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A Survey Paper on Inter-carrier Interference Reduction Techniques in OFDM Systems

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Abstract—Orthogonal Frequency Division Multiplexing (OFDM) is a multicarrier modulation technique that divides the available spectrum into many carriers. The efficient use of the spectrum makes it more suitable for transmitting high speed data candidate. However, the main drawback is its sensitivity to CFO causing Inter Carrier Interference (ICI). The Orthogonal Frequency Division Multiplexing systems (OFDM) suffering from interference between carriers in mobile environment due to loss of orthogonality between subcarriers caused by Doppler shifts. Many ICI Reduction techniques in this paper, to improve the performance of OFDM systems. This ICI causes severe degradation of the bit error rate (BER) of OFDM receiver. There are numerous techniques for reducing ICI windows, including time domain, frequency domain equalization, matrix technique and ICI self-cancellation.

Keywords—Bit error Rate (BER); Additive white Gaussian noise (AWGN); Inter carrier interference (ICI); carrier frequency offset (CFO); orthogonal frequency division multiplexing (OFDM)

I. INTRODUCTION

The growing demand for high speed wireless data transmission requires technologies that make use of electromagnetic resource smarter available. The main objectives are spectrum efficiency (bits per second per Hertz), robustness against the multipath, range, power consumption, and complexity of implementation. The Internet revolution has created the need for wireless technologies that can deliver data at high speeds spectrally efficient manner. However, support for such high data rates with sufficient robustness to radio channel impairments requires careful selection of modulation techniques. Currently, the best option seems to be OFDM (Orthogonal Frequency Division Multiplexing) .Orthogonal frequency division multiplexing (OFDM) is becoming the chosen modulation technique for wireless communications.

OFDM with high capacity transmission has been applied in many digital transmission systems such as digital transmission system audio (DAB), digital video broadcast system terrestrial TV (DVB-T), asymmetric digital subscriber line (ADSL), IEEE 802.11a/g, wireless local area network (WLAN), IEEE 802.16, Worldwide Interoperability for Microwave Access (WiMAX) systems, and ultra wideband (UWB) [1]. There are two major problems in OFDM named peak average power ratio (PAPR) and inter carrier interference (ICI). This paper considers a problem of Inter Carrier Interference. OFDM communications systems require accurate frequency synchronization because of otherwise produce ICI [2]. The major cause ICI is due to a synchronization error and Doppler Effect. There are numerous methods to reduce the effect of ICI called: windows time domain, the frequency domain equalization, the frequency offset estimation and ICI Cancellation and method of self-cancellation [9-10]. Among them, the simplest is ICI self-cancellation. There are two ways to convert self-cancellation and data conjugate method data. In this paper ICI cancellation using matrix and self cancellation based on data conversion and conjugate method is discussed. Moreover, the BER performances of data conversion method and data method combining the original OFDM with or without convolution coding are compared with each other. The rest of the article describes as: section II basics and model of OFDM system and the problem OFDM ICI described. In section III ICI cancellation techniques are introduced. Next section describe conclusion.

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II. BASICS MODEL OF OFDM SYSTEM

A. Basics of OFDM

Orthogonal Frequency Division Multiplexing (OFDM) has become more popular systems of high-speed communications media. OFDM technology is the future of wireless communications. Orthogonal Frequency Division Multiplexing (OFDM) is a multicarrier transmission technique, which divides the bandwidth into many carriers, each being modulated by a data stream of low rate [15-16].

OFDM evolution can be divided into three sections [17]. There has Frequency Division Multiplexing (FDM), Communication Multicarrier (MC) and Orthogonal Frequency Division Multiplexing.

1) Frequency Division Multiplexing: Frequency Division Multiplexing (FDM) has been used for a long time to carry a signal over a telephone line. FDM is the concept of using different frequency channels to carry information of different users. Each channel is identified by the central transmission frequency.

2) Multicarrier Communication: The multicarrier communication concept (MC) uses a form of FDM technology but only from a single data source and one data receiver [18].

