ICI Self-Cancellation Scheme with Phase-Rotated Data Allocation in OFDM Systems

Cheng-Ying Yang[1], Gwo-Ruey Lee[1] and Jyh-Horng Wen[2]

[1]Department of Computer Science, Taipei Municipal University of Education
No.1, Ai-Guo W. Rd., Taipei, Taiwan, ROC.
[2]Department of Electrical Engineering, Tunghai University
No.181, Section 3, Taichung Harbor Rd., Taichung, Taiwan, ROC.

Abstract— **In this paper, a scheme is proposed to eliminate the effect of intercarrier interference (ICI) in OFDM systems. Applying the desired phase-rotated data allocation within the proposed scheme, the ICI between the subcarriers can be reduced. Besides, the analysis to the ICI effect in the system is presented. The simulation results show that the BER performance with the proposed scheme is better than that with Zhao's scheme for a large frequency offset because the effect of phase error with the proposed scheme is lighter than that with Zhao's scheme.**

Keywords— **OFDM systems, Intercarrier interference, ICI-self-cancellation scheme, Data allocation.**

1. INTRODUCTION

Orthogonal frequency division multiplexing (OFDM) with the high data-rate transmission has been applied into many digital transmission systems [1-5]. However, with applying the OFDM technique, one of the well known problems in the systems is its sensitivity to the effect of ICI because of the presence of frequency offset.
Without the estimation and compensation for the frequency offset in the received signal, the ICI will degrade the system performance. Currently, four different methods including frequency-domain equalization, frequency synchronization algorithm, time-domain windowing schemes and ICI cancellation schemes have been developed for ICI reduction [6-10]. Among those schemes, the ICI-self-cancellation scheme is a simple way for ICI reduction [9-10]. The main idea of the ICI-self-cancellation scheme proposed by Y. Zhao is that the data within the next subcarrier is modulated with an inversed weighting within the current subcarrier. Hence, the ICI signals generated within a group can be "self-cancelled" each other.

In this paper, the phase rotation of desired received signal caused by the frequency offset (called as the phase error) is discussed. It is clearly shown that the phase rotation of the received signal in Zhao's scheme distorts the system performance when the frequency offset is large. In order to mitigate the effect of phase error, a new weighting coefficient is applied into the proposed scheme. With the proposed scheme, the ICI effect could be reduced. Hence, the BER in the OFDM system could be improved. In the following section, the OFDM system and the effect of ICI are described. In Section 3, the ICI cancellation scheme is proposed to combat the ICI effect in the OFDM system. Besides, the analysis of ICI effect with the proposed scheme is presented. In Section 4, the numerical results are shown. Finally, a conclusion is given in section 5.

2. THE OFDM SYSTEM AND THE ICI EFFECT

In an OFDM system, it usually contains the function of parallel transmission, signal modulation and inverse fast Fourier transform (IFFT)/ fast Fourier transform (FFT) [1-2]. Fig. 1 illustrates the block diagram of the baseband, discrete-time FFT-based OFDM systems.

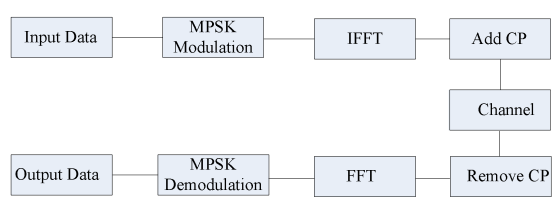

Fig. 1 Block diagram of the FFT-based OFDM systems

Each parallel data is mapped with M-ary PSK scheme and, then, those data are modulated by an IFFT on N-parallel subcarriers. With a cyclic prefix (CP), the complete OFDM symbol is transmitted under a discrete-time channel. At the receiver, the data are retrieved by an FFT and, then, de-mapped with corresponding scheme to obtain the estimated data.

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

$$x(n) = \frac{1}{N}\sum_{l=0}^{N-1} X(l) e^{j2\pi ln/N} , \tag{1}$$

where $x(n)$ denotes the nth sample of the OFDM transmitted signal, $X(l)$ denotes the modulated symbol within the lth subcarrier and N is the number of the total subcarriers. In this paper, symbol synchronization at the receiver is assumed to be perfect, however, the mismatch between the oscillators at the transmitter and receiver is occurred, i.e., the frequency offset is considered. The frequency offset, f_{off} , normalized by the subcarrier frequency spacing, f_d , is expressed as ε , that is, $\varepsilon = f_{off} / f_d$, and, then, the received signal in time domain could be written as

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

where $w(n)$ denotes a Gaussian noise. The corresponding frequency domain response could be obtained by FFT and listed as below.

$$Y(k) = X(k)S(0) + \sum_{\substack{l=0 \\ l \neq k}}^{N-1} X(l)S(l-k) + w(k), \quad k = 0, 1, ..., N-1 , \tag{3}$$

where $w(k)$ denotes Gaussian noise in frequency domain, and $S(l\text{-}k)$ denotes the ICI coefficient between the lth and the kth subcarriers, which could be expressed as

$$S(l-k) = \frac{\sin(\pi(l-k+\varepsilon))}{N \sin(\frac{\pi}{N}(l-k+\varepsilon))} \cdot \exp(j\pi(1-\frac{1}{N})(l-k+\varepsilon)) . \tag{4}$$

It is obvious that the amplitude of $S(l\text{-}k)$ is enlarged with a increasing frequency offset. In order to combat the effect of the frequency offset, a new ICI self-cancellation scheme is proposed in the following section.

