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AN IMPROVED PREAMBLE AIDED TIMING ESTIMATION METHOD FOR OFDM SYSTEMS

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Abstract
This paper presents an improved robust method for timing offset estimation in preamble-aided OFDM system. The proposed method is aimed to provide low complexity, high performance timing estimator under the high frequency offset conditions. It uses a modified preamble structure and utilizes double autocorrelation technique to achieve robust timing estimation performance with only moderate increase in complexity. We finally evaluated and compared the performance of the proposed method in terms of mean square error (MSE) in AWGN, Rayleigh fading ISI channels and HIPERLAN/2 indoor channel A. The results indicate that the new method has a significantly smaller estimator MSE than the previously presented methods.

Keywords:
OFDM, Timing Estimation, Preamble, Autocorrelation

1. INTRODUCTION

ORTHOGONAL frequency-division multiplexing (OFDM) has been of major interest and as a current trend for both wireline-based and wireless applications [1]–[3] due to its high data rate transmission capability with high bandwidth efficiency and its robustness to multipath delay spread. It is being used as a standard in many modern digital communications such as DAB, DVB-T, DVB-H, DVB-SH, WiFi, WiMAX and 3GPP LTE [13]. However, OFDM systems are very much sensitive to synchronization errors than single carrier systems [4], [5]. OFDM systems are sensitive to symbol time offset (STO) and carrier frequency offset (CFO). To get fast synchronization, several preamble-based timing methods have been proposed in the literature. To achieve synchronization there are basically two types of approaches exist in literature. In first approach it is based on data aided scheme. In data aided a preamble is transmitted to achieve synchronization based on autocorrelation [6]-[10] or cross correlation [11]-[14] properties of the received signal. Methods based on preamble aided technique which is independent of preamble structure [14]-[18] by taking the advantage of whole possible correlation products to increase timing estimation accuracy at the cost of increased computational complexity is also present.

The advantage of data aided scheme is the accuracy in synchronization in terms of lower estimator mean square error (MSE) while the drawback is reduced data throughput. On the other hand second approach to achieve synchronization is Non data aided schemes [19]. Synchronization is achieved based on statistical properties of the received signal. The advantage of non-data aided scheme is that there is no training sequence overhead while disadvantage is its high computational complexity with larger estimator MSE. Due to higher accuracy of data aided schemes we are looking to propose a scheme which utilizes system resources more effectively with less overhead.

In literature there are several data aided schemes were presented where in Schmidl & Cox [6] method a timing estimation method with a simple preamble structure is utilized which has two identical parts so by exploiting the auto correlation properties of received signal a timing metric is formed. But the drawback of that timing metric is that there is a plateau formed in it which makes it difficult to realize exact starting point.

In order to reduce uncertainty caused by [6] scheme's timing metric plateau to compute the exact starting point Minn [7] proposed an improvement in [6] preamble. This improvement causes the reduction in uncertainty, because peak is formed at the exact starting point. But due to structure of preamble, autocorrelation of the received signal forms timing metric which consists almost same value as of peak value at near points of exact starting point. This causes misdetection of exact starting point which causes larger estimator variance leading to larger estimator MSE as well.

Park [9] proposed a timing estimation method which extends the difference between the values near the exact starting point but due to nature of preamble, in timing metric other minor peaks corresponding to half symbol pattern match also occurs which leads to performance degradation in the multipath channel conditions.

In Adegbenga's method [12] preamble structure of [6] is utilized where in order to remove the effect of CFO they have applied the cross correlation between the frequency offset corrected received signal and the local copy of the preamble. In this method implementation complexity is increased because before application of cross correlation operation it required frequency offset correction of the received signal because cross correlation based methods are sensitive to CFO [18]. Without CFO correction the performance of this method becomes poor when there is large CFO present in the received signal. So there is need to propose a technique where there is no need of CFO correction in received signal and we can achieve smaller estimator MSE with less complexity.

In this paper, we have proposed an improved robust preamble aided technique that uses only one training symbol with a simple structure having two identical parts as well as symmetrical structure to achieve robust, OFDM synchronization in the time-domain. It combines autocorrelation technique applied twice in different ways to the same preamble to achieve reliable synchronization accuracy in AWGN, Rayleigh fading ISI channels and HIPERLAN/2 indoor channel A [9].

