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New ICI Self-Cancellation Scheme for Orthogonal Frequency Division Multiplexing Systems

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Abstract-- Orthogonal Frequency Division Multiplexing (OFDM) is a well-known technique for the broadband wireless communication system. However, a main problem in OFDM is its vulnerability to frequency offset errors due to which the orthogonality is destroyed that result in Inter carrier Interference (ICI). ICI causes power leakage among subcarriers thus degrading the system performance. This paper studies ICI cancellation scheme which performs better than standard OFDM system. In this paper an effective Intercarrier Interference Self-Cancellation method to compensate the effects of multiple carrier frequency offsets for orthogonal frequency division multiplexing (OFDM) systems is presented.

Index Terms: Additive white Gaussian noise (AWGN), Bit error Rate (BER), carrier frequency offset (CFO), inter carrier interference self-cancellation (ICI SC),orthogonal frequency division multiplexing (OFDM).

I. Introduction

Orthogonal frequency division multiplexing (OFDM) is promising technique in modern high data rate wireless communication system because of its multi carrier modulation technique. Due to high capacity transmission of OFDM, it has been applied to digital transmission system, such as digital audio broadcasting (DAB) system, digital video broadcasting TV (DVB-T) system, asymmetric digital subscriber line (ADSL), IEEE 802.11a/g designed to operate in the 5 GHz band, Wireless Local Area Network (WLAN), IEEE 802.16 Worldwide Interoperability for Microwave Access (WiMax) systems, and ultra-wideband (UWB) system [1]. OFDM is used as a multi carrier modulation method. In OFDM, the multiple frequency channels, known as sub-carriers, are orthogonal to each other. There exists a problem with orthogonal frequency division multiplexing (OFDM) system, that is its sensitivity to frequency offset between the transmitted and received signals, which may be caused by Doppler shift due to relative motion between transmitter and receiver, or by the difference between the transmitter and receiver local oscillator frequencies. This carrier frequency offset causes loss of orthogonality between sub-carriers and then the signals transmitted on each carrier are not independent of each other. The orthogonality of the carriers is no longer maintained, which results in inter carrier interference [2]. ICI problem would become more complicated when the multipath fading is present. If ICI is not properly compensated, it results in a power leakage among the sub carriers, thus this degrades the system performance There are numerous ways to perform self-cancellation. In this paper an improved ICI self-cancellation is introduced with improved CIR and reduced BER. Furthermore, BER performances of the proposed scheme are compared with standard OFDM signal and existing schemes. The rest of the paper is described as: in section II basic OFDM model and the ICI problem is described. In section III ICI Self-Cancellation is described and proposed scheme is introduced. Next in IV simulation results are shown and in V conclusions are made.

II. Ofdm Model

In OFDM communication system, inverse discrete Fourier transform (IDFT) is performed at transmitter and Discrete Fourier transform (DFT) is performed at receiver. Figure 1 shows the basic OFDM model.

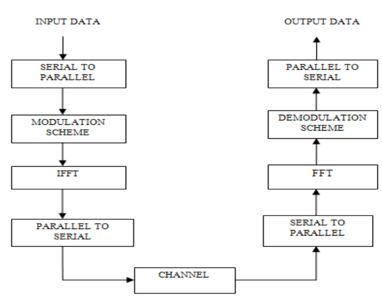

Figure 1: Basic OFDM Model

The basic OFDM system contains input data, serial to parallel transmission, modulation scheme, parallel to serial transmission, channel, demodulation scheme, IFFT and FFT as shown in figure 1. The input data stream is converted into parallel data stream and mapped with modulation scheme. Then the symbols are mapped with Inverse Fast Fourier Transform (IFFT) and converted to serial stream. The complete OFDM symbol is then transmitted through the channel. On the receiver side this symbols are converted back to parallel stream and mapped with FFT scheme. Then the symbols are mapped with demodulation scheme and converted to serial data as output data.

In an OFDM communication system, assuming the channel frequency offset normalized by the subcarrier separation is ε and then the received signal on subcarrier *k* can be written as:

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

$$where\ k = 0,1 \ldots . N-1$$

N is the total number of the subcarriers, X(k) denotes the transmitted symbol for the *k*th subcarrier and n_k is an additive noise sample. The first term in the right-hand side of eq. (1) represents the desired signal [3]. The second term is the ICI components. The sequence S(*l*-*k*) is defined as the ICI coefficient between *l*th and *k*th subcarriers, which can be expressed as:

$$S(l-k) = \frac{\sin\left(\pi(l+\epsilon-k)\right)}{N sin\left(\frac{\pi(l+\epsilon-k)}{N}\right)} exp^{\left(j\pi\left(1-\frac{1}{N}\right)(l+\epsilon-k)\right)} \qquad (2)$$

Fig. 2 shows the amplitude of the *S*(*l*-*k*) for frequency offset ε =0.1, 0.15 and 0.30 and for l=0, N=52

