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Intercarrier Interference Cancellation for Orthogonal Frequency Division Multiplexing

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Abstract— Future wireless systems are expected to support a wide range of services which includes video, data and voice. Orthogonal Frequency Division Multiplexing (OFDM) is a promising candidate for achieving high data rates because of multicarrier modulation technique and ability to convert a frequency selective fading channel into several nearly flat fading channels. A well known problem of OFDM , is the sensitivity to frequency offset between the transmitted and received signals, which may be caused by Doppler shift in the channel, or by the difference between the transmitter and receiver local oscillator frequencies. This CFO causes loss of orthogonality between sub-carriers. If the orthogonality of the carriers is no longer maintained, there will be inter-carrier interference (ICI). ICI reduction techniques are essential in improving the performance of an OFDM system in an environment which induces frequency offset error in the transmitted signal. One of the efficient ICI cancellation method is the ICI self-cancellation scheme. This paper analyzes the ICI self cancellation scheme and presents a new ICI self cancellation scheme called self cancellation scheme with correlative coding. In terms of bit error rate (BER) the proposed scheme provides better performance than the self cancellation scheme.

Index Terms— BPSK, BER, CFO, correlative coding, ICI , OFDM ,Self cancellation

1 Introduction

ORTHOGONAL Frequency Division Multiplexing is emerging up as a popular implementation for multicarrier technique broadband wireless communications. OFDM is the key broadband wireless technology for Long Term Evolution (LTE) and Worldwide Interoperability for Microwave Access (WiMAX) and also it has been accepted for the wireless local area network standard such as IEEE 802.11a/g/n High performance LAN type2 (Hiper LAN/2) etc. The major advantages of OFDM are its ability to convert a frequency selective fading channel into several nearly flat fading channels and high spectral efficiency. The basic intention of OFDM is to provide resistance against frequency-selectivity of the channel for wideband data transmission. This is implemented by splitting up the entire spectrum into number of subcarriers which are narrow-banded with respect to the coherence bandwidth of the channel and is orthogonal to each other. But mobility and/or the mismatch of the local oscillators of the transmitter and the receiver can cause Doppler frequency shift in the transmitted signal. This results in the well documented phenomena of frequency offset errors in OFDM systems. Due to this, the orthogonality of the subcarriers is no longer maintained that results in inter-carrier interference (ICI). Many methods have been proposed to mitigate the frequency-offset problem to cancel the ICI for OFDM system. Most of such methods use signal processing and coding techniques to reduce the sensitivity of the OFDM system to the frequency offset. The most common approach for ICI reduction in OFDM system is to estimate the frequency offset[1][2][3] first then correct it. However this method requires considerable computational complexity. An effective method to cancel ICI is self cancellation scheme [5]. ICI self-cancellation is a scheme that was introduced by Yuping Zhao and Sven-Gustav Haggman to combat and suppress ICI in OFDM. But the ICI self-cancellation reduce ICI at the price of lowering the transmission rate and reducing the bandwidth efficiency. This work investigates one of the efficient ICI cancellation method termed ICI self cancellation scheme and presents a new ICI self cancellation scheme called self cancellation scheme with correlative coding which provides better performance than the self cancellation scheme in terms of bit error rate.

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1.1 Intercarrier Interference

The main disadvantage of OFDM, is its susceptibility to small differences in frequency at the transmitter and receiver, normally referred to as frequency offset. This frequency offset is 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. Here, the frequency offset is modeled as a multiplicative factor introduced in the channel. The received signal is given by,

$$y(n)=x(n)\exp(j2n\varepsilon\pi/N)+w(n) \quad (1)$$

where ε is the normalized frequency offset, and is given by $\Delta fNts$. Δf is the frequency difference between the transmitted and received carrier frequencies and ts is the subcarrier symbol period. w(n) is the additive white gaussian noise introduced in the channel. The effect of this frequency offset on the received symbol can be understood by considering the received symbol Y(k) on the kth sub-carrier.

$$Y(k) = X(k)S(0) + \sum_{l=0, l\neq k}^{N-1} X(l)S(l-k) + n_k : k = 0,1,\ldots N-1 \quad (2)$$

N is the total number of subcarriers, X(k) is the transmitted symbol (M-ary phase-shift keying (M-PSK), for exam-

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ple) for the kth 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 interference causing signals transmitted on sub-carriers other than the kth sub-carrier. The complex coefficients are given by