3. THE PROPOSED ICI-SELF-CANCELLATION SCHEME

The ICI-self-cancellation scheme based on a data allocation of $\left(X(k), X(k+1) = -X(k)\right)$, k = 0, 2,…, N-2, was proposed by Y. Zhao to cancel the intercarrier interference in the OFDM system [9]. In the scheme, the received signal $Y(k)$ is determined by the difference between the adjacent subcarriers. In this paper, a desired data allocation with $\left(X(k), X(k+1) = e^{-j\pi/2} X(k)\right)$ is proposed to modulate the data within the subcarriers. The data modulated within k+1th subcarrier is the rotated phase $-\pi/2$ of the modulated data within the kth subcarrier. The block diagram of ICI-self-cancellation scheme for the OFDM system is shown in Fig. 2.

With the proposed scheme, the transmitted symbols are composed of $X(k+1) = e^{-j\pi/2} X(k)$, $k = 0, 2, ..., N-2$. At the receiver, the received signal on the kth subcarrier could be derived as

$$Y(k) = \sum_{\substack{l=0 \\ even}}^{N-2} X(l)\left[S(l-k) + e^{-j\pi/2} S(l+1-k)\right] + w(k) \tag{5}$$

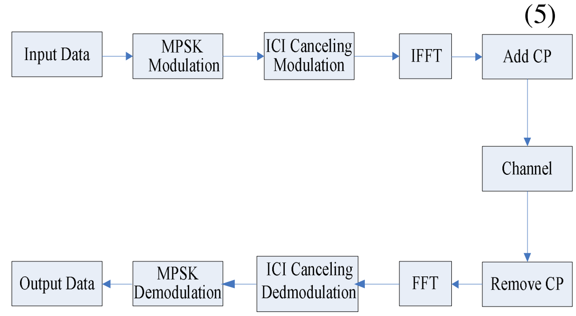

Fig. 2 Block diagram of the proposed ICI-self-cancellation scheme

Consequently, the signal $Y_d(k)$ could be obtained by the difference between $Y(k)$ and $Y(k+1)$ and, then, used to achieve the symbol decision. It could be derived as

$$\begin{aligned} Y_d(k) &= Y(k) - Y(k+1) \\ &= \sum_{\substack{l=0 \\ even}}^{N-2} X(l)\Big\{S(l-k) - S(l-k-1) \\ &\quad + e^{-j\pi/2}\left[S(l+1-k) - S(l-k)\right]\Big\} + w'(k) \\ &= X(k)\left\{S(0) - S(-1) + e^{-j\pi/2}\left[S(1) - S(0)\right]\right\} \\ &\quad + \sum_{\substack{l=0 \\ even \\ l \neq k}}^{N-2} X(l) \left\{ \begin{array}{l} S(l-k) - S(l-k-1) \\ + e^{-j\pi/2}\left[S(l+1-k) - S(l-k)\right] \end{array} \right\} + w'(k) . \end{aligned} \tag{6}$$

The phase rotation of the desired signal $X(k)$ caused by the frequency offset is

$$\sqrt{2} S(0) - S(-1) e^{-j\pi/4} + S(1) e^{-j3\pi/4} . \tag{7}$$

In addition, the ICI coefficient could be denoted as

$$S_I(l-k) = S(l-k) - S(l-k-1)$$

$$+e^{-j\pi/2}\left[S(l+1-k)-S(l-k)\right]. \quad (8)$$

The vector representation of $\sqrt{2}S(0)-S(-1)\times e^{-j\pi/4}+S(1)e^{-j3\pi/4}$ is shown in Fig. 3. In Eq. (4), $S(1)\cong -S(-1)$ when N is large. Therefore, the improved phase rotated factor θ_1 in the proposed scheme can be written as

$$\theta_1 \cong \tan^{-1}\left(\frac{\left|\sqrt{2}\left[S(1)\right]\right|}{\left|\sqrt{2}S(0)\right|}\right)$$

$$=\tan^{-1}\left(\frac{\sin(\frac{\pi}{N}\varepsilon)}{\sin(\frac{\pi}{N}(1+\varepsilon))}\right). \quad (9)$$

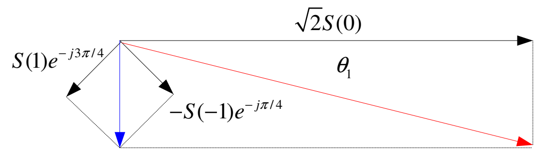

Fig. 3 Vector representation for the phase rotation of the desired signal

Based on the proposed scheme with the phase rotation, the performance on the BER is given in the following section.

