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ICI SELF CANCELLATION SCHEME FOR OFDM SYSTEM

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Abstract—Orthogonal frequency division multiplexing (OFDM) is emerging as the preferred modulation scheme in modern high data rate wireless communication systems. Orthogonal frequency-division multiplexing (OFDM) systems is their inherent sensitivity to any frequency shift in the signal. A frequency offset between the local oscillators at the transmitter and receiver causes a single frequency shift in the signal, while a time-varying channel can cause a spread of frequency shifts known as the Doppler spread. Frequency shifts ruin the orthogonality of OFDM subcarriers and cause intercarrier interference (ICI); therefore, quickly diminishing the performance of the system. ICI self-cancellation schemes have been proposed to reduce the sensitivity of OFDM systems to frequency shifts.

I. INTRODUCTION

OFDM is an emerging modulation scheme in the current broadband wireless mobile communication system due to the high spectral efficiency and robustness to multi-path Interference [1]. A well-known disadvantage of the OFDM system is its sensitivity to frequency offset between transmitted and received signals, which may be caused by Doppler shift in the channel [2], or by the difference between the transmitter and receiver local oscillator frequencies. The carrier frequency offset causes loss of orthogonality and then the signals transmitted on each carrier are not independent of each other, thus leading to ICI [3]. ICI self-cancellation schemes have been proposed to reduce the sensitivity of OFDM systems to frequency shifts. These schemes use signal processing and frequency domain coding to reduce the amount of ICI generated as a result of frequency shifts, with little additional computational complexity.

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II. Analysis of ICI

The main disadvantage of OFDM, however, is its susceptibility to small differences in frequency at the transmitter and receiver, normally referred to as frequency offset. This frequency offset can be caused by Doppler shift due to relative motion between the transmitter and receiver, or by differences between the frequencies of the local oscillators at the transmitter and receiver. In this project, the frequency offset is modeled as a multiplicative factor introduced in the channel, as shown in Figure 1

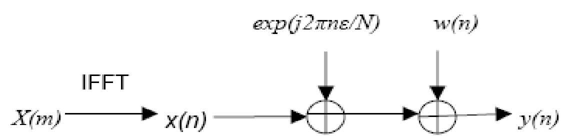

Figure 1 Frequency Offset Model

The received signal is given by,

$$y(n)=x(n)\exp(j2\pi n\varepsilon/N)+w(n) \quad (1)$$

Where, ε is the normalized frequency offset, and is given by ΔfNT_s. Δf is the frequency difference between the transmitted and received carrier frequencies and T_s is the subcarrier symbol period. w (n) is the AWGN introduced in the channel. The effect of this frequency offset on the received symbol stream can be understood by considering the received symbol Y(k) on the k^{th} sub-carrier[4].

$$Y(k)=X(k)S(0)+\sum X(l)S(l-k)+n_k, k=0,1,\ldots.N-1 \quad (2)$$

Where, N is the total number of subcarriers, X (k) is the transmitted symbol (M- phase-shift keying (M-PSK), for example) for the k^{th} subcarrier, n_k is the FFT of w(n), and S(l-k) are the complex coefficients for the ICI components in the received signal. The ICI components are the interfering signals transmitted on sub-carriers other than the k^{th} sub-carrier. The complex coefficients are given by,

$$S(l-k)=\frac{Sin(\pi(l+\varepsilon-k))}{N\sin(\pi(l+\varepsilon-k)/N)}\exp(j\pi(1-\frac{1}{N})(l+\varepsilon-k)) \quad (3)$$

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To analyze the effect of ICI on the received signal, we consider a system with N=16 carriers. The frequency offset values used are 0.2 and 0.4, and l is taken as 0, that is, we are analyzing the signal received at the sub-carrier with index 0. The complex ICI coefficients S(l-k) are plotted for all sub-carrier indices in Figure 2.

