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REDUCTION OF INTER-CARRIER INTERFERENCE IN ORTHOGONAL FREQUENCY DIVISION MULTIPLEXING SYSTEM USING ICI SELF CANCELLATION METHOD

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ABSTRACT: Orthogonal Frequency Division Multiplexing (OFDM) is known to be a multicarrier digital communication scheme which helps in addressing problems of interference which are the Inter-carrier Interference (ICI) and Inter-symbol Interference (ISI). OFDM gather large number of low data rate carrier to build a complex high data rate communication system. OFDM is a technique for transmitting data in parallel by the usage of large number of modulated subcarriers and the said subcarriers are separated in frequency after dividing the available bandwidth so that they are orthogonal. OFDM problem is that it is sensitive to frequency offset caused by the relative motion which occurs between the transmitter and the receiver (Doppler shift) which introduces Inter-carrier Interference (loss of orthogonality between sub-carriers) in the OFDM symbol and the use of ICI Self cancellation method will help to reduce the ICI which has been analyzed in this paper and the MATLAB simulation was carried out on the receiver and its transmitter in terms of carrier-to-interference ratio (CIR).

KEYWORDS: Inter-carrier Interference (ICI), Orthogonal Frequency Division Multiplexing (OFDM), ICI self cancellation method.

1 INTRODUCTION

There is need for higher data rate services such as voice and data over wired and wireless lines due to the advancement of communication technology. Multipath propagation problems such as delay spread, Doppler spread and Signal fading affects the system and causes interference in the system [7], [9], [11]. OFDM problem is that it is sensitive to frequency offset caused by the relative motion which occurs between the transmitter and the receiver and this frequency offset predominates loss of orthogonality between the sub-carriers and the signal which is transmitted on each carrier are not independent on each other leading to ICI [4]. The idea of OFDM is the usage of parallel data and FDM with overlapping sub-channels and to achieve this technique, there is need for reduction of cross talk between sub-carriers which implies the orthogonality between the different modulated carriers is desired [2]. The OFDM overlapping method predominates a better spectral efficiency than the remaining system types like the Frequency Division Multiple Access (FDMA) where spectral overlap of carriers is prohibited and the modulator with the demodulator implementation using FFT algorithm on the receiver side and the inverse FFT on the sender side in OFDM system is possible due to the orthogonality which exist between the subcarriers. OFDM being a form of multicarrier modulation scheme helps to eliminate the use of complex equalizer, meet high data rate, withstand severe channel condition and changes a frequency selective wideband channels into a group of non-selective narrowband channel which in turn makes it robust against large delay spread by maintaining its orthogonality in the frequency domain [3], [5], [8].

2 DESCRIPTION OF OFDM SYSTEM

The input bit stream is multiplexed into N-symbol stream and each has a symbol period T_s, each symbol stream is then used in modulating parallel sub-carriers [10]. The subcarriers are orthogonal over the interval (0, T_s) hence they are spaced by $1/NT_s$ in frequency.

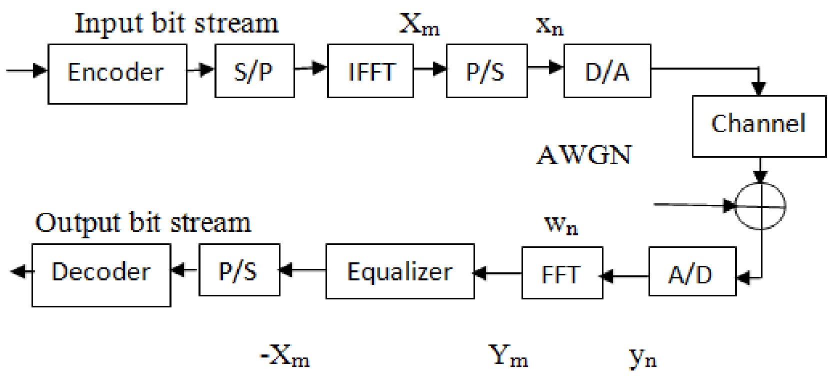

Fig. 1. OFDM Baseband Transeiver.

OFDM symbol is expressed as: $x(n) = \frac{1}{N}\sum_{m=0}^{N-1} \mathrm{Xm}\,e^{\frac{j2\pi nm}{N}}$ (1)

X_m's are baseband symbols on each subcarrier while the digital-to-analogue (D/A) converter creates an analogue time-domain signal which is transmitted through the channel.

From figure 1, a serial-to-parallel (S/P) converter divides the stream of input bits into groups from the source encoder into categories of Log_2M bits whereby the M stands for alphabet of size of the modulation scheme (digital modulation) used on each sub-carrier. The total of such N symbols X_m are created and the N symbols are thus mapped to the bins of Inverse FFT which corresponds to the orthogonized sub-carriers which is in the Orthogonal Frequency Division Multiplexing (OFDM) symbol. The signal is then converted back to a discrete N point sequence $y_{(n)}$ at d receiver corresponding to each sub-carrier. The discrete signal is then demodulated using an N-point FFT operation at the receiver and the demodulated symbol stream is given as: $Y(m) = \sum_{n=0}^{N-1} y(n)\, e^{\frac{-j2\pi nm}{N}} + W(m)$ (2)

W(m) is the FFT of the samples of w(n) which is the Additive White Gaussian Noise (AWGN)) brought into the channel.