Actually, it is the concept of splitting a signal into a number of signals, modulation of each of these new signals through its own frequency channel, multiplexing these different frequency channels together in a way FDM; feeding the received signal through a receiving antenna feeding a demultiplexer different frequency channels to different receivers and combining the output data from the receivers to form the received signal.

3) Orthogonal Frequency Division Multiplexing: Orthogonal Frequency Division Multiplexing (OFDM) is simply defined as a form where the multicarrier demodulation carrier spacing is carefully selected so that each subcarrier is orthogonal to the other subcarriers. Orthogonality can be achieved by careful selection of the sub-carrier frequencies.

B. Model of OFDM System

In the OFDM communication system, inverse discrete Fourier (IDFT) is performed at the transmitter and Discrete Fourier Transform (DFT) is performed at the receiver. Figure 1 shows the basic model OFDM. On the transmitter side first high speed data becomes many low data using the conversion serial to parallel, then after modulating IDFT is performed and the OFDM symbols eventually become serial. Then the orthogonal symbols are transmitted through the wireless channel. Similarly at the receiving end of the data series is converted into parallel first FFT is then performed to obtain the data in the frequency domain. The output data obtained after demodulation and serial conversion [13-14]. In an OFDM communication system, assuming that the channel frequency offset normalized by the subcarrier separation is ε, then the received signal in the sub carrier k can be written as:

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

Whereas $k = 0,1,2........(N-1)$

N is the total number of subcarriers, $X(k)$ denotes the k_{th} transmitted to the subcarrier, and n_k is a sign symbol of additive noise. The first term on the right side of the equation (1) represents the desired signal [3]. The second term is the ICI components. The sequence $S(l-k)$ is defined as the ratio between subcarriers ICI k_{th} and l_{th} that can be expressed as:

$$S(l-k) = \frac{\sin\left(\pi(l+\varepsilon-k)\right)}{N\sin\left(\frac{\pi(l+\varepsilon-k)}{N}\right)} \exp^{\left(j\pi\left(1-\frac{1}{N}\right)(l+\varepsilon-k)\right)} \quad (2)$$

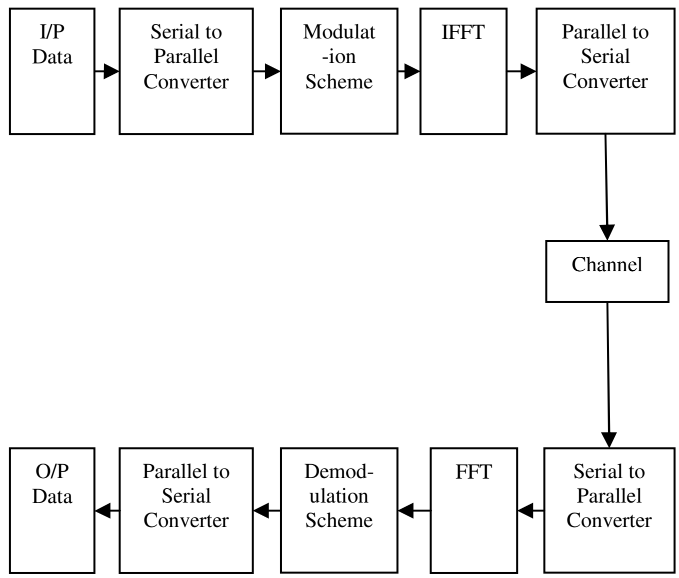

Fig. 1- Basic OFDM Model

Where $\varepsilon =$ normalized frequency offset, is given by, $\varepsilon = \partial F / \partial f$ is the offset frequency, ∂f is the system bandwidth OFDM subcarrier. It is reasonable to assume that $0 \leq \varepsilon < 1$. Now we denote vector $\vec{X}$ is the transmitted symbol $\vec{X} = \{X(0), X(1).....X(N-1)\}$, the vector $\vec{Y}$ is the received signal vector $\vec{Y} = \{Y(0), Y(1).....Y(N-1)\}$, and $\vec{n} = \{n_0, n_1, ...n_{N-1}\}$ we have:

$$\vec{Y} = \vec{X}\, S + \vec{n} \quad (3)$$

Where S=ICI coefficient matrix, p_{th}, q_{th} are row and column of $N \times N$ matrix of S. Than

$$S_{p,q} = S(p-q) \quad (4)$$

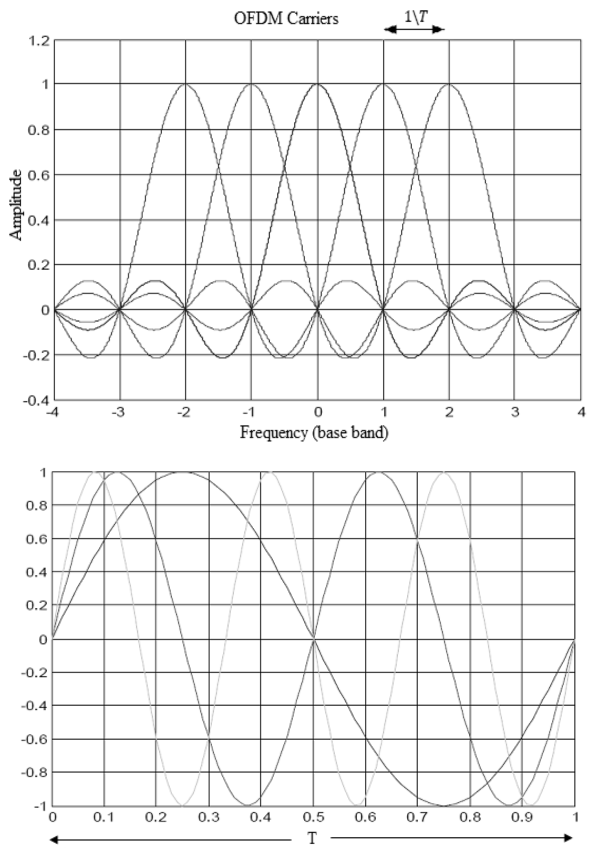

Fig. 2- Frequency spectrum and carrier signals in an OFDM transmission

III. ICI CANCELLATION TECHNIQUES

A. Frequency Domain Equalization

The fading distortion in the channel makes SI in the OFDM demodulator. ICI pattern varies from frame to frame to the data demodulator, but remains unchanged for all symbols within a frame of modulated data. Compensation for fading distortion in the time domain, introduces the problem of noise enhancement. Equalization process and frequency domain approaches to reduce ICI by using appropriate equalization techniques. You can only reduce the ICI caused by fading distortion is not the main source of ICI. The main source of ICI is due to frequency mismatch between the transmitter and receiver, and the Doppler shift.

B. Time Domain Windowing

We know that the OFDM signal is widely spread power spectrum. So if this signal is transmitted in a band limited channel, some portion of the signal spectrum is cut, leading to inter-carrier interference.

To reduce the interference spectrum of the waveform signal must be more concentrated. This is achieved by the window signal. Window is basically the process of multiplying the proper waveform function of the transmitted signal. The same window is used on the receiver side to recover the original signal.

You can only reduce the ICI caused by the band-limited channel that is not the main source of ICI. The main source of ICI is due to frequency mismatch between the transmitter and receiver, and the Doppler shift.

C. Matrix Technique

The ICI cancellation matrix technique, to remove all ICI in OFDM systems without transmitting any data rate reduction symbol. Than the matrix S is equal to

$$\begin{bmatrix} S(0) & S(-1) & ..... & S(1-N) \\ S(1) & S(0) & ..... & S(2-N) \\ ... & ... & ...... & ..... \\ S(N-1) & S(N-2) & & S(0) \end{bmatrix} \quad (5)$$

From equ. (3), the received signal can be viewed as a signal with N users, information symbol of k_{th} user is $X(k)$ and spreading code of the k_{th} user is the k_{th} column of matrix S. However, it is important that the ICI coefficient matrix S is an orthogonal matrix, than

$$SS^{'*} = I \quad (6)$$

Where I= identity matrix and $S^{'*}$ = conjugate transpose matrix of S.