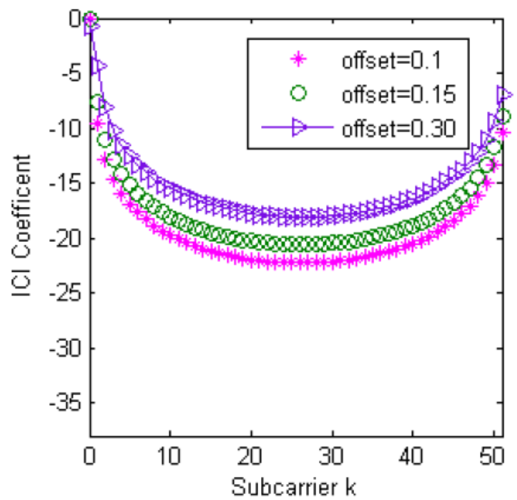

Fig 2 Amplitude of S(l-k)

It is clear from the figure 2 that as the offset value increases the ICI coefficient also increases. Hence it is necessary to reduce the inter carrier interference.

III Ici Self Cancellation

It is seen that the difference of ICI coefficient between two consecutive subcarrier 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 onto a group of subcarriers with predefined weighting coefficients. By doing so, the ICI signals generated within a group can be self-cancelled each other [4]. Thus it is called self-cancellation method.

A Data conversion

The data-conversion self-cancellation scheme for ICI mitigation based on a data symbol allocation of *X'* (*k*) = *X* (*k*), *X'*(*k* +1) = -*X* (*k*) for *k* = 0,2,…. *N* - 2 in consecutive subcarriers to deal with the ICI [3]. The received signal on subcarrier k will be

$$Y'(k) = \sum_{\substack{l=0,\\ l=even}}^{N-2} X(l)[S(l-k) - S(l+1-k)] + n(k) \qquad (3)$$

And on the subcarrier k+1 the received signal will be

$$Y'(k+1) = \sum_{\substack{l=0,\\ l=even}}^{N-2} X(l)[S(l-k-1) - S(1-k)] + n(k+1) \qquad (4)$$

To further reduce ICI, demodulation is done. The resultant signal *Y* (*k*) is determined by the difference between the adjacent subcarriers.

$$Y''(k) = \frac{1}{2}[Y'(k) - Y'(k+1)] \qquad (5)$$

CIR of data conversion method is given as

$$CIR = \frac{|2S(0) - S(1) - S(-1)|^2}{\sum_{\substack{l=2\\ l=even}}^{N-2} |2S(l) - S(l+1) - S(l-1)|^2} \qquad (6)$$

B Data conjugate

In the data-conjugate scheme, subcarrier signals are remapped in the form of *X'* (*k*) = *X* (*k*), *X'*(*k* +1) = **-** *X**(*k*) for k= 0,2 ….. N-2

The final recovered signal is as follows [5]

$$Y''(k) = \frac{1}{2}[Y'(k) - Y'^{*}(k+1)] \qquad (7)$$

CIR of data conjugate scheme is given by

$$CIR = \frac{|S(0) + S^{*}(0)|^2 + |S(1) + S^{*}(-1)|^2}{\sum_{\substack{l=2\\ l=even}}^{N-2} [|S(l) + S^{*}(l)|^2 + |S(l+1) + S^{*}(l-1)|^2]} \qquad (8)$$

C Symmetric data conversion

In the symmetric data-conversion scheme [6], subcarrier signals are remapped in the form of *X'* (*k*) = *X* (*k*), *X'*(N-*k* -1) = **-** *X*(*k*) for k= 0,2 ….. N-2

The final recovered signal is as follows

$$Y''(k) = \frac{1}{2}[Y'(k) - Y'(N-k-1)] \qquad (9)$$

CIR of data conjugate scheme is given by

$$CIR = \frac{|2S(0) - S(N-1) - S(1-N)|^2}{\sum_{\substack{l=2\\ l=even}}^{N-2} [|S(l) + S(-l) - S(N-l-1) - S(l-N+1)|^2]} \qquad (10)$$

D Real constant weighted conversion

In the constant weighted data-conversion scheme, subcarrier signals are remapped in the form of *X'* (*k*) = *X* (*k*), *X'*(*k* +1) = **-** µ*X*(*k*) for k= 0,2 ….. N-2, where µ is a real constant.

