Design of Low-Complexity Blind CFO Estimation for OFDM Systems

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Abstract- **The estimation of carrier frequency offset (CFO) is an important issue in the study of the orthogonal frequency division multiplexing (OFDM) systems. In the past, many CFO estimation methods have been proposed. In this paper, we propose a new blind CFO estimation for OFDM systems based on the so-called demodulated received vectors. The CFO estimate is given by a closed form formula. The proposed method has very low complexity and its performance is robust to different modulation symbols and the presence of virtual carriers. Orthogonal frequency division multiplexing (OFDM) is a multicarrier modulation technique that is widely used in wireless broadband communication systems. The spectral e ciency of OFDM is very high since the subcarriers are spaced as closely as possible while maintaining orthogonality. However, one of the major problems with OFDM that can cause performance degradation is carrier frequency o set (CFO) which impairs the orthogonality among OFDM subcarriers, as a consequence, results in inter-subcarrier interference. In this thesis, an iterative algorithm for joint CFO estimation and data detection in OFDM systems over frequency selective channels is proposed. The proposed algo-rithm is performing both CFO estimation and data detection in the frequency domain based on the Expectation-Maximization (EM) algorithm. The proposed algorithm can achieve the same bit-error-rate (BER) performance as that of its time-domain counterpart with much lower complexity. Simulation results show that the proposed algorithm can converge after three iterations and an estimate of CFO can be obtained with high accuracy.**

1. INTRODUCTION

The essential characteristic of OFDM system is that it employs orthogonal sub-carriers. In a conventional frequency division multiplexing (FDM), to eliminate ICI, the subcarriers are spaced apart by inserting guard bands between them in the frequency domain, as shown in Fig. 1.1. However, this kind of arraignment for the subcarriers wastes bandwidth. An alternative method is to overlap the subcarriers to save the bandwidth as shown in Fig. 1.1.

But overlapping the subcarriers could introduce ICI. Thus, to save bandwidth without having ICI, orthogonal subcarriers are the best choice. OFDM is the technique that employs orthogonal subcarriers to transmit the data. the OFDM subcarriers exhibit orthogonal-ity on a symbol interval if they are spaced in the frequency domain exactly at the reciprocal of the symbol interval, which can be accomplished by utilizing the discrete Fourier transform (DFT).

2. PROBLEM STATEMENT

Nonetheless, due to the imperfect channel condition, OFDM still has several limitations that would a ect the performance of the system. First, in practice, a wireless channel cannot be considered as an ideal channel [1]. As a result, the received signal is not the same as the transmitted signal. Thus the data need to be recovered according to the actual channel. Also, an OFDM signal can have a large peak-to-average-power ratio (PAPR) value with high probability [8]. Moreover, strict frequency synchronization is impossible to OFDM system [9] which is related to carrier frequency offset (CFO). Furthermore, both CP and null guard tones at the edge of the spectrum can decrease the spectral efficiency of the system. However, this Project will focus only on reducing the effect of CFO on the performance of a practical OFDM system

When considering the performance of a wireless communication system, the bit error rate (BER) plays an essential role. The probability of bit error, also called, the BER is a measure of deterioration in digital communications. Lower BER means higher performance. In OFDM systems, due to the characteristics of the physical channel, the BER is highly related to both parameters estimation and data detection. Generally speaking, the parameters contain timing error, channel information and carrier frequency o set (CFO). These parameters are independent of each other. Since the OFDM system is not sensitive to timing error [10], and the channel can be estimated accurately by inserting a set of known symbols, called pilots, [11].