4. Numerical Results

Performance of the proposed algorithm is evaluated under the frequency selective fading channel for OFDM transmission. In the simulation with 4096000 running, the number of subcarriers and the length of the cyclic prefix are N=128 and CP=32, respectively. In the system, the QPSK modulation scheme is used. The performance of the proposed scheme is evaluated based on the phase rotation factor, the BER. The phase errors of the desired signal with Zhao's scheme and the proposed scheme are shown in Fig. 4. The result shows that the phase error in the proposed scheme is smaller than that in Zhao's scheme and that in the conventional OFDM systems. The result shows the effect of phase error with the proposed scheme is lighter than that with Zhao's scheme.

In Fig. 5, the BER performance with the proposed scheme is better than that with Zhao's scheme for a large frequency offset because the effect of phase error with the proposed scheme is lighter than that with Zhao's scheme. For a larger frequency offset, the BERs with the proposed scheme perform better than those with Zhao's scheme in Fig. 5 (in the case of ε =0.15).

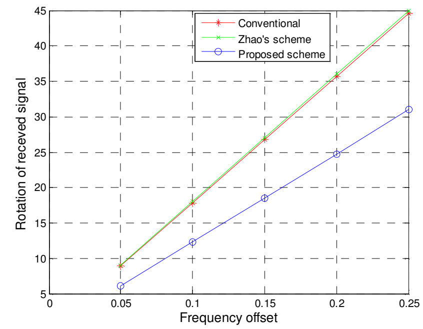

Fig. 4 Comparison of the phase rotated factors

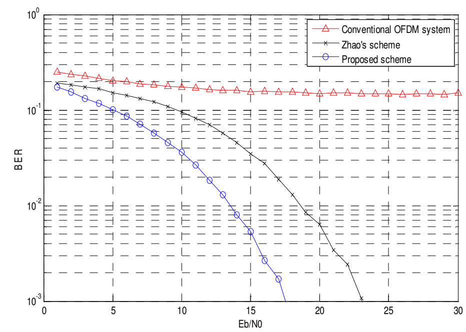

Fig. 5 The performance on BER versus E_b/N_0

5. Conclusion

In this paper, the ICI-self-cancellation scheme is proposed to mitigate the effect of ICI in OFDM systems. The scheme is with a less complexity when compared to the other ICI cancellation or reduction schemes. Although the bandwidth efficiency of the scheme is reduced by half due to the repetition symbols, it can be solved by increasing the number of subcarriers or using larger signal alphabet size. Besides, the proposed scheme is implemented to mitigate the phase error without applying any coding scheme. In addition, the simulation results show the phase error with the proposed scheme is lighter and the performance on BER with the proposed scheme is better than that with Zhao's scheme.

References

[1]. M. Engels, *Wireless OFDM Systems: How to Make Them Work?* Kluwer Academic Publishers, first edition, 2002.

[2]. K. Baum, B. Classon and P. Sartori, *Principles of Broadband OFDM Cellular System Design*, John Wiley, 2009.

[3]. T. Hwang, C. Yang, G. Wu, S. Li and Y. Li, "OFDM and its wireless applications: A survey," *IEEE Transactions on Vehicular*

Technology, vol. 58, no. 4, pp. 1673-1694, May 2009.

[4]. H. Rohling, T. May, K. Bruninghaus and R. Grunheid, "Broad-band OFDM radio transmission for multimedia applications," *Proceedings of the IEEE*, vol. 87, no. 10, pp. 1778-1789, 1999.

[5]. L. Ma and D. Jia, "The competition and cooperation of WiMAX, WLAN and 3G," *Proceedings of International Conference on Mobile Technology, Applications and Systems*, pp. 1-5, 2005.

[6]. J. Ahn and H.S. Lee, "Frequency domain equalization of OFDM signal over frequency nonselective Rayleigh fading channels," *Electronics Letters,* vol. 29, no. 16, pp. 1476-1477, 1993.

[7]. W.G. Jeon, K.H. Chang and Y.S. Cho, "An equalization technique for orthogonal frequency-division multiplexing systems in time-variant multipath channels," *IEEE Transactions on Communications*, vol. 47, no. 1, pp. 27-32, 1999.

[8]. J.H. Wen, G.R. Lee, J.W. Liu and T.L. Kung, "Frame synchronization, channel estimation scheme and signal compensation using regression method in OFDM systems," *Computer Communications*, vol. 31, no. 10, pp. 2124-2130, 2008.

[9]. Y. Zhao and S. G. Häggman, "Intercarrier interference self-cancellation scheme for OFDM mobile communication systems," *IEEE Transactions on Communications*, vol. 49, no. 27, pp. 1185-1191, 2001.

[10]. S. Tang, K. Going, J. Song, C. Pan and Z. Yang, "Intercarrier interference cancellation with frequency diversity for OFDM systems," *IEEE Transactions on Broadcasting*, vol. 53, no. 1, pp. 132-137, 2007.