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Carrier Frequency Offset Estimation Techniques in OFDM System: A Survey

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Abstract— Orthogonal Frequency Division Multiplexing (OFDM) has proved it is ability to provide the required services and offer large data rates with sufficient strength to Electromagnetic wave channel destruction The major drawback concern in the OFDM data transmission is loss of orthogonality of signal due to Carrier Frequency Offset (CFO), caused either due to mismatching of frequency of oscillator at transmitter side and receiver side or due to Doppler shift. CFO leads to create problems like Inter carrier interference (ICI) and Signal to Noise plus Interference Ratio decrease (SINR). As a result, the overall capacity of the system is reduced. The estimation of CFO is difficult problem. Researchers have proposed various CFO estimation techniques to compensate the effect of CFO by now. This paper provides major CFO estimation algorithm and techniques in literature briefly along with the analysis of their advantages and disadvantages.

Keywords— OFDM, orthogonality, Maximum likelihood (ML), Cyclic Prefix (CP), Inter Carrier Interference (ICI), Signal to Noise plus Interference Ratio (SINR)

I. INTRODUCTION

With the advent of personal communications, the demand for mobile and broad-band wireless access has been ever increasing. The requirement for higher data rates has been met by the use of multicarrier techniques. Multicarrier techniques are particularly favored because of their robustness against frequency-selective fading encountered in mobile communications [1].Frequency Division Multiplexing (FDM), Direct-Sequence Spread Spectrum (DSSS), and Orthogonal Frequency Division Multiplexing (OFDM) are some of the commonly employed techniques for multicarrier transmission. OFDM is favored in several communication standards because of the simplicity of its implementation and bandwidth efficiency. Fourth-generation (4G) systems, such as Mobile WiMAX and Long Term Evolution (LTE), favor the use of OFDM over DSSS which was the prominent choice in Third-generation (3G) systems. OFDM is an integral part of several wireless (IEEE 802.11a/g/n, DVB-T, and WiMAX) and wire line (ADSL and ITU-T G.hn) transmission protocols.

The basic model of a OFDM system is shown in Figure 1. where input data is in binary form and data is encoded and modulated by Quardature Amplitutde Modulation (QAM) , Bipolar Phase Shift Keying (BPSK) like modulation techniques then data is multiplexed through Inverse Fast Fourier Transfomation (IFFT) . Cyclic Prefix (CP) is added and then signal is converted into analog form then upconverted and transmitted . Signal is passed through the channel it may be Additive White Gaussian Noise (AWGN) , fadingn channel etc. The signal received at receiver side is affected by the many problems like fading, frequency offset etc. then to receive the whole data by reversing the process of transmitter at the receiver side [6] .

The paper is organized as follows: in section II OFDM system model describe then in section III challenges and issues are discussed, in Section IV Carrier Frequency Offset methods with a brief overview of their advantages and disadvantages. Conclusion is presented in Section V.

II. OFDM SYSTEM MODEL

A baseband OFDM system model is shown in Figure 1. where input data is in binary form and data is encoded and modulated by Quardature Amplitutde Modulation (QAM) , Bipolar Phase Shift Keying (BPSK) like modulation techniques , complex data symbols are modulated by means o Fast Fourier Transform (FFT) on parallel subcarriers . Cyclic Prefix (CP) is added to each OFDM symbol. The resulting OFDM sybmols are transmitted serially over a descrete time channel. The channel response assume to be smaller than smaples. Signal is converted into analog form, upconverted and transmitted . Signal is passed through the channel it may be Additive White Gaussian Noise (AWGN) , fading channel etc. The signal received at receiver side is affected by the many problems like fading, frequency offset etc. then to receive the whole data is retrieved at the receiver side by the means of Inverse Fast Fourier Transformation [5].

Addition of redundant data in front of each OFDM symbol termed as Cyclic Prefix. The main idea about addition of cyclic prefix is to avoid Inter-symbol Interference (ISI) and maintaining the orthogonality between subcarriers of the OFDM signal. The total length of the OFDM symbol is Cyclic Prefix added plus OFDM symbol body.

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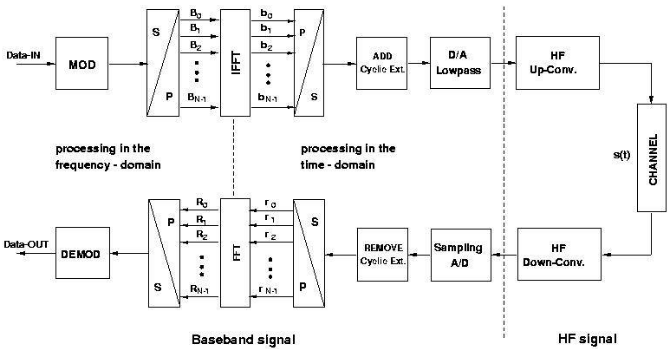

Fig 1: Basic OFDM system model

In the proposed technique analysis, assume that the signal is affected by Additive White Gaussian Noise (AWGN) channel only. However, performance of estimator is evaluated for both Random noise channel and AWGN channel [1] [6].

