Overview of Frequency Synchronization in OFDM System

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Abstract-
The faster growth in wireless device, coupled with the expansion of wireless service, spectrum is getting scarcer and more valuable. To preserve bandwidth, spectrally efficient signalling scheme for digital communications that is OFDM is introduced and is achieved by placing the subcarriers orthogonal to each other. Compare to FDM technique OFDM preserves 50% of bandwidth. The major downside in OFDM is carrier frequency offset because it destroys the orthogonality among carriers causing inter carrier interference (ICI). In this paper, the impact of CFO on the SNR in an OFDM system are studied. Various CFO estimation algorithms are analysed to identify best estimator.

Keywords—OFDM, CFO, ICI

1. Introduction
Orthogonal frequency division multiplexing (OFDM) is a bandwidth efficient scheme and it is a kind of multicarrier transmission where a high speed data stream are chunked into several sub stream and transmitted over a number of linear independent subcarriers for which the sub carrier spacing is reciprocal to the symbol period. Exact carrier offset estimation and compensation is more challenging in OFDM than other modulation schemes. However, this OFDM modulation technique is very sensitive to the frequency offset between the transmitter and the receiver oscillators. This is due to Doppler shift and a mismatch between the local oscillator at the transmitter and receiver. In fact, in the presence of a frequency error, the subcarriers making up the Multi carrier signal lose their orthogonality and the system performance becomes degraded. Unlike single carrier digital transmission systems, since frequency synchronization is essential, few studies have been carried out concerning frequency synchronization for Multi Carrier systems. Most existing carrier estimation techniques depends on repetitive transmission of reference symbols with some shorter period, which reduces bandwidth efficiency. The purpose of this paper is to analyse various CFO estimation technique and to identify the best estimator with low complexity. The paper is organized as follows: the next section briefly describes sources and effects of carrier frequency offset in multicarrier system. In Section 3 we discuss various frequency offset estimation algorithm. Section 4 describes conclusion and gives a comparative report of various frequency offset estimation algorithm. Finally, Section 5 is for future directions.

Frequency Offset (CFO) deteriorates its performance by introducing InterCarrier-Interference (ICI). CFO refers to the difference in carrier frequency at transmitter and receiver. The carrier modulation helps in converting the baseband transmit signal up to the pass-band and then helps in converting it down to the level of baseband by the taking the local signal as carrier with the equivalent carrier frequency at the reception side. Two types of distortions are related with the signal used as carrier, first was the phase offset which causes due to the occurrence of instability in the carrier signal generators which are being applied at the Transmitter and Receiver section, which could be further modeled as a Wiener random process as zero-mean. The other one considered was the Carrier Frequency Offset (CFO) that is caused by Doppler shift in frequency and a mismatch between the local oscillator at the transmitter and receiver. CFO does not preserve the orthogonality between the sub-carriers. Therefore, the CFO impairment is essential to OFDM system.
II. Impact of CFO on OFDM System

As mentioned above, the main causes of CFO in communication systems are Doppler frequency shift $f_D$ and frequency mismatch $f_m$ between transmitter and receiver. The OFDM modulated signal is expressed as

$$s(n) = x(n) \exp(2\pi f_D n / f_s) + w(n), \quad (1)$$

where $0 \leq n \leq N$, $f_s$ is the sampling frequency.

Let $\text{foffset} = f_c - f_c'$ \quad (2)

Doppler frequency $f_d = \frac{\nu f_c}{c}$ \quad (3)

Where $f_c$ is the carrier frequency, $\nu$ velocity of receiver and $c$ is the speed of light.

Normalized CFO $\epsilon = \frac{\text{foffset}}{\Delta f}$ \quad (4)

Where $\Delta f$ is the subcarrier spacing and $\text{foffset}$ is CFO. If normalized CFO $\epsilon$ is defined as a ratio of CFO to spacing in subcarrier $\Delta f$.

From the expression (1) it is observed that each and every sample in the time domain have linear phase shift. The difference between the phase shift is a function of $2\pi f_D n / f_s$. Each and every sample is going to be rotated by certain phase. The effect of this can be seen in constellation diagram (Fig. 1). Due to frequency error, the constellation points have just rotated over the decision boundaries. Correct demodulation is not possible. To eliminate this error, suitable estimation techniques have to be introduced. Based upon the estimation, the compensation should be provided in the receiver side. The CFO estimation algorithm is discussed in the next section.

Fig. 2 illustrates the SNR degradation as a function of the frequency offset to the subcarrier spacing. From this figure, the values for $E_s / N_0$ will be 5, 10, 15 and 20 dB. However, the maximum acceptable frequency offset can only happen when the frequency offset is less than one percent of the subcarrier space. As a result, for overcoming the mentioned problem, the frequency synchronization must be used before the FFT.