The final recovered signal is as follows [7]

$$Y''(k) = \frac{1}{1+\mu}[Y'(k) - Y'(k+1)] \qquad (11)$$

CIR of data conjugate scheme is given by

$$CIR = \frac{|(1+\mu)S(0) - \mu S(1) - S(-1)|^2}{\sum_{\substack{l=2 \\ l=even}}^{N-2} |(1+\mu)S(l) - \mu S(l+1) - S(l-1)|^2} \quad (12)$$

E plural weighted data conversion

In the plural weighted data-conversion scheme, subcarrier signals are remapped in the form of $X'(k) = X(k)$, $X'(k+1) = e^{-j\pi/2} X(k)$ for k= 0,2 ….. N-2

The final recovered signal is as follows

$$Y''(k) = \frac{1}{2}\left[Y'(k) - Y'(k+1)e^{-j\pi/2}\right] \quad (13)$$

CIR of data conjugate scheme is given by [8]

$$CIR = \frac{|2S(0) + e^{-\frac{j\pi}{2}}[S(1) - S(-1)]|^2}{\sum_{\substack{l=2 \\ l=even}}^{N-2} |2S(l) + e^{-\frac{j\pi}{2}}[S(l+1) - S(l-1)]|^2} \quad (14)$$

F Plural Conjugate data conversion

In this scheme, subcarrier signals are remapped in the form of $X'(k) = X(k)$, $X'(k+1) = e^{j\pi/2} X^*(k)$ for k= 0,2 ….. N-2 [9]

The final recovered signal is as follows

$$Y''(k) = \frac{1}{2}\left[Y'(k) - Y'^*(k+1)e^{-j\pi/2}\right] \quad (15)$$

CIR of data conjugate scheme is given by

$$CIR = \frac{|S(0) + S^*(0)|^2 + |e^{j\pi/2}S(1) + e^{-j\pi/2}S^*(-1)|^2}{\sum_{\substack{l=2 \\ l=even}}^{N-2} [|S(l) + S^*(l)|^2 + |e^{j\pi/2}S(l+1) + e^{-j\pi/2}S^*(l-1)|^2]} \quad (16)$$

IV Simulation Results

A simulation is done to evaluate the performance of proposed scheme. The parameters for the simulations are the total number of subcarriers $N = 256$, QPSK modulation, the normalized frequency offset $\varepsilon = (0.05, 0.25)$, AWGN fading channel are considered. The typical results for BER versus signal-to-noise ratio (E_b/N_0) are shown in Fig.3. Simulation results show that BER performance of OFDM systems and the previous ICI Self-cancellation schemes along with proposed scheme in the AWGN channel. As seen in the figure 3 the plural conjugate scheme has improved BER performance, compared with all the previous schemes described earlier.

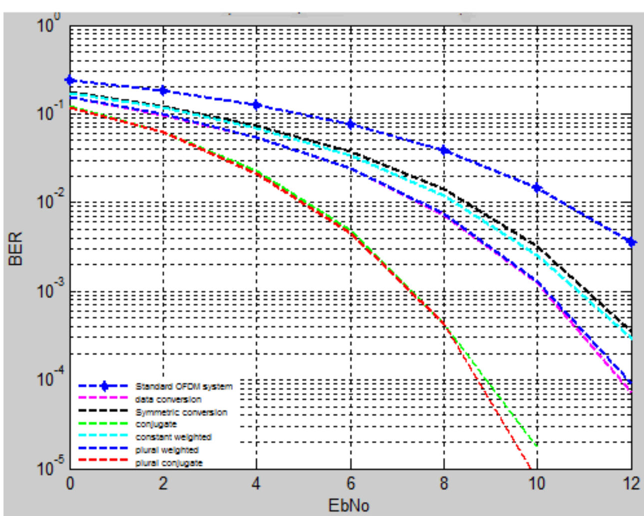

Fig. 3 BER versus SNR for QPSK, N=256, ε=0.05

Also figure 4 show the CIR of proposed scheme is better than the standard OFDM systems.

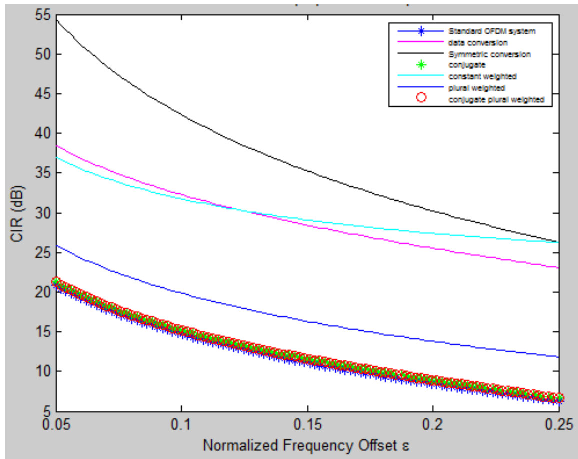

Fig. 4 CIR versus frequency offset

V Conclusion

This paper studies the ICI self-cancellation schemes to cancel the effect of ICI caused by frequency offset in OFDM systems. A new ICI self-cancellation scheme is presented. Although the bandwidth efficiency of the scheme is reduced by half due to the redundant symbols, it can be solved by increasing the number of subcarriers or using larger signal alphabet size and it is less complex as compared to the other frequency offset estimation and correction schemes. Simulation results show that the plural conjugate scheme can outperform other ICI SC schemes on the basis of BER.

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