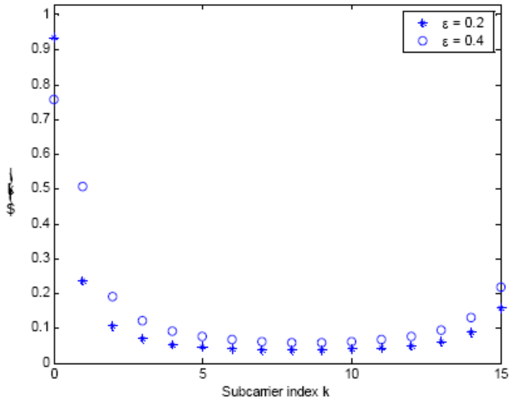

Figure 2 ICI Coefficients for N=16 Carriers

This figure shows that for a larger ε, the weight of the desired signal component, S(0), decreases, while the weights of the ICI components increases. It is also noticed that the adjacent carrier has the maximum contribution to the ICI. This fact is used in the ICI self-cancellation technique [1].

The carrier-to-interference ratio (CIR) is the ratio of the signal power to the power in the interference components. It serves as a good indication of signal quality. The derivation assumes that the standard transmitted data has zero mean and the symbols transmitted on the different sub-carriers are statistically independent.

$$CIR = \frac{|S(k)|^2}{\sum_{\substack{l=0 \\ l=k}}^{N-1} |S(l-k)|^2} = \frac{|S(0)|^2}{\sum_{l=0}^{N-1} |S(l)|^2} \tag{4}$$

III. Factors Including ICI

ICI is different from the co-channel interference in MIMO systems. The co-channel interference is caused by reused channels in other cells, while ICI results from the other sub-channels in the same data block of the same user. Even if only one user is in communication, ICI might occur, yet the co-channel interference will not happen [2]. There are two factors that cause the ICI, namely frequency offset and time variation. As discussed in, some kinds of time variations of channels can be modeled as a white Gaussian random noise when N is large enough, while other time variations can be modeled as frequency offsets, such as Doppler shift. ICI problem would become more complicated when the multipath fading is present.

A. Doppler Effect:

The relative motion between receiver and transmitter, or mobile medium among them, would result in the Doppler effect, a frequency shift in narrow-band communications. For example, the Doppler effect would influence the quality of a cell phone conversation in a moving car.In general, the Doppler frequency shift can be formulated in a function of the relative velocity, the angle between the velocity direction and the communication link, and the carrier frequency [3].

The value of Doppler shift could be given as:-

$$f_d = \frac{v}{\lambda} 2\pi \cos(\theta) \tag{5}$$

Where, *q* is the angle between the velocity and the communication link, which is generally modeled as a uniform distribution between 0 and 2*p* , *v* is the receiver velocity, and the *l* is the carrier wavelength.

Let us assume that electromagnetic wave velocity is C, the wavelength of carrier can be written as, where *fc* is the carrier frequency.:-

$$\lambda = \frac{C}{f_c} \tag{6}$$

B. Synchronization Error:

It can be assumed that most of the wireless receivers cannot make perfect frequency synchronization. In fact, practical oscillators for synchronization are usually unstable, which introduce frequency offset. Although this small offset is negligible in traditional communication systems, it is a severe problem in the OFDM systems. In most situations, the oscillator frequency offset varies from 20 ppm (Parts Per Million) to 100 ppm. Provided an OFDM system operates at 5 GHz, the maximum offset would be 100 KHz to 500 KHz (20-100 ppm.). However, the subcarriers frequency spacing is only 312.5 KHz [5]. Hence; the frequency offset could not be ignored. In most literatures, the frequency offset can be normalized by the reciprocal of symbol duration. For example, if a system has a bandwidth of 10 MHz, and the number of subcarriers is 128, then the subcarrier frequency spacing would be 10M/128 = 78 KHz. If the receiver frequency offset is 1 KHz, then the normalized frequency offset will be 1/78=1.3%. If the normalized frequency offset is larger than 1, only the decimal part needs to be considered.

