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Inter Carrier Interference Cancellation in OFDM System

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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.
Keywords- **Carrier Interference Ratio, Inter Carrier Interference, Orthogonal Frequency Division Multiplexing**

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. Multi-carrier modulation is the concept of splitting a signal into a number of signals, modulating each of these new signals to several frequency channels, and combining the data received on the multiple channels at the receiver [2]. In OFDM, the multiple frequency channels, known as sub-carriers, are orthogonal to each other [3].

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 The orthogonality of the carriers is no longer maintained, which results in inter carrier interference [4]. 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.

II. SYSTEM DESCRIPTION

In an OFDM system, the input bit stream is multiplexed into N symbol streams, each with symbol period T_s and each symbol stream is used to modulate parallel, synchronous sub-carriers. The sub-carriers are spaced by 1 in frequency, thus they are orthogonal over the interval $(0, T_s)$. Fig 1 shows the block diagram of a typical OFDM system.

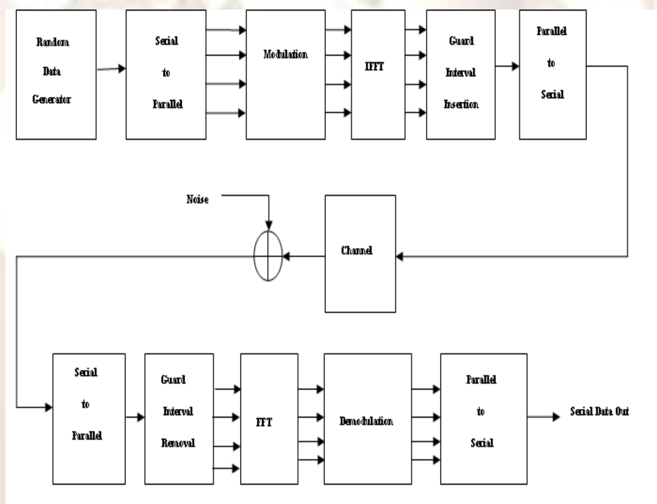


Fig.1. Block diagram of OFDM system

In OFDM system, the high data rate serial input bit stream is fed into serial to parallel converter to get low data rate output parallel bit stream. The low data rate parallel bit stream is modulated. Modulation is a process by which a carrier signal is altered according to information in a message signal. The modulated data are served as input to inverse fast Fourier transform so that each subcarrier is assigned with a specific frequency. The frequencies selected are orthogonal frequencies. As the modulated data is sent to an IFFT and are transformed and multiplexed to x(n).

$$x(n) = \frac{1}{N}\sum_{m=0}^{N-1} X_m e^{\frac{j2\pi nm}{N}} \qquad (1)$$

Where the X_m are the baseband symbols on each sub-carrier. At the receiver, the signal is converted back to a discrete N point sequence y(n), corresponding to each sub-carrier. This discrete signal is demodulated using an N-point fast Fourier transform (FFT) operation at the receiver. The demodulated symbol is given as

$$Y(m) = \sum_{n=0}^{N-1} y(n) e^{\frac{j2\pi nm}{N}} + W(m) \qquad (2)$$

$W(m)$ is the FFT of the samples of w(n). Because of the low data rate transmission, a narrowband signal sent at a high data rate through a multipath channel will experience greater negative effects of the multipath delay spread, because the symbols are much closer together [3]. Multipath distortion can also cause inter-symbol interference (ISI) where adjacent symbols overlap with each other. This is prevented in OFDM by the insertion of a cyclic prefix between successive OFDM symbols. This cyclic prefix is discarded at the receiver to cancel out ISI. It is due to the robustness of OFDM to ISI and multipath distortion.

III. ICI MECHANISM OF STANDARD OFDM SYSTEM

Frequency offset is main drawback of OFDM system that can be caused by Doppler shift [8] due to relative motion between the transmitter and receiver, or by differences between the frequencies of the local oscillators at the transmitter and receiver.

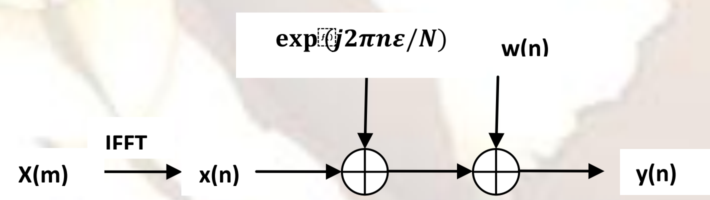


Fig.2. Frequency offset model

The received signal is given by

$$y(n) = x(n) e^{\frac{j2\pi n\varepsilon}{N}} + w(n) \qquad (3)$$

Where ε is the normalized frequency offset, and is given by $\Delta f N T_s$. 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.