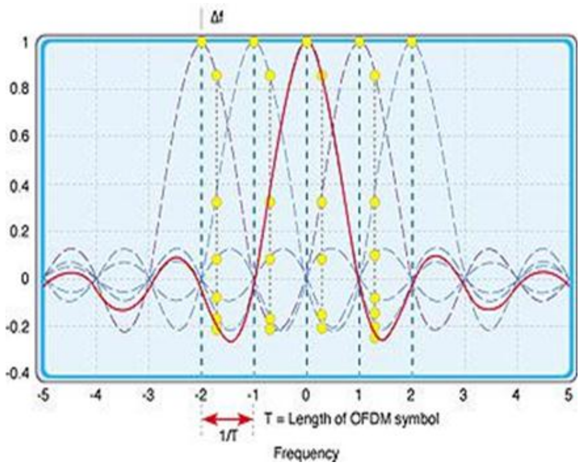

Fig. 1: CFO Effect

Hence, the performance of the system is slightly a effected by these two parameters. However, the CFO cannot be easily estimated by using the pilots. The CFO is the normalized frequency error between the transmitter and the receiver. In practical OFDM systems, the CFO can be caused by the mismatch between the oscillator in the transmitter and the receiver or the Doppler shift in frequency selective channels, [12]. In practical mobile communication systems, the channel is a frequency selective channel. Fig. 1shows how the Doppler shift leads to a frequency error. As seen in, in OFDM systems, the existence of CFO destroys the orthogonality among OFDM subcarriers, as a consequence, results in inter-subcarrier interference [13]. And this inter-subcarrier interference can cause BER performance degradation. As seen from Fig. 1, OFDM is very sensitive to CFO [14], even a small CFO in an OFDM system can lead to a huge error.

3. FREQUENCY OFFSET ESTIMATION METHODS

It is desired to design a joint estimation algorithm to deal with the CFO effect for an OFDM system with frequency selective channel. From the previous chapters, we can see that the system model which both considering the CFO and the transmitted data is a linear complex matrix equation with nonlinear parameters. Although it is extremely di cult to jointly solve this kind of problem, there are still several algorithms that can be considered to deal with it. In the following paragraphs, the estimation theory and associated algorithms would be reviewed first. Then based on the comparison of the presented algorithms, the EM algorithm would be picked to deal with the joint estimation problem and explained in the second part of this chapter.

COARSE ESTIMATION

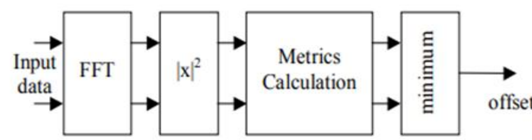

Fig. 5.1 Coarse frequency offset estimation

The general scheme of the integer frequency offset estimation has been shown below. We assume that the fractional part of the frequency offset has been already removed in front of the FFT. After OFDM demodulation we calculate the power received at each subcarrier and the metrics M(n), where n ranges within the interval of subcarrier indices determining the possible position of the DC subcarrier in the received OFDM signal. Minimum of this metric indicates the estimated frequency offset or, equivalently, the location of the null in the middle of the received signal spectrum. One can notice that all proposed algorithms are immune to a constant phase shift (e.g. caused by timing errors) since they apply the received subcarrier power only.

FINE ESTIMATION

The receiver architecture and the distinction between time and frequency domain processing have been shown in Figure 5.2

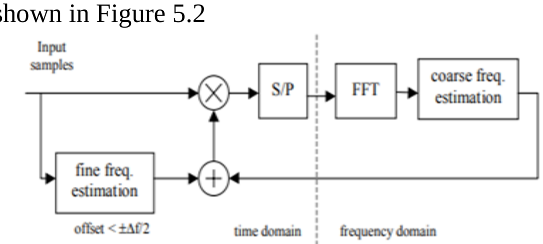

Fig. 5.2 Frequency offset estimation iñ receiver architecture

The fine frequency offset BLIND estimation algorithm operates in the time domain. Such an algorithm is able to estimate a fractional part of the frequency offset (smaller than a half of the subcarrier spacing Δf). After this estimation, the fractional part of the frequency offset is removed from the input signal and in this manner the FFT output is almost free of the ICI. The algorithms described in this paper are placed after the FFT and are denoted as coarse frequency estimation. These algorithms allow for estimation of the integer part of the frequency offset. Since in many practical systems the FFT introduces significant delay, the estimates can not be used in the same frame. It will be shown, that the performance of these algorithms drops when the frequency offset walks away from the integer multiple of Δf. This is why another algorithm estimating and correcting a fractional part of the normalized frequency offset should be applied at the beginning of the synchronization process. Simulation results presented in this paper have been obtained when no cyclic prefix is present in front of the preamble symbol, as it is often the case for the OFDM symbol preambles. The impact of the cyclic prefix on the algorithm performance has been analyzed in the last section.

which is the first part of the synchronization preamble placed at the beginning of the signal burst. This symbol consists of two identical short preamble symbols, which are used by the timing offset estimation algorithm. This is caused by the requirements imposed by signal filtering and is aimed at decreasing interference introduced into neighboring channels. To obtain two identical short preamble symbols the DC subcarrier has to be switched off as well. The first algorithm presented in the next section searches for the DC subcarrier in the received signal spectrum. Similar idea and architecture was presented in [1]. However, in [1] a bank of filters designed for the Doppler shift that is expected in the channel has been reported. This causes that the correct estimate can be obtained after a relatively long time period. Additionally, oversampling was applied in the algorithm presented in [1] and a channel without selective fading was assumed in the simulations. Simulation results obtained for the WIND-FLEX channel models [9] clearly show that the last assumption does not hold in the WIND-FLEX modem SOHO environment.

