIONS RESULTS

In this paper, we use MATLAB simulation results to present the effectiveness of the proposed Hybrid ICI Self Cancellation scheme. We provide BER and CIR simulation results for the proposed scheme, existing IWCT scheme and standard OFDM in AWGN channel. All the systems are assumed to have $N = 256$ subcarriers and employ BPSK modulation. The simulation parameters for the proposed scheme are shown in Table 1.

Table 1: Simulation Parameters

PARAMETERS	SPECIFICATION
FFT Size	256
Subcarrier	256
Modulation	BPSK
Channel	AWGN
Cyclic Prefix	12
Frequency offset Ɛ	0 - 0.5
OFDM symbols	1000

a. Analysis of ICI components

The effect of ICI components on adjacent subcarriers can be analysed by calculating the ICI coefficients *S(l-k)*, *S'(l-k)* and *S"(l-k)* as in Equation (12) and (14), where N=64, *l*=0, *k*=0,2,4…N-2 and Ɛ=0.2 and the result is plotted in figure 1.

b. Bit Error Rate (BER)

Figure 2 shows the BER performance comparison graph among proposed SC scheme, Existing SC scheme (IWCT) and Standard OFDM without SC scheme. For optimum simulation result '*w*' value is taken as 0.7. The figure shows that intially the BER of both proposed scheme and existing scheme are almost same but as the EbNo value increases proposed scheme provides less BER which is better than existing scheme.

c. Carrier-Interface Ratio (CIR)

The CIR comparison of Standard OFDM, existing (IWCT) scheme and proposed (Hybrid SC) scheme is shown in figure 3. The figure shows that CIR of the proposed scheme is intially same as that of existing scheem and higher than the standard OFDM CIR but as the Ɛ value increases it goes less than the existing scheme and standard OFDM CIR.

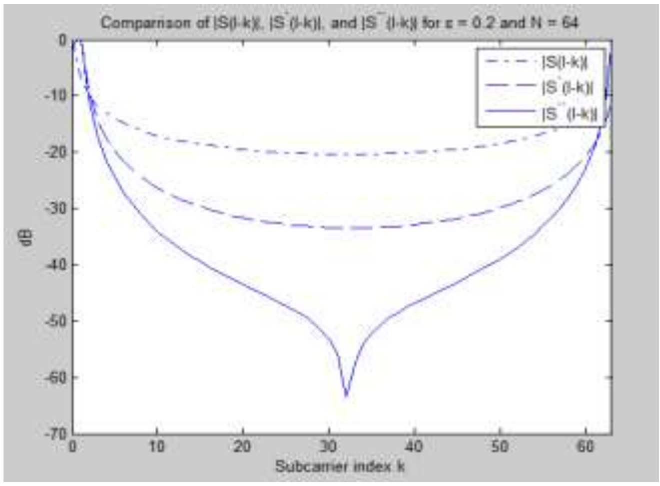

Figure 1: Comparison of S(l-k), S'(l-k) and S"(l-k)

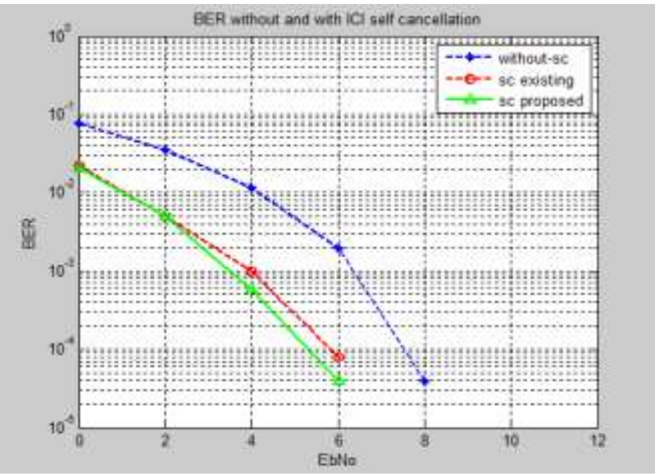

Figure 2: BER comparison of standard OFDM system without SC scheme, existing IWCT scheme and proposed SC scheme.

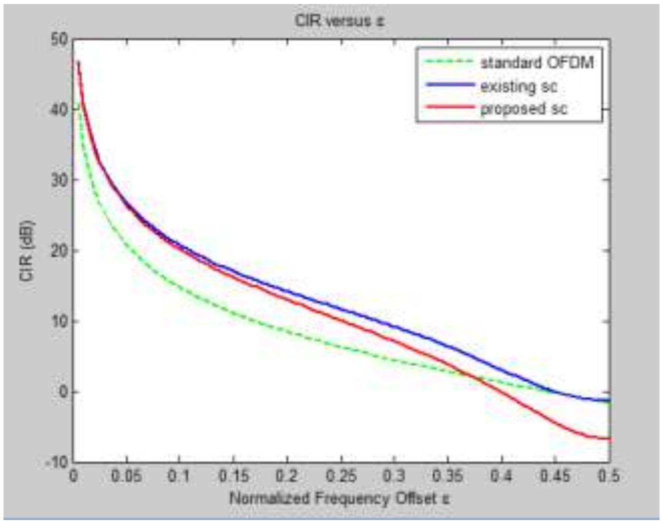

Figure 3: CIR comparison of standard OFDM system, existing sc and proposed sc scheme.

7. CONCLUSION

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 combined (RCWDC and IWCT) 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 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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