MINIMIZATION OF INTER CARRIER INTERFERENCE IN OFDM SYSTEMS

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Abstract: In the area of wireless communications, the demand for high data rate transmission is rapidly increasing. Orthogonal frequency division multiplexing (OFDM) has proved to be a promising technique for the demand in rise of high data rate transmission however the loss of orthogonality between the various sub carriers in OFDM has proved to have a detrimental effect over the Signal to Noise Ratio (SNR) this loss of orthogonality between various sub carriers resulting from the frequency offset at the trans-receiver ends is addressed using self –cancellation technique. In this paper a self-cancellation technique is proposed for OFDM systems without compromising the band width efficiency and transmission rate.

Index Terms: ICI, SC, BER, OFDM.

OFDM, being a multi-carrier modulation technique involves splitting a signal into a number of sub-signals, modulating each of these sub-signals to several frequency channels known as sub-carriers which happen to be orthogonal to each other and combining the data received on the multiple channels at the receiver [1]

A well-known problem of OFDM, however, is its 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 carrier frequency offset causes loss of orthogonality between sub-carriers and the signals transmitted on each carrier are not independent of each other, leading to inter-carrier interference (ICI) [2]. In this context various methods to combat the ICI in OFDM systems are proposed. The existing approaches that have been developed to reduce ICI can be categorized as frequency-domain equalization [3,4], time-domain windowing [5], and the ICI self-cancellation (SC) scheme [6].

In this paper, the effects of ICI have been analyzed and a solution to combat ICI has been presented. Using self-cancellation scheme, in which redundant data is transmitted onto adjacent sub-carriers such that the ICI between adjacent sub-carriers cancels out at the receiver.

OFDM SYSTEM DESCRIPTION

Considering an OFDM system, with the input bit stream multiplexed into N symbol streams, each with symbol period T, and each symbol stream is used to modulate parallel, synchronous sub-carriers [7]. The sub-carriers are spaced by 1 in frequency, thus they are orthogonal over the interval (0, Ts). First, a serial-to-parallel (S/P) converter groups the stream of input bits from the source encoder into groups of $\log_2 M$ bits, where M is the alphabet of size of the digital modulation scheme employed on each sub-carrier. A total of N such symbols, X_m, are created. Then, the N symbols are mapped to bins of an inverse fast Fourier transform (IFFT). These IFFT bins correspond to the orthogonal sub-carriers in the OFDM symbol. Therefore, the OFDM symbol can be expressed as

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

Where the X_m's are the baseband symbols on each sub-carrier, N is the no. of sub-carriers mapping the input stream into groups of $\log_2 m$ where m is the size of each symbol. A typical OFDM system is shown below.