IV Intercarrier Interference and Signal-to- interference Ratio

The channel can be expressed as a matrix *C.* The received

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signal can therefore be written as:-

$$Y = CS + N_w \tag{7}$$

Where, S is the N M input data, M is the number of blocks, each block consists of N input bits, and w N is the white noise[4]. Noise components will not be discussed and then will be neglected from now on. Ideally, C is an N N identity matrix. However, with the existence of CFO, the matrix has nontrivial off-diagonal elements. Hence, above equation could be rewritten as:-

$$Y(k) = S(k)C_{kk} + \sum_{l - k} S(l)C_{kl} \tag{8}$$

The first part in above equation consists of the information-bearing signals, while the second part is intercarrier interference. However, C will be different in simple local models and multipath models.

A. ICI in Simple Local Model:-

In this case, the matrix C is cyclic as follows:-

$$C = \begin{bmatrix} C_O & C_1 & \cdots & \cdots & C_{N-1} \\ C_{N-1} & C_o & C_1 & \cdots & C_{N-2} \\ C_{N-2} & C_{N-1} & C_o & \cdots & C_{N-1} \\ \vdots & \vdots & \vdots & \vdots & \vdots \\ C_1 & C_2 & \cdots & \cdots & C_o \end{bmatrix} \tag{9}$$

In other words, all sub-channels can be characterized by the same impulse response. And the entries of the complex matrix C can be written as:

$$C_i = \frac{Sin(\pi(i+\varepsilon))}{Sin(\frac{\pi(i+\varepsilon)}{N})} \exp(\frac{j\pi(N-1)(i+\varepsilon)}{N}) \tag{10}$$

Where, ε is the normalized frequency offset and N is IFFT length.Then we get:-

$$Y(k) = S(k)C_o + \sum_{l=1}^{N-1} S(l)C(l-k) \tag{11}$$

B. ICI in Multipath Model:-

The ICI in multipath model is more complicated. We just rewrite the equation here.

$$C_{k,l,n} = \frac{1}{N} \sum_{p=1}^{M} g_p \sum_{l=0}^{N-1} \exp[-2\pi j(f_c L_c T + f_c \tau_\rho - k \frac{\tau_\rho}{T})]$$
$$\exp(\frac{2\pi j(k - m + \Delta f_p T)}{N}) p_T(\frac{\pi - N\tau_p}{NT}) + \frac{1}{N} \sum_{p=1}^{M} g_p$$
$$\sum_{l=0}^{N-1} \exp[2\pi j(fc(1 - Lc)T - fc\tau p + \Delta fp(T - \tau p) - k \frac{\tau p}{T})] \tag{12}$$

In this equation, power gains subcarrier-dependent. In other words, different subcarriers have different power gains [4]. C is not a simple cyclic matrix here as that in the simple model.

C. Signal to Interference Ratio:-

The signal to interference ratio (SIR) measure is often quantify ICI. For a simple channel model, SIR can be written as Eq.13,

$$SIR_c = \frac{|C_o|^2}{\sum_{i=1}^{N-1} |C_i|^2} \tag{13}$$

In a multipath case, SIR of the *Lth* sub-channels is given as:

$$SIR_L = \frac{|C_{LL}|^2}{\sum_{\substack{i=0 \\ i=L}}^{N-1} |C_{Li}|^2}, \quad L = 0, 1, 2, \ldots, N-1 \tag{14}$$

The overall SIR of all sub-channels can be defined as SIR_π $E(SIR_L)$

V. ICI Canceling Modulation

The ICI self-cancellation scheme requires that the transmitted signals be constrained such that X(1)=-X(0), X(3)=-X(2), …,X(N-1)=-X(N-2). This assignment of transmitted symbols allows the received signal on subcarriers k and k + 1 to be written as:-

$$Y'(k) = \sum_{\substack{l=0 \\ l=even}}^{N-2} X(l)[S(l-k) - S(l+1-k)] + n_k \tag{15}$$

$$Y'(k+1) = \sum_{\substack{l=0 \\ l=even}}^{N-2} X(l)[S(l-k-1) - S(l-k)] + n_k + 1 \tag{16}$$

