ML Estimation of Initial Symbol Timing and Frequency Offset in OFDM Systems

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Abstract—In this paper, we present a simple and efficient novel joint synchronization algorithm for OFDM system. It is based on training cyclic prefix to estimate the Initial symbol timing and carrier frequency offsets. Training sequence is an important part of the symbols which organize the frame timing and initial symbol timing. Cyclic prefix used the circular property for insertion and removal itself. Hence, advantages of both training sequence and cyclic prefix is being used in the algorithm. The simulation results show that the new algorithm improved the performance

Keywords-OFDM; Frame Timing; Initial timing; frequency offset ; maximum likelihood(ML).

I. INTRODUCTION

In wireless environment OFDM has received great focus as an effective multicarrier modulation technique for high speed transmission. It has been applied to applications including wireline modems (ADSL), powerline modems, broadcast video (DVB), digital radio (DAB, DRM) wireless LAN (802.11a/n), military communications (WNW), and cellular/BWA (WiMAX, UMB, LTE). In an OFDM system, the input data stream is divided into several parallel sub-streams of reduced data rate (thus increased symbol duration) and each sub-stream is modulated and transmitted on a separate orthogonal subcarrier. The increased symbol duration and the use of cyclic prefix and frequency domain equalization improve the robustness of OFDM to multipath delay spread in NLOS channels.[1]Compared to conventional single carrier system, OFDM improves spectral efficiency and increases robustness against inter symbol interference (ISI) and fading caused by multipath propagation. However, the OFDM is far more sensitive to synchronization errors than single carrier system. Synchronization of an OFDM signal requires finding the symbol timing and carrier frequency offset. Finding the symbol timing for OFDM means finding an estimate of where the symbol starts. There is usually some tolerance for symbol timing errors when a cyclic prefix is used to extend the symbol. Synchronization of the carrier frequency at the receiver must be performed very accurately, or there will be loss of orthogonality between the sub symbols. OFDM systems are very sensitive to carrier frequency offsets since they can only tolerate offsets which are a fraction of the spacing between the subcarriers without a large degradation in system performance [2]. Various approaches have been proposed to estimate timing and frequency offsets In general, the synchronization techniques of symbol timing and frequency offset in OFDM systems can be classified into two categories: data-aided [3-5] and non data-aided techniques [6-10]. The data aided structure needs some specialized synchronization symbols such as pilot symbol or training sequence. However, the insertion of such symbol decreases the system capacity. The non data-aided estimation uses cyclic prefix samples; are the replica of last part of useful data samples to make correlation of the cyclic prefix samples and the useful data samples. This technique has poor performance in multipath fading channel estimation performance.

In this paper, a new synchronization algorithm is proposed to achieve robust, low complexity time frequency OFDM synchronization.

II. OFDM SIGNAL MODEL

In OFDM system N complex data symbol are modulated onto N subcarrier by IFFT as shown in figure 1. The last *Ng* IFFT samples of length L are inserted at the beginning of each OFDM symbol to form the guard interval.

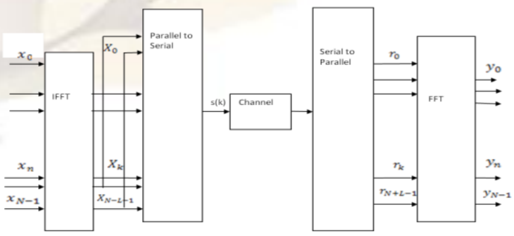

Figure 1. OFDM basic architecture.

$$X(k) = 1/N \sum_{n=0}^{N-1} x_n exp\left(j\frac{2\pi k\,(k-L)}{N}\right) \qquad (1)$$

The x_n is the data symbol mapping results of constellation points. Each OFDM period T equals N+L. When $X(k)$ passes through multipath channel with the impulse response $H(k,l)$ the output signal $s(k)$ can be expressed as

$$s(k) = \sum_l H(k,l)X(k-l) \quad (2)$$

In the receiver, as the influence of timing offset and carrier frequency offset the actual received signal expressed as:

$$r(k) = X(k-d)e^{j2\pi\Delta fn/N} + w(k) \quad (3)$$

The d is the symbol timing offset. The Δf is carrier frequency offset aroused by the Doppler frequency shift and the difference of oscillation frequency between the receiver and transmitter. The $w(k)$ is Gaussian white noise with zero mean, which is independent of x_n.

The last section of the symbol is copied and inserted at the beginning of the symbol. This is called the cyclic prefix (CP). At the mobile station (MS) the CP allows the signal to be treated as circular after its removal. The received signal has been modified by the channel and additive noise.

The first step of the synchronization process is to detect the training sequence and estimate the coarse symbol timing in the presence of carrier frequency offset (CFO) [11]. The symbol timing and CFO can be estimated jointly or individually. The most practical approach is to decouple the estimates. The timing estimation has been studied by many authors [12]–[19]. This paper will build upon some of these ideas. The CFO estimation has been studied by several authors [6], [17], [19], [20]. The CFO is then compensated and the symbol is extracted prior to FFT processing.