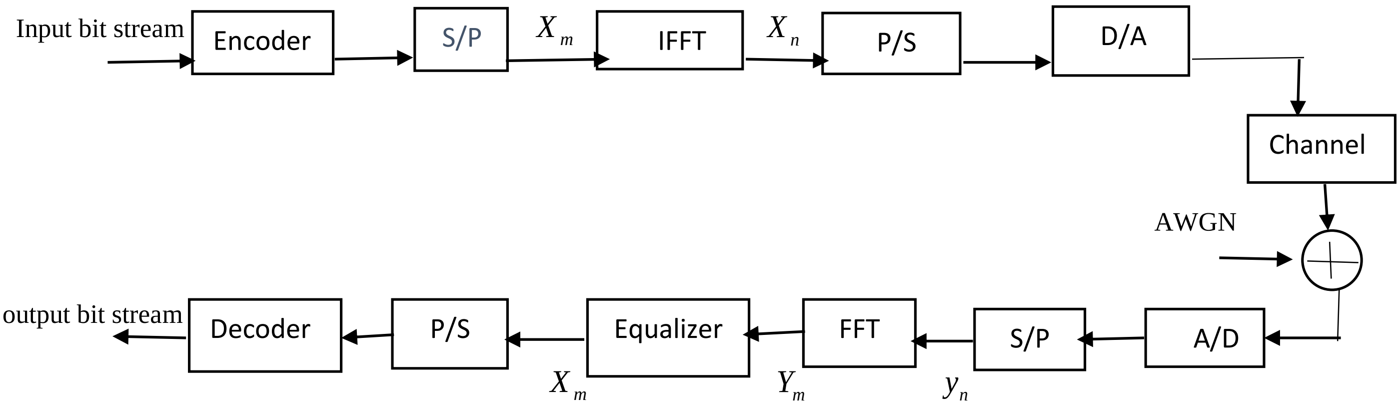

Figure1: Baseband OFDM transceiver system

At the receiver end, the discrete signal is demodulated using an N-point fast Fourier transform (FFT) operation. The demodulated symbol stream is given by:

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

Where, W(m) corresponds to the FFT of the samples of w(n), which is the Additive White Gaussian Noise (AWGN) introduced in the channel.

ANALYSIS OF INTER-CARRIER INTERFERENCE

The relative motion between the transmitter and receiver or the differences between the frequencies of the local oscillators at the transmitter and receiver results in frequency offset which in turn manifests as inter carrier interference. In this paper, the frequency offset is modeled as a multiplicative factor introduced in the channel, as shown in Figure 2

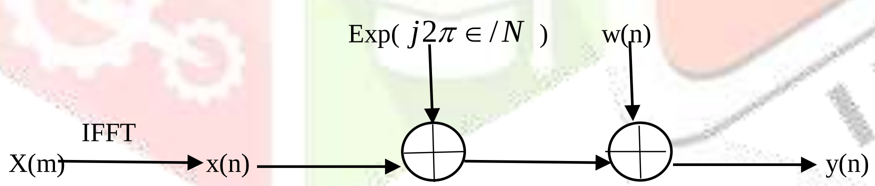

Figure2: Frequency Offset Model

The received signal is given by,

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

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.

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

where N is the total number of subcarriers, X(k) is the transmitted symbol for the k^{th} subcarrier, 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

$$S(\mathrm{l}-\mathrm{k}) = \frac{\sin(\pi(\mathrm{l}+\in-k))}{N\sin(\pi(\mathrm{l}+\in-k)/N)}\exp(\mathrm{j}\,\pi(1-\frac{1}{N})(\mathrm{l}+\in-k)) \tag{5}$$

ICI SELF-CANCELLATION SCHEME

self-cancellation scheme assumes predefined coefficients for the input data symbols mapped onto a group of subcarriers such that the generated ICI signals within that group cancel each other, hence the name self- cancellation.

ICI Canceling Modulation

The ICI self-cancellation scheme requires that the transmitted signals be constrained such that $X(1) = -\mathrm{X}(0), \mathrm{X}(3) = -\mathrm{X}(2), ..., \mathrm{X}(\mathrm{N}-1) = -\mathrm{X}(\mathrm{N}-2).$ Using (5), this assignment of transmitted symbols allows the received signal on subcarriers k and k + 1 to be written as

$$Y'(k) = \sum_{l=0,l=even}^{N-1} X(l)[S(l-k) - S(l+1-k)] + n_k \tag{6}$$

$$Y'(k+1) = \sum_{l=0,l=even}^{N-2} X(l)[S(l-k-1) - S(l-k)] + n_{k+1} \tag{7}$$

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

$$S'(l-k) = S(\mathrm{l}-\mathrm{k}) - \mathrm{S}(\mathrm{l}+1-\mathrm{k}) \tag{8}$$

ICI Canceling Demodulation:

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

$$Y''(\mathrm{k}) = \mathrm{Y'(k)} - \mathrm{Y'(k+1)}$$

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

Subsequently, the ICI coefficients for this received signal becomes

$$S''(\mathrm{l}-\mathrm{k}) = -\mathrm{S}(\mathrm{l}-\mathrm{k}-1) + 2\mathrm{S}(\mathrm{l}-\mathrm{k}) - \mathrm{S}(\mathrm{l}-\mathrm{k}+1) \tag{10}$$

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.