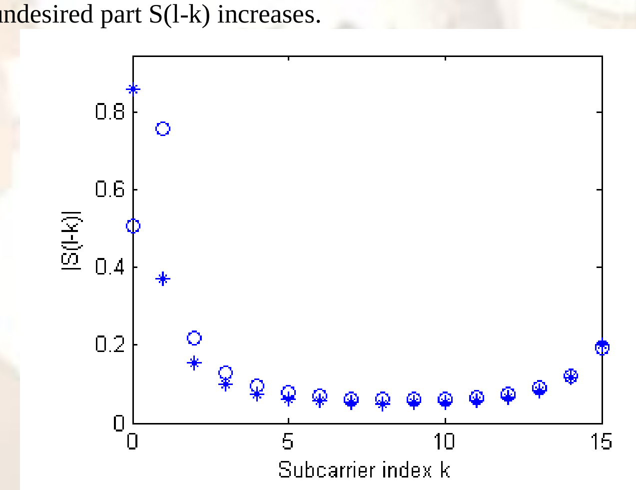
The effect of this frequency offset on the received symbol stream can be understood by considering the received symbol Y(k) on the *k*th sub-carrier.

$$Y(k) = X(k)S(0) + \sum_{l=0, l\neq k}^{N-1} X(l)S(l-k) + n_k$$
$$k = 0,1,2,\ldots N-1 \qquad (4)$$

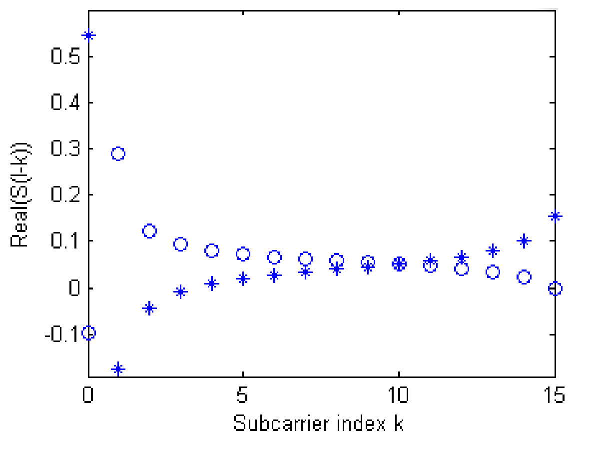
Where N is the total number of subcarriers, X(k) is the transmitted symbol for the *k*th subcarrier, n_k is the FFT of w(n), and S(l-k) are the complex coefficients for the ICI components in the received signal. The ICI components are the interfering signals transmitted on sub-carriers other than the *k*th sub-carrier. The first term is desired signal, with ε=0, S(0) has maximum value S(0)=1. The second term is ICI component. The complex coefficients are given as

$$S(l-k) = \frac{\sin(\pi(l+\varepsilon-k))}{N\sin(\pi(l+\varepsilon-k)/N)} e^{(j\pi\left(1-\frac{1}{N}\right)(l+\varepsilon-k))} \qquad (5)$$

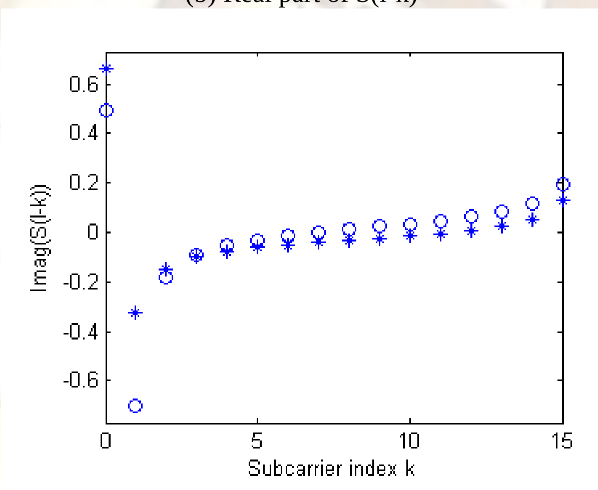
The Fig 3 shows the plots for S(l-k) when N=16, *l*=0 and frequency offset 0.3 and 0.6. This is clear that as the frequency offset becomes large, the desired part S(0) decreases and undesired part S(l-k) increases.



(a) Amplitude of S(l-k)



(b) Real part of S(l-k)



(c) Imaginary part of S(l-k)

Fig.3. ICI coefficients for N=16

The carrier to interference ratio is ratio of signal power to the power in the interference components. The CIR [5] expression for subcarrier 0<k<N-1 can be expressed as [6], [7].

$$CIR = \frac{|S(k)|^2}{\sum_{l=0,l\neq k}^{N-1} |S(l-k)|^2} = \frac{|S(0)|^2}{\sum_{l=1}^{N-1} |S(l)|^2} \qquad (6)$$