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

The carrier-to-interference ratio (CIR) is defined as the ratio of the signal power to the power in the interference components. CIR serves as a good indication of signal quality. Assuming that the standard transmitted data has

$$CIR = \frac{|S(k)|^2}{\Sigma_{l=0}^{N-1},_{l\neq k} |S_(l-k)|^2} = \frac{|S(0)|^2}{\Sigma_{l=0}^{N-1} |S_(l)|^2}$$

$$CIR = \frac{|S(k)|^2}{\Sigma_{l=0}^{N-1},_{l\neq k} |S_(l-k)|^2} = \frac{|S(0)|^2}{\Sigma_{l=0}^{N-1} |S_(l)|^2} \quad (4)$$

2 SELF CANCELLATION SCHEME FOR OFDM

ICI self-cancellation is a scheme that was introduced by Yuping Zhao and Sven-Gustav Haggman to suppress ICI in OFDM. The main idea used in this scheme is to modulate the input data symbol onto a group of subcarriers with predefined coefficients such that the generated ICI signals within that group cancel each other, hence the name self cancellation.

2.1 Modulation in Self Cancellation Scheme

In the ICI self-cancellation scheme the transmitted signals are modulated 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

$$Y'(k) = X(k)S(0) + \sum^{N-2} X(l(S(l-k) - S(l+1-k)) + n_k \quad (5)$$

$$Y'(k+1) = X(k)S(0) + \sum_{l=0,l=even}^{N-2} X(l(S(l-k-1) - S(l-k)) + n_{k+1} \quad (6)$$

and the ICI coefficient S′ (l − k) is denoted as

$$S'(l-k) = S(l-k) - S(l+1-k) \quad (7)$$

For most of the l-k values it is seen that |S′ (l − k)| <<|S(l − k)|.

2.2 .Demodulation in Self Cancellation Scheme

The modulation introduces redundancy in the received signal since each pair of subcarriers transmit only one data symbol. To take the advantage of the redundancy introduced in the transmitter, the received signal at the (k + 1)th subcarrier, where k is even, is subtracted from the kth subcarrier. This can be expressed mathematically as

$$\begin{aligned} Y''(k) &= Y'(k) - Y'(k+1) \\ &= \sum_{l=0,l=even}^{N-2} X(l)(S(l-k-1) \\ &\quad +2S(l-k) - S(l-k+1)) + n_k - n_{k+1} \end{aligned} \quad (8)$$

The ICI coefficients for this received signal becomes

$$S''(l-k) = -S(l-k-1) + 2S(l-k) - S(l-k+1) \quad (9)$$

|S′′ (l–k)| has the smallest ICI coefficients, for the majority of l–k values 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. This combined modulation and demodulation method is called the ICI self cancellation scheme. The reduction of the ICI signal levels in the ICI self cancellation method leads to a higher CIR. The theoretical CIR can be derived as

$$CIR = \frac{|-S(-1) + 2S(0) - S(1)|^2}{\Sigma_{l=2,4,6,\ldots}^{N-2} |-S(l-1) + 2S(l) - S(l+1)|^2} \quad (10)$$

The carrier to interference ratio is greatly improved using the ICI self-cancellation method. For $0 < \varepsilon < 0.5$ the improvement can be greater than 15 dB. The redundancy in the self cancellation scheme reduces the bandwidth efficiency by half. This problem could be compensated by transmitting signals of larger alphabet size.

3 PROPOSED SCHEME: SELF CANCELLATION SCHEME WITH CORRELATIVE CODING FOR OFDM

We introduce correlative coding [4] into the self cancellation scheme. Correlative coding is a simple solution to ICI problems, and makes OFDM systems less sensitive to frequency errors. In addition, system bandwidth efficiency will not be reduced by introducing correlative coding into the system.

A simplified block diagram of the proposed binary phase shift keying (BPSK)-OFDM system using correlative coding and self cancellation scheme is shown in Fig. 1. The proposed scheme considers the use of frequency-domain correlative coding with correlation polynomial F(D) = 1-D in OFDM mobile communication systems to compress the intercarrier interference caused by channel frequency errors. Here ”D” denotes the unit delay of the subcarrier index and the proposed coding with correlation polynomial F(D)=1-D is performed as

$$b_k = a_k - a_{k-1} \quad (11)$$

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The coded symbols b_k , k E [0, N − 1] are modulated on subcarriers. The symbol b_k takes three possible values (-2,0,2) Equation (11) introduces correlation between the adjacent symbols (b_k , b_{k-1}), so the independence condition is no longer maintained. In order to avoid error propagation in the decoding procedure due to correlative coding, precoding (modulo 2) is performed before BPSK modulation, in a similar way to the duobinary signaling in single carrier communication systems. In the tramitting section after the coding procedure self cancelling modulation is performed. Then IFFT of the symbols is taken and transmitted through the channel.