And the ICI coefficient S'(l-k) is denoted as:-

S'(l-k) = S(l-k) – S(l+1-k) (17)

VI. ICI Canceling Demodulation

The redundancy in this scheme reduces the bandwidth efficiency by half. This could be compensated by transmitting signals of larger alphabet size. Using the theoretical results for the improvement of the CIR should increase the power efficiency in the system and gives better results for the BER. Hence, there is a tradeoff between bandwidth and power tradeoff in the ICI self-cancellation scheme. Figure 3 below shows the comparison of the theoretical CIR curve of the ICI self-cancellation scheme, and the CIR of a standard OFDM system calculated [4]. As expected, the CIR is greatly improved using the ICI self-cancellation scheme. The improvement can be greater than 15 dB for 0 < ε <0.5. ICI modulation introduces redundancy in the received signal since each pair of subcarriers transmit only one data symbol. This redundancy can be exploited to improve the system power performance, while it surely decreases the bandwidth efficiency. To take advantage of this redundancy, the received signal at the $(k + 1)^{th}$ subcarrier, where k is even, is subtracted from the k^{th} subcarrier. This is expressed mathematically as:-

$$Y'(k) = Y'(k) - Y'(K+1) \tag{18}$$

$$= \sum_{\substack{l=0 \\ l=even}}^{N=2} X(l)[-S(l-k-1) + 2S(l-k) - S(l-k+1)] + n_k - n_{k+1} \tag{19}$$

Subsequently, the ICI coefficients for this received signal becomes,

$$S''(l-k) = -S(l-k-1) + 2S(l-k) - S(l-k+1) \tag{20}$$

When compared to the two previous ICI coefficients |S(l-k)| for the standard OFDM system and |S'(l-k)| for the ICI canceling modulation, |S''(l-k)| has the smallest ICI coefficients, for the majority of l-k values, followed by |S'(l-k)| and |S(l-k)|.The combined modulation and demodulation method is called the ICI self-cancellation scheme. The reduction of the ICI signal levels in the ICI self-cancellation scheme leads to a higher CIR.

$$CIR = \frac{|-S(-1) + 2S(0) - S(1)|^2}{\sum_{l=2,4,6}^{N-1} |-S(l-1) + 2S(l) - S(l+1)|^2} \tag{21}$$

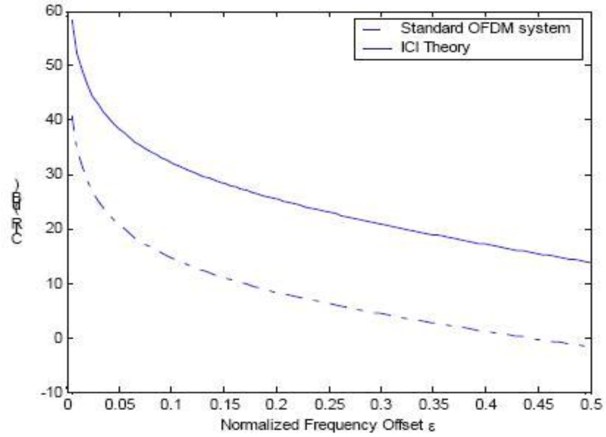

Figure 3 CIR versus ε for a standard OFDM system

VII. Conclusion

In this paper an improved DFT-IDFT based ICI-self cancellation scheme is proposed. By analyzing the ICI coefficients and BER plots for different schemes, it can be concluded that the proposed scheme produces better ICI reduction as compared to the DFT-based ICI-self cancellation scheme for small values of normalized frequency offset (ε 0.3) without any reduction in the spectral efficiency of the system. For large values of frequency offset there is only slight improvement in the performance of the proposed scheme in terms of BER. Thus, the proposed scheme reduces the ICI effectively as compared to the DFT-based ICI self-cancellation scheme

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