Consider at the receiver side of this OFDM symbol arrival time and carrier frequency is uncertain. Uncertain in carrier frequency gives rise a distortion of complex multiplication of received data i.e. difference in the oscillator's frequency in the transmitter and receiver as a small part of inter carrier spacing.

III. Challenges And Issues in OFDM

In OFDM system of modulation scheme there are no. of issues and challenges that degrades the performance of the OFDM system. Major problems are:

- *a)* Synchronization (CFO or STO)
- *b)* Sensitivity to carrier frequency Offset
- *c)* High PAPR
- *d)* Suitable modulation technique
- *e)* Size of antenna array
- *f)* Need of FFT units at transmitter and receiver

IV. Frequency offset estimation methods

Among all issues in OFDM system Carrier Frequency Offset (CFO) is main issues in OFDM system, which can induce the loss of Orthogonality among subcarriers and result in significant performance degradation, if critical to be estimated and compensated for. A number of approaches have been proposed by various researchers in the literature to estimation CFO in OFDM system which can be classified as:

A. Frequency domain Estimation technique
   - *a)* ML Estimation technique

B. Time Domain Estimation techniques
   - *b)* Training Sequence based Estimation
   - *c)* Pilot based Estimation
   - *d)* Blind CFO Estimation
   - *e)* CP based Estimation

A. FREQUENCY DOMAIN ESTIMATION TECHNIQUES

a) ML BASED ESTIMATION TECHNIQUE

This technique involves repetition of data symbols and comparison of the phases of each of the subcarrier between the successive symbols. Since the modulation phase values are not changes the phase of the each of the carriers between the successive repeated symbols is due to frequency offset. This frequency offset is estimated using the MLE algorithm. The acquisition range of this method is ±1/2 times the subcarrier spacing.

It is possible to obtain very accurate estimates even when the offset is too great i.e. there is too much ICI. This range can be intended by using shorter symbol with more than two identical parts but at the price of reduced estimation accuracy [5].

$$\epsilon = \frac{1}{2\pi}\tan^{-1}\left\{\left(\sum Im[Y_{2k}Y^*_{2k}]\right) / \left(\sum Re[Y_{2k}Y^*_{2k}]\right)\right\} \quad (1)$$

Where:

ξ is the Maximum Likelihood Estimate (MLE) for CFO, *Im* is the imaginary part, *Re* is the real part and * means the complex conjugate.

According to the paper, the limit of accurate estimation (for acquisition range) for this algorithm is |ξ | ≤ 0.5 ⇒ (-0.5 ≤ Acquisition Range ≤ 0.5) therefore the acquisition range for subcarrier spacing is between -0.5 and 0.5, which is smaller than the value that is in the IEEE 802.11a.When acquisition range goes towards the 0.5, ξ may due to the noise and the discontinuity of the arctangent, jump to -0.5 when this occurs the estimate is no longer unbiased and in practice, it becomes useless. This estimation for the small values of CFO is conditionally unbiased. However, the big weakness for suggested algorithm in Moose's paper is its dependency to the starting point; therefore the algorithm needs to know the start point of the OFDM symbol.

B. TIME DOMAIN BASED ESTIMATION TECHNIQUES

b) TRAINING SYMBOL BASED CFO ESTIMATION

This technique proposed the idea to avoid the extra overhead of using a null symbol, while allowing a large acquisition range for the carrier frequency offset. By using one unique symbol which has a repetition within half a symbol period, this method can be used for bursts of data to find whether a burst is present and to find the start of the burst. Acquisition is achieved in two separate steps through the use of a two-symbol training sequence, which will usually be placed at the start of the frame. First the symbol/frame timing is found by searching for a symbol in which the first half is identical to the second half in the time domain. Then the carrier frequency offset is partially corrected, and a correlation with a second symbol is performed to find the carrier frequency offset [7].