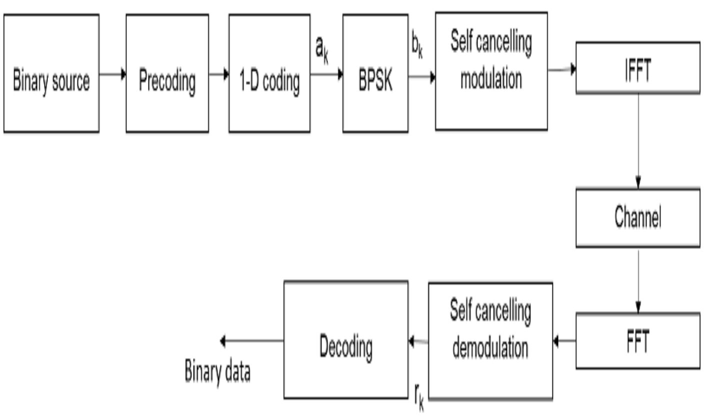

Fig1. Block diagram of the proposed scheme

In the receiver FFT of the received data is taken prior to self cancelling demodulation. After performing self cancelling demodulation, Binary decoder is used it decides "0" if $|r_k| \leq 1$and otherwise "1" where r_k represents the symbols obtained by performing self cancelling demodulation.

4 SIMULATION RESULTS

4.1 Results for Self Cancellation Scheme

Figure 2 shows a comparison between ICI coefficients $|S''(l-k)|$, $|S'(l-k)|$ and $|S(l-k)|$ on a logarithmic scale. For most of the l-k values it is seen that $|S'(l-k)| << |S(l-k)|$. When compared to the two ICI coefficients $|S(l-k)|$ for the standard OFDM system and $|S'(l-k)|$for the ICI canceling modulation,ICI coefficient for the ICI canceling demodulation $|S''(l-k)|$ has the smallest value, for the majority of l-k values, followed by $|S'(l-k)|$ and $|S(l-k)|$. This is shown in figure 2, for 64 subcarriers and carrier frequency offset ε = 0.2. The carrier-to-interference ratio (CIR) is defined as the ratio of the signal power to the power in the interference components. It serves as a good indication of the signal quality. The reduction of the ICI signal levels in the ICI self-cancellation scheme leads to a higher CIR. Fgure 3 below shows the comparison of the theoretical CIR curve of the ICI self-cancellation scheme, calculated by (10), and the CIR of a standard OFDM system calculated (4).