III. CFO Estimation Algorithm

Kay Estimator is a type of least squared based estimator, it exhibits high threshold value making them not suited for most application in Digital communication.

Fitz estimator gives accurate estimates over a range slightly smaller than $\pm 10\%$ of $1/T$, where $T$ is the symbol period.

Luise and Reggiani (L&R) Estimator is a type of Autocorrelation based estimator. At high SNR estimation range is bounded. Beyond this limit estimate is inaccurate and can operate at low SNR. Estimation range is about $\pm 15\%$ of $1/T$.

Based upon the operating condition, judiciously can choose the various options mentioned above. Most of the research papers were discussed the Kays, Fitz and L&R frequency estimator algorithm[9]. So we wish to discuss CP, Classen, Moose and Kalman filtering in detail.

A. CP Based Method:
In CP (Cyclic Prefix) method we are calculating the phase angle at Guard Interval (GI). The formula for the CP based estimation is shown below.

\[ X_{CP} = \text{Phase angle (GI*CP part of the signal)} \]

**B. Moose Algorithm**

It is well-known that the Moose’s algorithm can estimate the frequency offset based on the maximum likelihood criterion by using the characteristics of the long training signal consists of two successive OFDM symbols. In this method, we are calculating the phase angle for the multiplied signal of first and second symbol.

\[ X_{Moose} = \text{Phase angle (Symbol_2*Symbol_1')} \]

The CFO estimation range covered by this technique is \( \varepsilon \leq 1/2 \)

**C. Classen Method**

As proposed by Classen, pilot tones can be inserted in the frequency domain and transmitted in every OFDM symbol for CFO tracking. First, two OFDM symbols, are saved in the memory after synchronization. Then, the signals are transformed into frequency domain via FFT, from which pilot tones are extracted. After estimating CFO from pilot tones in the frequency domain, the signal is compensated with the estimated CFO in the time domain, in this we are multiplying the original pilots to received signal at pilot locations and then we are calculating the phase angle as are Moose method.

\[ X_{Classen} = \text{Phase angle (Symbol_2(pilot_location)*Xpilots* (Symbol_1(pilot_location)*Xpilots'))} \]

**D. Kalman Filtering**

Kalman filters are common in communication and signal processing. The Kalman filter is versatile and powerful algorithm used in many applications such as adaptive equalization of fading dispersive channels, and adaptive antenna arrays. As a recursive filter, it is applicable to non-stationary processes. The Kalman filter computes estimates of own performance as part of recursion and use this information to update the estimate at each step. The estimation procedure is adjusted to time variant statistical characteristics of the random process.

The EKF method gives a significant boost to the BER performance for higher values of \( \varepsilon \). This is attributed to the fact that the EKF method estimate the frequency offset very accurately and cancel the offset using this estimated value. Another important advantage is that it does not reduce bandwidth efficiency as in self-cancellation method because the frequency offset can be estimated from the preamble of the data sequence in each OFDM frame.

**IV. Conclusion**

In this paper various frequency offset estimation techniques in OFDM system have been discussed. Pilot based frequency offset estimation is better than CP based and symbol based estimation, because it has superior MSE performance. The Moose method assumes no data symbol transmission, so it is suitable only for preamble period. On the other hand, Classen method allows the data symbol transmission. The method of CP auto-correlation cannot precisely estimate Doppler frequency. On the contrary, the method of frequency offset estimation using cross-correlation can precisely estimate Doppler frequency in cell boundary. EKF method estimate the frequency offset and correct the offset using the estimated value at the receiver, and it does not reduce the bandwidth efficiency like self-cancellation, as the frequency offset can be estimated from the preamble of the data sequence in each frame.

We examined the CFO estimation methods in frequency domain using Pilot tone-based method have better performance than the estimation methods in time domain using CP-based method and training sequence method. The EKF method gives a significant boost to the BER performance for higher values of \( \varepsilon \) and has best performance compared to all four methods.

**V. Future Work**

In this survey, we have provided a comprehensive classification of various carrier synchronization algorithm and their limitations for the different communication systems. Researchers can extend their work in cognitive networks where synchronization is major issue to be dealt. Cognitive radio is a key technology in enhancing bandwidth.
utilization. A variety of spectrum allocation and detection algorithms have been proposed for cognitive networks, which allow secondary users to sense the environment and transmit only when the primary users are silent. However, the majority of these approaches are based on the assumption of perfect synchronization. This assumption must be relaxed to realize more practical spectrum detection algorithms for cognitive radio networks. In addition, synchronization aspects for cognitive networks need to be explored.

References


[8] Mattias Olsson and Hakan Johansson Dept. of Electrical Engineering, Linköping University, Blind OFDM Carrier Frequency Offset Estimation by Locating Null Subcarriers