III. OFDM SYNCHRONIZATION ALGORITHM USING TRAINING CYCLIC PREFIX

The maximum likelihood estimation algorithm as in [6] using data dependency theory is as follow:

$$d_{ML} = arg\ max_d \left\{ \left| \sum_{k=d}^{d+L-1} r(k)r*(k+N) \right| \right\} \quad (4)$$

$$\Delta f_{ML} = -\frac{1}{2\pi}\angle\sum_{k=d_{ML}}^{d_{ML}+L-1} r(k)r*(k+N) \quad (5)$$

This algorithm is based on Gaussian channel environment. Due to influences of multipath fading channel, the repeated character of the cyclic prefix decreases. Then, the timing point d and ML function value of sample points on both sides of it. It results the estimation performance decline markedly .Therefore, the performance frequency estimation declines also [21].

To overcome the defects of algorithm. The training sequence is inserted to back-end of each OFDM symbol. The cyclic prefix is got according this training sequence, as shown in Figure 1. There have been several approaches to coarse timing estimation. There are two basic distinctions between the various approaches. First is the property exploited. This includes the redundancy in the CP and the redundancy in the training sequence . A shortcoming of using the CP alone is that it is short by design, so only small fraction of the signal information is utilized. These results in decreased detection sensitivity. By utilizing the redundancy in training sequence more of the signal's energy can be utilized.

Figure 2. OFDM symbols structure after inserted training sequence.

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In this paper detection of the training sequence is done by correlation factor. Training sequence is detected when correlation factor reaches its threshold value. For correlation estimation different methods are used. Delayed Correlation is the autocorrelation of the received waveform evaluated at a specific lag *d.* When the correlation function reaches its threshold value then training sequence is detected [22].

$$R_{yy}(n,d) = 1/M \sum_{m=0}^{M-1} \mathrm{y}(\mathrm{n}+\mathrm{m})\mathrm{y}*(\mathrm{n}+\mathrm{m}+\mathrm{d}) \quad (6)$$

Here d represents the correlation lag, and is fixed. The value of the lag is determined by the repetition period of the signal. The delay correlate computational burden is minimized by using an iterative moving average implementation.

$$R_{YY}(n+1,d) = R_{yy}(n,d) + y \times (n+d)y(n+d+M) - y \times (n)y(n+M) \quad (7)$$

where N is the FFT size, Ng is the cyclic Prefix length, and M is the correlation integration length. The simplest detection metric is the un-normalized maximum correlation metric [13]. This approach is problematic for determining a threshold that will work well under a varied channel conditions.

A normalized version of this idea was developed by Maximum likelihood to average all the signal samples used in the calculation .

$$M_{M,L}(n) = \frac{2\left|R_{yy}(n,L)\right|^2}{\left(R_{yy}(n,0)+R_{yy}(n+L,0)\right)^2} \quad (8)$$

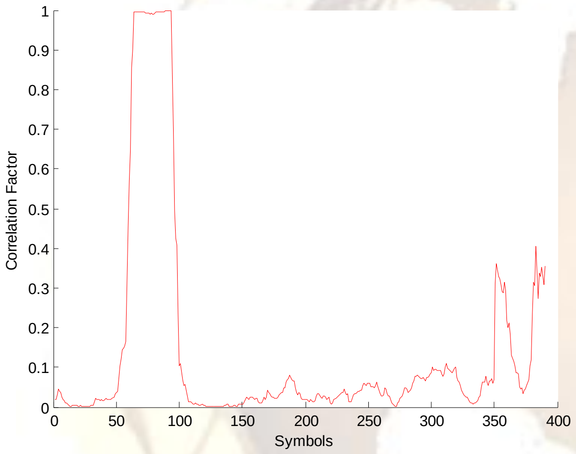

Figure 3. Initial symbol detection by correlation method.

The back-end data of OFDM symbols, as known training sequence. Then, the fine carrier frequency offset estimation can be calculated as

$$\Delta f_{ML} = -\frac{1}{2\pi}\angle \sum_{k=d_{ML}}^{d_{ML}+L-1} r(k)r*(k+N)$$

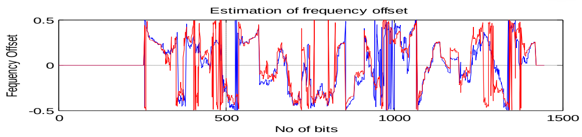

Figure 4. OFDM signals that generates ML frequency estimates with training sequence and with CP.

This estimate is similar to that of the frequency estimator proposed in [9]. It is noted that the maximum-likelihood estimate for the frequency offset is independent of the noise power [10].

IV. SIMULATION RESULTS

ML reach the threshold value at the 50 for CP ¼ for the total number of symbol used is 256 and Training sequence starts from the 50th symbol, for ML correlation performance for detection of the training sequence as shown in fig 3 .The frequency estimator performs better as shown in figure 4.

V. CONCLUSION

A method has been presented for the rapid and robust synchronization of OFDM signals, and acquisition is obtained upon the receipt of just one training sequence. It works well in frequency selective channels, by averaging over all the sub channels. This method also gives very accurate detection of initial symbol timing and carrier frequency offset. The probability of false locks or missing the training symbols is very low. For a wireless LAN, a synchronization process which is fast and having low overhead is required. Here, there will be only one training sequence transmitted in each burst for synchronization.

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