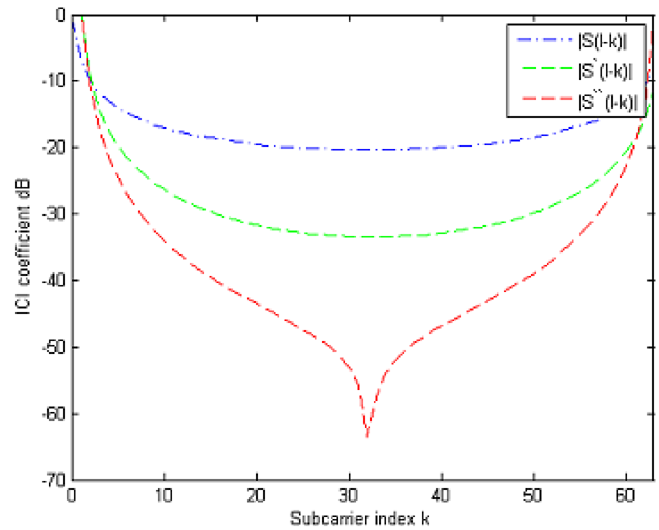

Fig. 2. Comparison of ICI coefficients for ε=0.2 and N=64

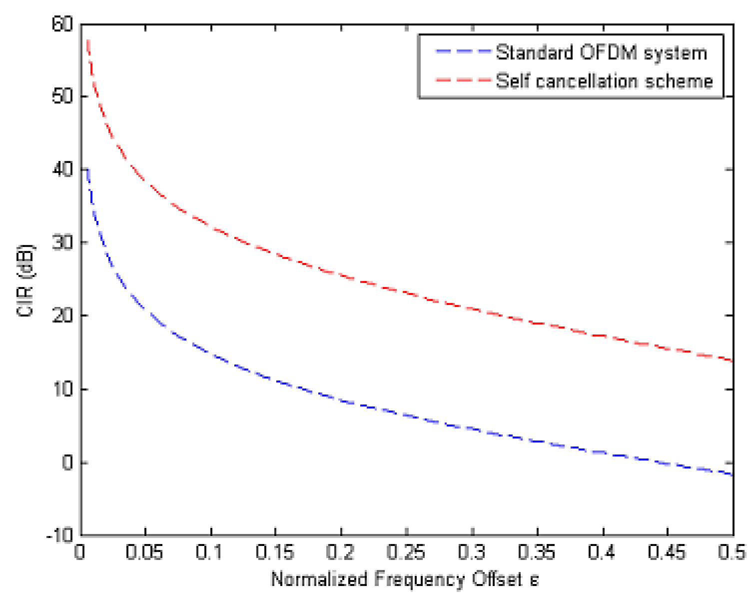

Fig.3. CIR comparison

The CIR is greatly improved using the ICI self-cancellation scheme.Simulation is performed to estimate the probability of error of the received signals when transmission occurs using OFDM. Simulation is performed for 64 subcarriers, BPSK modulation is used. The SNR of the channels is varied and the probability of error is estimated for each case of SNR in the AWGN channel and for a normalised frequency offset of 0.2. Figure 4 shows the BER curve obtained for the AWGN channel. As signal to noise ratio (SNR) in dB increases BPSK bit error rate (BER) curve leans downward which indicates reduction in bit error rate. BER curve is simulated for self cancellation scheme also and compared with the BER curve of standard OFDM. Self cancellation scheme provides much better performance than standard OFDM in AWGN channel.

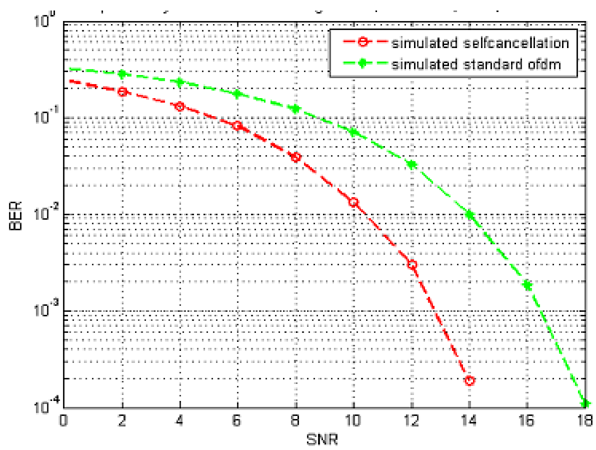

Fig.4. BER probability curve for BPSK using OFDM,NCFO=0.2,N=64,AWGN Channel

4.2 Results for Self Cancellation Scheme with correlative coding

BER performance is simulated for 64 subcarriers, BPSK modulation is used. The SNR of the channels is varied and the bit error rate is estimated for each case of SNR in the AWGN channel for a normalised frequency offset of 0.2. In figure 5 the black line shows the BER curve simulated for standard OFDM system ,red line represents the BER curve of self cancellation scheme, green line shows the BER curve of OFDM with correlative coding and magenta line shows the BER curve of self cancellation scheme with correlative coding. The best performance in terms of BER is obtained when correlative coding is combined with the self cancellation scheme. Compared to standard OFDM system the self cancellation scheme and OFDM system with correlative coding perform better.

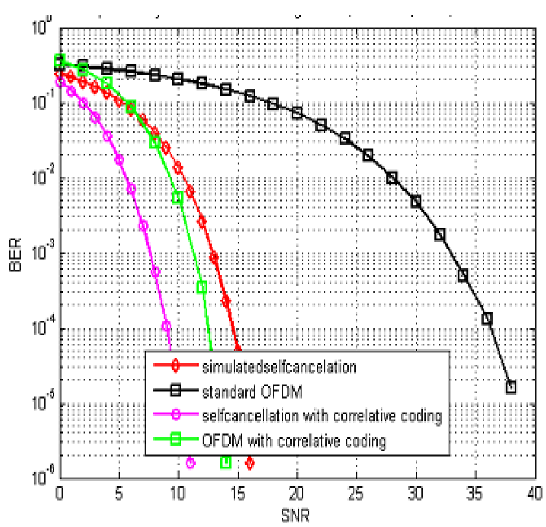

Fig.5. BER probability curve for BPSK using OFDM,NCFO=0.2, N=64,AWGN Channel

5. CONCLUSION

We have considered one of the efficient ICI reduction method called ICI Self cancellation scheme to reduce the effect of carrier frequency offset in OFDM systems. The ICI self cancellation scheme is simple way to suppress the ICI. This scheme provides much better performance than standard OFDM in terms of BER and CIR. Self-cancellation scheme reduce ICI at the price of lowering the bandwidth efficiency. This problem could be compensated by transmitting signals of larger alphabet size. We proposed a new method by introducing correlative coding to self cancellation scheme. When we compare these two methods in terms of BER performance, the self cancellation scheme with correlative coding performs better than Self cancellation scheme . So the effect of offset and ICI can be reduced efficiently by the method self cancellation with correlative coding.

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