3 Inter-Carrier Interference Analysis

The vulnerability to small difference in frequency at the transmitter and the receiver is called "Frequency Offset" which is usually caused by Doppler shift due to the relative motion which exist between the system transmitter and the system receiver or by differences between the frequency of the local oscillators at the transmitter and receiver. Frequency offset is been modeled as a multiplicative factor brought in the channel.

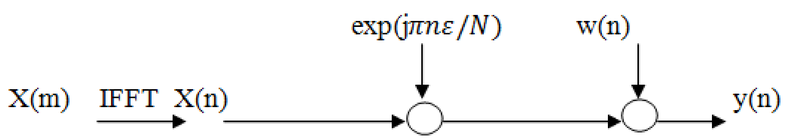

Fig. 2: Frequency Offset Model.

The received signal is given by,

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

w(n) is referred to as the Additive White Gaussian Noise introduced into the channel, ε is the normalized frequency which is stated as ΔFNT_s, ΔF is the frequency difference, T_s is the sub-carrier symbol period and N is the total number of sub-carrier. The frequency offset effect on the signal stream received can be understood by putting into consideration the received symbol Y(k) on the K^{th}sub-carrier

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

K = 0,1,…N-1

n_k is the FFT of w(n), X(k) is the transmitted symbol for the K^{th}sub-carrier, N is the total number of sub-carrier and S(*l*-k) are the complex co-efficient for the Inter-carrier Interference components in the signal received. The first term on the right hand side of equation (4) represent the desired signal and the second term is the ICI component. The interfering signal transmitted on the sub-carriers other than the K^{th} sub-carrier are called the ICI components and the complex co-efficient are given by:

$$S(l\text{-}k) = \frac{Sin(\pi(l+\varepsilon-k))}{NSin(\pi(l+\varepsilon-k)/N)} \exp\left(j\pi\left(1-\frac{1}{N}\right)(l+\varepsilon-k)\right) \qquad (5)$$

The plots for S (*l*-k) when *l* =0, frequency offset are 0.2 and 0.4 and when N=16 is shown in fig. 3 and it is seen that as the desired part S(0) decreases and the undesired part S (*l*-k) increases the frequency offset becomes large.

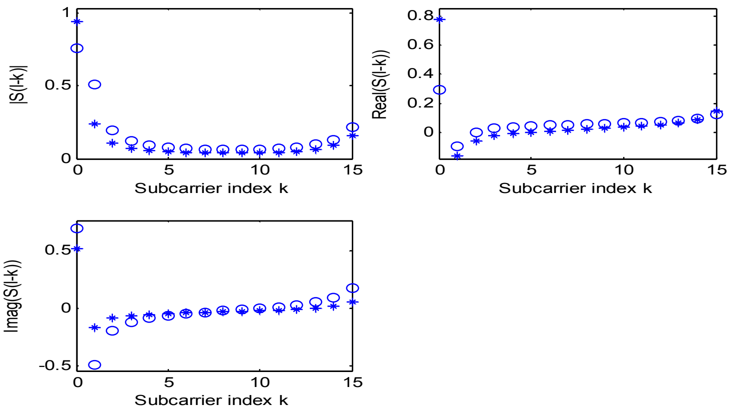

Fig. 3: ICI co-efficient for N=16.

The adjacent carrier has a maximum contribution to the Inter-carrier Interference thus, it is used in the ICI self cancellation method.

The carrier-to-interference ratio (CIR) is known as the ratio of the signal power in the interference component and it serves as a very good indication of quality signal. The CIR is derived from (4) in [1], [6] and it is given below:

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

3.1 ICI CANCELLING MODULATION

When ε is reduced then the ICI will equally reduce and this is achieved by increasing the sub-carriers separation, reducing the time domain symbol length and allowing guard interval take a big portion of useful signal which predominantly reduced bandwidth efficiency.

The difference of ICI co-efficient between two consecutive sub-carriers {S(*l*-k) and S(1+*l*-k)} is very minimal for majority of the *l*-k values. However, if a data pair (a, -a) is modulated onto two adjacent sub-carriers (*l*, *l* + 1) where "a" is a complex. The ICI signal obtained by the sub-carrier *l* will be nullified significantly by the ICI generated by sub-carrier *l* + 1. Assuming that the transmitted symbols are given as X(1) = -X(0), X(3) = -X(2)…X(N-1) = -X(N-2), then the received signal on sub-carrier K becomes:

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

Also, the received signal on sub-carrier K + 1 becomes:

$$Y'(K+1) = \sum_{l=0,l=even}^{N-2} X(l)[S(l-k) - S(l+1-K)] + n_k + 1 \qquad (8)$$

In that case, the ICI co-efficient is denoted by:

$S'(l-k) = S(l-k) - S(l+1-k)$ and it is found that $S'(l-k) << S(l\text{-}k)$ (9)

Only even sub-carriers are involved in the summation and that makes the total number of interference to be halved.