As a result, the ICI can be completely removed from the OFDM system if we apply a matrix multiplication for the received signal vector $\vec{Y}$. Than the received signal vector $\vec{R}$ is

$$\vec{R} = \vec{Y} S^{'*} = \left[\vec{X} S + \vec{n} \right] S^{'*} = \vec{X} + \vec{n} S^{'*} \quad (7)$$

Thus, ICI is eliminated and would yield the same BER of an OFDM system without ICI at all.

D. Self Cancellation Technique

It is seen that the difference in coefficient of ICI between two consecutive subcarrier $S(l-k)$ and $S(l+1-k)$ is very small. Therefore the idea of self-cancellation is generated. The main idea is to modulate data symbol subcarriers in a group of predefined weighting coefficients. In doing so, ICI signals generated within a group may be self-cancelled each other [3], [11-12]. This method is called self-cancellation. Two forms of self-cancellation are data conversion and data conjugate.

1) Data Conversion: The self-cancellation scheme of data conversion for ICI mitigation based on an allocation of data symbols $X^{'}(k) = X(k), X^{'}(K+1) = -X(k)$ for $k = 0,2,.....N-2$ non-consecutive subcarriers to address with the ICI [2]. The received signal is sub carrier k will be

$$Y^{'}(k) = \sum_{l=0,l=even}^{N-2} X(l)\left[S(l-k) - S(l+1-k) + n(k)\right] \quad (8)$$

and the received signal is sub carrier $k+1$ will be

$$Y'(k+1) = \sum_{l=0,l=even}^{N-2} X(l)\left[S(l-k-1) - S(1-k) + n(k+1)\right] \quad (9)$$

To further reduce ICI, the demodulation is performed. The resulting signal $Y(k)$ is determined by the difference between adjacent subcarriers.

$$Y''(k) = \frac{1}{2}\left[Y'(k) - Y'(k+1)\right] \quad (10)$$

CIR data conversion scheme is given as [4]

$$CIR = \frac{\left|2S(0) - S(1) - S(-1)\right|^2}{\sum_{l=2,l=even}^{N-2}\left|2S(l) - S(l+1) - S(l-1)\right|^2} \quad (11)$$

2) Data Conjugate: In data conjugate scheme, subcarrier signals are remapped in the shaped of $X'(k) = X(k), X'(k+1) = -X^*(k)$ for $k = 0,2........N-2$.

The final recovered signal will be [4]

$$Y''(k) = \frac{1}{2}\left[Y'(k) - Y'^*(k+1)\right] \quad (12)$$

CIR data conjugate scheme is given as

$$CIR = \frac{\left|S(0) + S^*(0)\right|^2 + \left|S(1) + S^*(-1)\right|^2}{\sum_{l=2,l=even}^{N-2}\left[\left|S(l) + S^*(l)\right|^2 + \left|S(l+1) + S^*(l-1)\right|^2\right]} \quad (13)$$

IV. CONCLUSION

Orthogonal Frequency Division Multiplexing (OFDM) is a modulation technique very important in broadband multimedia communication and wireless communication systems. The overview of OFDM system in the presence of frequency offset between the transmitter and the receiver has been analyzing which problem persists in OFDM system which in terms of ICI. The paper focuses on reducing the effect of ICI using various techniques. Such techniques will improve the performance of existing OFDM systems and gives the best BER performance [5].

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Brijesh Ahirwar was born in Gourjhamar (Sagar) India on 22nd Dec 1990. He received his B.E. from Jiwaji University, Gwalior. At present he is pursuing M.Tech in Digital Communication from BTIRT Sagar on the topic of ICI Reduction in OFDM system. His research interests are wireless communication system, High frequency OFDM, Low frequency OFDM System.