The main difference between the two halves of the first training symbol will be a phase difference of

$$\Phi = \pi \Delta f T \quad (2)$$

This can be estimated by:

$$\hat{\varphi} = \text{angle}\ (P\ (d)) \qquad (3)$$

Where Δf is frequency offset, P(d) is sum of product of first half training symbol with second half training symbol of length 2L sample training symbol near the best timing point. If $|\hat{\varphi}|$ can be guaranteed to be less than π then frequency offset estimate is

$$\Delta f = \Phi / \pi T \qquad (4)$$

Another extended of this algorithm is proposed by considering a training symbol composed of length L > 2 identical parts. This makes it possible to achieve a better accuracy at the cost of some increase in computational load. Its accuracy is slightly superior to that of the Schmidl and Cox method but Mean Square performance of the estimator decreases. The estimation range can be made as large as desired without the need of a second training symbol, as required by the Schmidl and Cox method [3]. Following equations are developed by the M.M and U. Mengali for the estimation of the frequency offset υ.

$$\upsilon = 1/(2\pi/L)\sum w(m) \qquad (5)$$

Where, w (m) mth component of

$$w = C\varphi - 11/1TC \qquad (6)$$

Where,

C_φ is the covariance matrix of the φ.

C. PILOTS BASED CFO ESTIMATION

In this technique scattered pilots used to estimate both integer and fractional CFO, which are usually estimated by continual pilots. Since scattered pilots are usually used to estimate CFR (channel frequency response), using them, at the same time, to estimate frequency-offset will not bring about additional cost for the system. Thus, sub channels, applied to transmit the continual pilots, will be saved for useful data, which increases the spectral efficiency [4]. In OFDM systems, CFO is usually divided into integer part and fractional part, which are detected by deferent information extracted from received singles. In this cyclic prefix are used to detect coarse fractional CFO and scattered pilots are used to detect fine fractional CFO as well.

Another pilot based estimation designed in which pilot symbol assisted modulation for carrier frequency offset and channel estimation in orthogonal frequency division multiplexing transmissions over multi input multi output frequency selective fading channels. The CFO and channel estimation tasks rely on null subcarrier and nonzero pilot symbols that they insert and hop from block to block. This novel technique separate CFO and channel estimation from symbol detection. Specifically in this method training symbols designed that enable decoupling of CFO and channel estimation from symbol decoding [9].

D. BLIND CFO ESTIMATION

In this technique a new carrier offset estimation technique for OFDM communications over a Frequency selective fading channel is proposed. In this method they exploit the intrinsic structure information of OFDM signals to derive a carrier offset estimator that offers the accuracy of a super resolution subspace method, ESPRIT. This method proposed a new solution to the carrier offset estimation problem without using reference symbols, pilot carriers, or excess CP. The technique provides CFO estimation by taking advantage of the inherent structure of OFDM signals even when the OFDM signal is distorted by an unknown carrier offset; the received signal possesses a certain algebraic structure which will be shown to be sufficient to accomplish blind carrier estimation. The proposed technique is in analytic form.[8]

Another blind CFO estimation based technique is developed called kurtosis based blind CFO estimator for OFDM system. This novel cost function is able to uniquely identify the CFO within the range of half subcarrier spacing, while lending itself to very low complexity algorithms. A closed form expression for the MSE of the CFO estimate was obtained for frequency flat channels. This approach applied to MIMO-OFDM and multiuser OFDM system. For MIMO-OFDM, they also investigated the effects of multiple transmit and receive antennas on the performance of the CFO estimator [10]. The kurtosis type cost function used in this method is

$$\text{Kurtosis}\ (J(\epsilon)) = \{E[|y|4] - 2(E[|y|2])2 - |E[y2]|2\}/(E[|y|2])^2 \qquad (7)$$

Where | y | is the Fourier transform of the received signal at the receiver side. A CFO estimate can be obtained by minimizing the function J (Є). After calculation the estimate Є can be obtained as follows:

$$\epsilon = \begin{cases} \frac{1}{2\pi}\sin^{-1} & \text{if } a \geq 0 \\ \frac{1}{2} - \frac{1}{2\pi}\sin^{-1}(b) & \text{if } a < 0 \text{ and } b \leq 0 \\ -\frac{1}{2} - \frac{1}{2\pi}\sin^{-1}(b) & \text{if } a < 0 \text{ and } b \leq 0 \end{cases} \qquad (8)$$

Where,

a= (J (1/4) + J (-1/4)/2 – J (0), and b= (J (-1/4) – J (1/4)/2

E. CP BASED CFO ESTIMATION

A Cyclic Prefix based estimation technique is proposed in which present the joint maximum likelihood (ML) symbol time and carrier frequency offset estimator in orthogonal frequency division multiplexing (OFDM) system. In this the redundant information contained within the cyclic prefix. Their novel exploits the cyclic prefix preceding the OFDM symbols, thus reducing the need for pilots. It is derived under the assumption that the channel distortion only consists of additive noise [5].

V. Conclusion

CFO estimation is key task in the OFDM system to remove ICI and SINR. The challenges associated with the task of estimation are discussed and a handful of spectrum sensing techniques are reviewed in this paper along with an overview about their advantages and disadvantages.

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