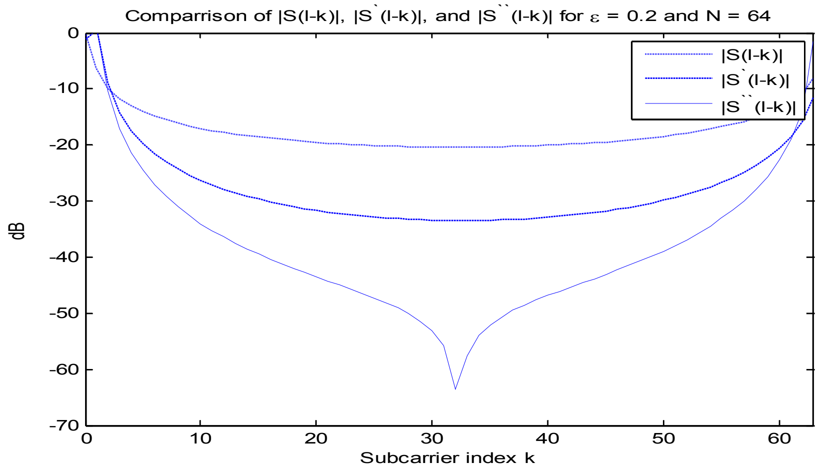

Fig. 4: Comparison of $|S(l-k)|, |S'(l-k)|$ and $|S''(l-k)|$.

3.2 ICI CANCELLING DEMODULATION

The received signal experience redundancy which is introduced by ICI modulation since each pair of sub-carrier transmit only one data symbol. Therefore, the received signal at the (k + 1)th subcarrier, where k is even and it is subtracted from the K^{th}sub-carrier so as to take advantage of the redundancy and it is expressed mathematically as:

$$Y''(k) = Y'(k) - Y'(k + 1) \tag{10}$$

$$Y''(k)=\sum_{l=0,l=even}^{N-2} X(l)[-S(l-K-1)+\ 2S(l-K)-S(l-K+1)] + n_k - n_k + 1 \tag{11}$$

Therefore, ICI co-efficient for this received signal becomes:

$$S''(l\text{-}k) = -S(l\text{-}k+1) + 2S(l\text{-}k) - S(l\text{-}k+1) \tag{12}$$

When compared to the two ICI co-efficient that was earlier shown in fig. 4 which are: $|S(l-k)|$ for the standard Orthogonal Frequency Division Modulation system, $|S'(l-k)|$ for the Inter-carrier Interference cancelling modulation and $|S''(l-k)|$ which has the smallest Inter-carrier Interference co-efficient for the majority of the l-k value preceded by the $|S'(l-k)|$ and $|S(l-k)|$.

The combination of these modulation and demodulation process is referred to as the ICI Self-cancellation scheme and using the ICI co-efficient given by (12), the theoretical CIR expression is given as:

$$CIR = \frac{|-S(-1)+\ 2S(0)-\ S(1)|2}{\sum_{l=2,4,6...}^{N-1} |-S(l-1)+\ 2S(l)-\ S(l+1)|2} \tag{13}$$

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

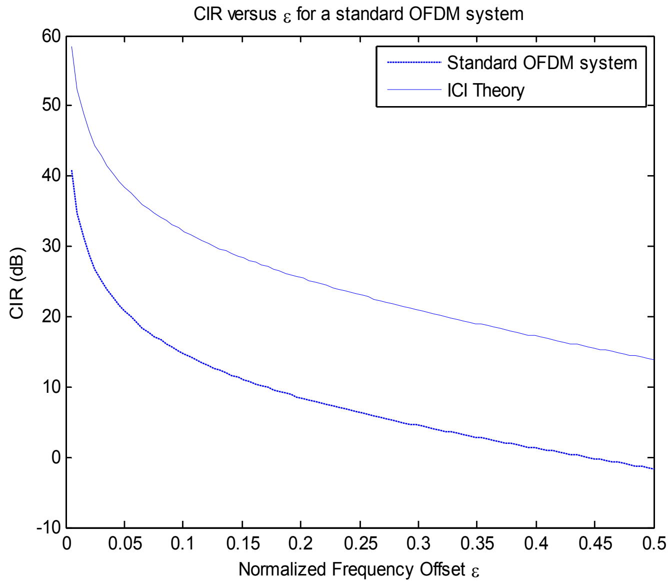

Fig. 5: CIR against ε for standard OFDM system.

4 Conclusion

In this paper, the performance of OFDM system was studied when frequency offset is present between the transmitter and the receiver and the study was accomplished in terms of Carrier-to-Interference Ratio performance. The frequency offset which gives rise to ICI degrades the performance of the OFDM system. ICI self-cancellation scheme was used in combating the impact of ICI on OFDM system for different frequency offset value, the scheme doesn't require complex hardware or software for implementation and the scheme also provides significant CIR improvement.

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