From (10), the theoretical CIR can be derived as

$$CIR = \frac{|-S(-1)+2S(0)-S(1)|^2}{\sum_{l=2,4,6,...}^{N-1} |-S(l-1)+2S(l)-S(l+1)|^2} \tag{11}$$

Figure 3 below shows the comparison of the theoretical CIR curve of the ICI self-cancellation scheme, calculated by (11), and the CIR of a standard OFDM system calculated by (5). As expected, the CIR is greatly improved using the ICI self-cancellation scheme. The improvement can be greater than 15 dB for $0 < \varepsilon < 0.5$.

As mentioned above, 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.

Conclusion: BER curves for the considered OFDM system is evaluated for different frequency offsets by considering the self-cancellation scheme it was found that the BER has come down by a factor of 10^{-3}

Results:

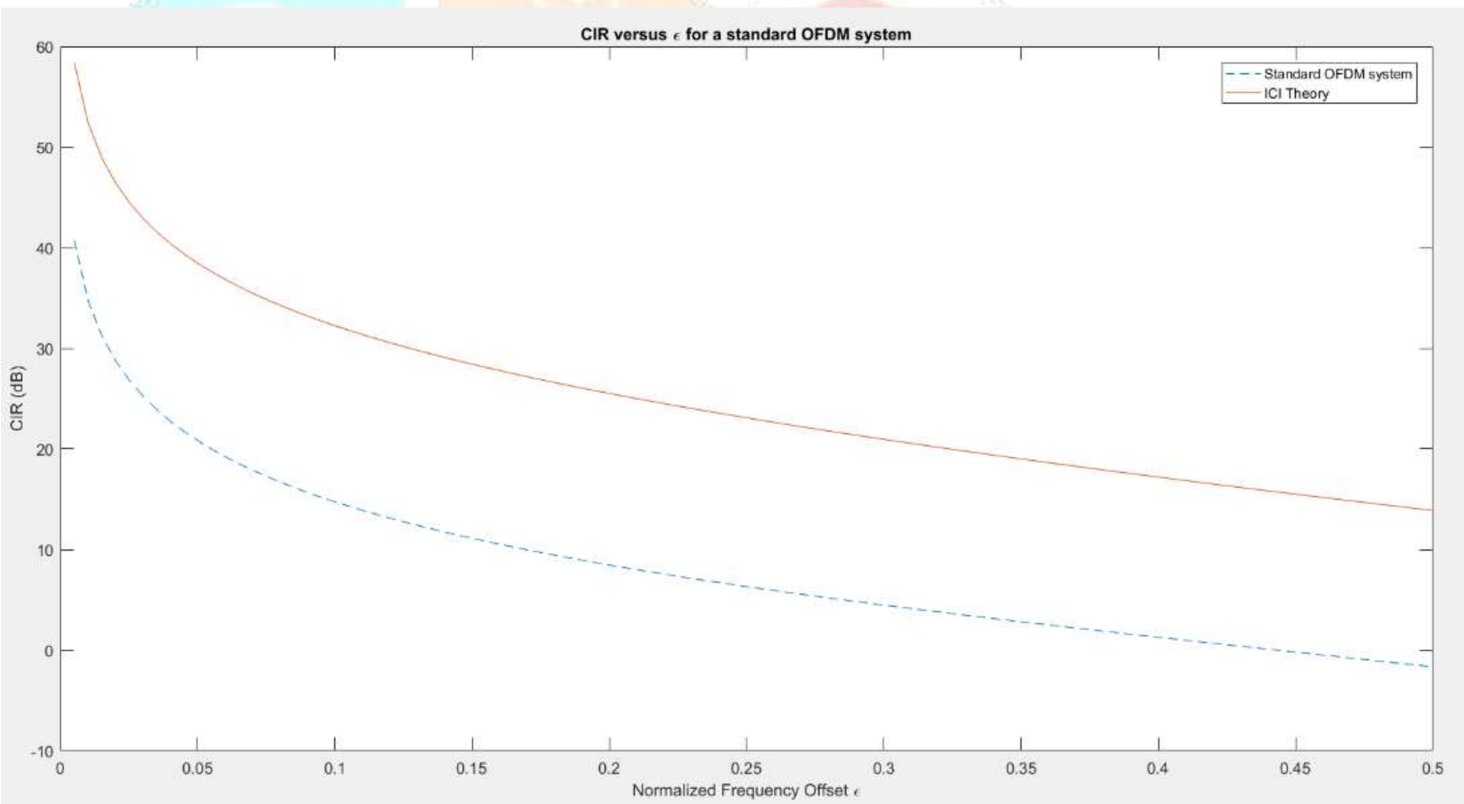

Figure 3: CIR versus $\in$ for a standard OFDM system

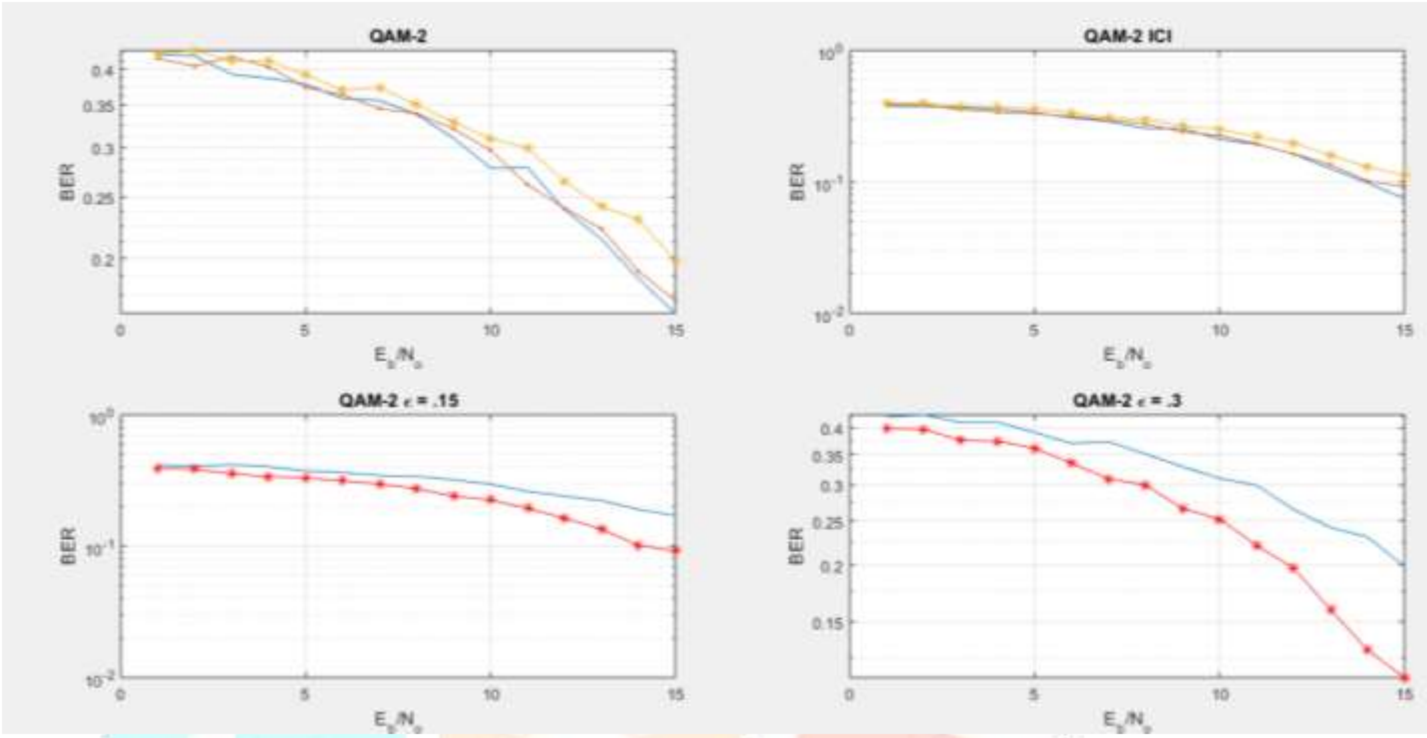

Figure 4: BER vs Eb/N0 plots for QAM-2 : (a)without self cancellation, (b)with self cancellation, (c) for epsilon=0.15, (d) for epsilon=0.3

9. REFERENCES

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