IV. ICI CANCELLING MODULATION

The inter carrier interference (ICI) cannot be reduced until the ε value is reduced. This can be done by increasing the subcarriers separation but the time domain symbol length will be reduced and the guard interval will take a large portion of useful signal resulting in reduction of bandwidth efficiency. For majority of *l-k* values, the difference of ICI coefficient between two consecutive subcarrier {(S (*l-k*) and S(*l*+1-*k*)} is very small. Therefore, if a data pair (a, -a) is modulated onto two adjacent subcarriers (*l* , *l*+1), where a is a complex data, then the ICI signals generated by the subcarrier *l* will be cancelled out significantly by the ICI generated by subcarrier *l*+1 . Assuming the transmitted symbols are such that $X(1) = -X(0), X(3) = -X(2) \ldots X(N-1) = -X(N-2)$, then the received signal on subcarrier *k* becomes

$$Y'(k) = \sum_{l=0}^{N-1} X(l)S(l-k) + n_k \qquad (7)$$

$$Y'(k) = X(0)S(0-k) - X(1)S(1-k) + \cdots + n_k \qquad (8)$$

$$Y'(k) = \sum_{\substack{l=0 \\ l=even}}^{N-2} X(l)[S(l-k) - S(l+1-k)] + n_k \qquad (9)$$

Similarly the received signal on subcarrier *k*+1 becomes

$$Y'(k+1) = \sum_{\substack{l=0 \\ l=evan}}^{N-2} X(l)[S(l-k-1) - S(l-k)] + n_{k+1} \qquad (10)$$

In such a case, the ICI coefficient is denoted as

$$S'(l-k) = S(l-k) - S(l+1-k) \qquad (11)$$

The comparison between $|S(l-k)|$ and $|S'(l-k)|$ on logarithmic scale is shown in fig 4. It is found that $|S'(l-k\ll|S(l-k)|$ for most of l-k values. The total no. of interference signals are halved because only the even subcarriers are involved in the summation.

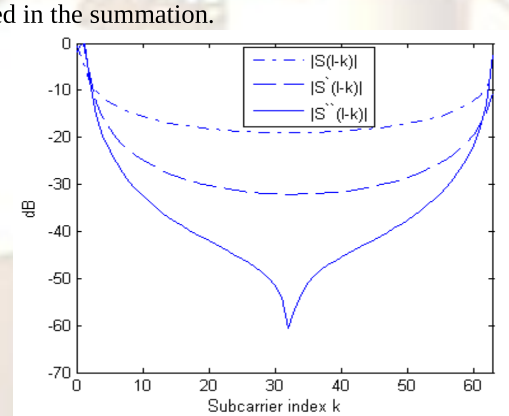


Fig.4. Comparison of $|S(l-k)|$,$|S'(l-k)|$ and $|S''(l-k)|$

V. ICI CANCELLING DEMODULATION

ICI modulation introduces redundancy in the received signal since each pair of subcarriers transmit only one data symbol. To take advantage of this redundancy, the received signal at the *(k + 1)*th subcarrier, where k is even and is subtracted from the *k*th subcarrier. This is expressed mathematically as

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

$$Y''(k) = \sum_{\substack{l=0 \\ l=even}}^{N-2} X(l)[-S(l-k-1) + 2S(l-k) - S(l-k+1)] + n_k - n_{k+1} \qquad (13)$$

The ICI coefficients for this received signal becomes

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

Fig 4 shows the amplitude comparison of $|S(l-k)|$,$|S'(l-k)|$ and $|S''(l-k)|$.For majority of *l-k* values, $|S''(l-k)| \ll |S'(l-k)| \ll |S(l-k)|$.The ICI is reduced by applying ICI cancelling modulation. ICI cancelling demodulation can reduce residual ICI in the received signals. This combined ICI cancelling modulation and demodulation method is called the ICI self cancellation scheme. Using ICI coefficients given by (14), the theoretical CIR expression is given as

$$CIR = \frac{|-S(-1)+2S(0)-S(1)|^2}{\sum_{i=2,4,6..}^{N-1} |-S(l-1)+2S(l)-S(l+1)|^2} \quad (15)$$

Fig 5 shows the CIR that is greatly improved by ICI cancellation scheme.

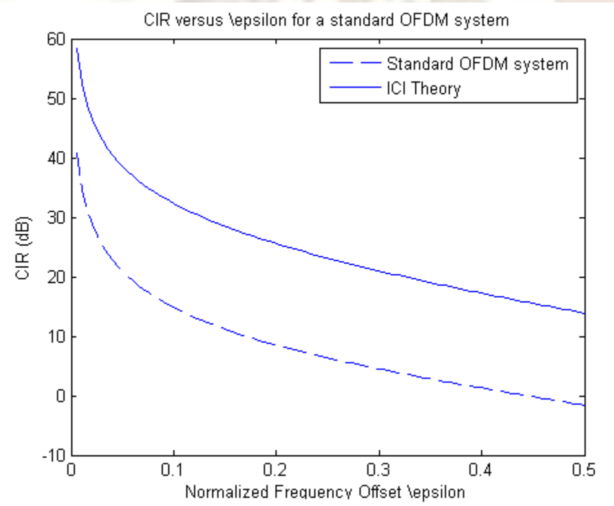


Fig.5. CIR vs. ε for standard OFDM system

VI. CONCLUSION

The main disadvantages of OFDM is its sensitivity against carrier frequency offset which causes inter carrier interference (ICI).The undesired ICI degrades the signal heavily and hence degrades the performance of the system. This paper investigates an ICI self cancellation scheme for combating the impact of ICI on OFDM systems for different frequency offset values. This scheme also provides significant CIR improvement and is easy to implement without increasing system complexity.

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