4. SIMULATION RESULTS

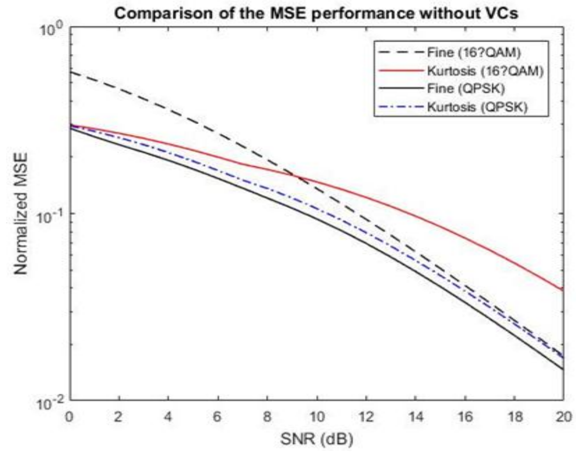

Fig 6.1 Comparison of the MSE performance without VCs

First, we assume that there are no virtual carriers. we plot the performances of the “Coarse” estimation in , the “Fine” estimation , the “Kurtosis”-based algorithm. The Kurtosis algorithm does not perform well for 16-QAM because it is based on constant modulus modulation. For both cases of 16-QAM and QPSK, the fine estimation has an error floor at about 10−4 at high SNR. The proposed fine estimation method has the best performance, and its performance does not dependent on the modulation symbols.

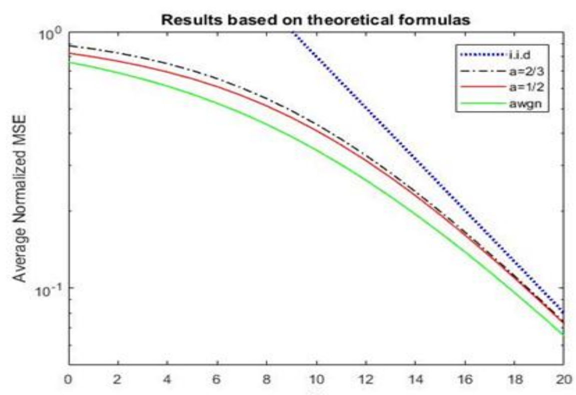

Fig 6.2 MSE versus number of the smallest diagonal entries in the cost function

We plot MSE versus m for different classes of channel models.. We plot the MSE for the random channels with exponentially decaying power . “i.i.d.” means that the channel taps are generated as independent and identically distributed (i.i.d.) random variables, or equivalently, a = 1.

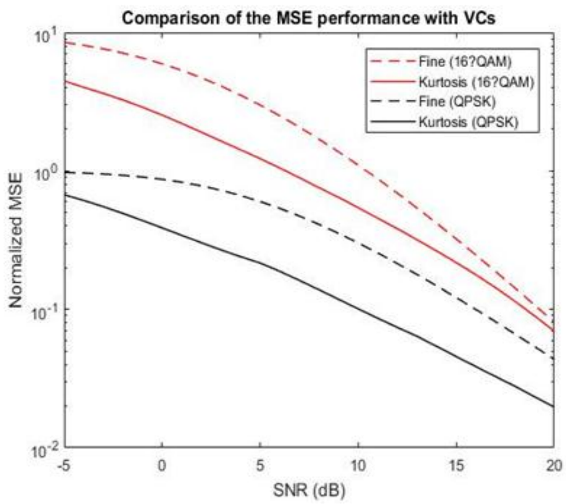

Fig. 6.4: Comparison of the MSE performance with VCs

Next we consider OFDM systems with virtual carriers. we find that the presence of VCs seriously degrades the performance of the kurtosis algorithm. The performance of the Kurtosis method is also affected by the presence of VCs. On the other hand, the presence of VCs has little effect on the proposed method. The proposed fine method has the best performance in the case of VCs as well.

5. CONSLUSION

In this Project, the problem of carrier frequency o set (CFO) in orthogonal frequency division multiplexing (OFDM) systems over frequency selective channels has been addressed. To tackle this problem, first, an algorithm for joint CFO estimation and data detection in the time domain was developed. Then a new algorithm as the frequency-domain counterpart of the first one was proposed to reduce the computational complexity of the former one. Both algorithms are based on the expectation maximization (EM) algorithm which is employed as an iterative algorithm. By exploiting the channel estimate, the proposed algorithms can accurately perform CFO estimation and data detection in OFDM systems over frequency selective channels.

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