The rest of this paper is organized as follows. In section 2 we introduce the OFDM signal description. In section 3, proposed scheme for symbol timing synchronization is presented.

Simulation parameters, results and analysis are detailed in section 4 and conclusion of the work is presented in section 5.

2. OFDM SIGNAL DESCRIPTION

OFDM is a multicarrier transmission technique where a single data stream is divided into number of lower data stream. These lower data rate stream is placed onto number of different sub-bands where these lower data rate stream modulates each subcarrier corresponding to each sub bands and these subcarriers are orthogonal to each other. After combining all these modulated signals we can achieve an OFDM signal. The Fig.1 shows typical transmitter structure of OFDM signal and Fig.2 shows orthogonality among subcarriers [2]. One of the main reasons of doing this splitting of data stream is to increase the symbol duration which will reduce the relative amount of time dispersion caused by the delay spread which occurs through wireless channel propagation so that a frequency selective fading channel will be observed as a flat fading channel.

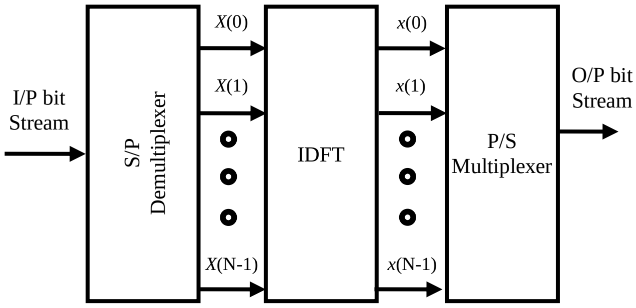


Fig.1. Schematic diagram of OFDM signal generation

Consider we have N symbols $X(0)$, $X(1)$……… $X(N\text{-}1)$, that will be transmitted using N number of carrier such as $\phi_0[n]$, $\phi_1[n]$………… $\phi_{n-1}[n]$ so final output signal can be given as

$$x[n] = X(0)\phi_0[n] + X(1)\phi_1[n] + \ldots + X(N-1)\phi_{N-1}[n] \qquad (1)$$

To get the orthogonality among subcarriers we take N different rows of the IDFT matrix as the N subcarriers [2].

where, $\phi_k[n] = \frac{1}{\sqrt{N}} e^{j2\pi kn/N}$ corresponds to the k^{th} row of the IDFT matrix. This IDFT operation can be done efficiently by implementing IFFT algorithm. OFDM signal can be represented using Eq.(1) as follows,

$$x[n] = \frac{1}{\sqrt{N}} \sum_{k=0}^{N-1} X(k) e^{j2\pi kn/N} \text{ for } 0 \le n \le N\text{-}1 \qquad (2)$$

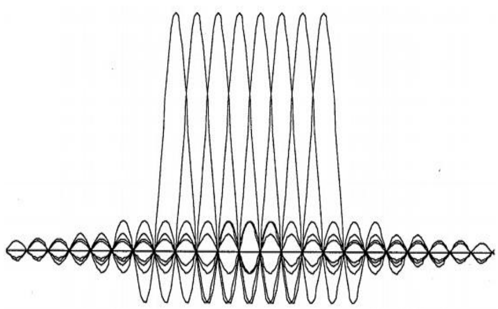


Fig.2. Illustration of orthogonality among subcarriers

Modulation and demodulation are key aspects of any communication system. In OFDM system IFFT and FFT operations are used for modulation and demodulation purpose at the transmitter and receiver respectively. So before an OFDM system can perform demodulation task it has to first find out the exact symbol starting point in order to avoid the effect of inter carrier interference (ICI) and inter symbol interference (ISI). Secondly it has to estimate the amount of CFO introduced in the received signal and correct that CFO as well. The CFO is caused due to carrier frequency misalignment between transmitter and receiver or due to Doppler shift when there is relative motion between transmitter and receiver. The effect of CFO is very severe as it introduces loss of orthogonality among the subcarriers leading to ICI. In order to characterize received signal under the presence of CFO and STO , let consider ϵ as the normalized CFO and δ as the normalized STO then the received signal can be given as follows,

$$r(n) = \frac{1}{N} \sum_{k=0}^{N-1} X(k) H(k) e^{j2\pi(k+\epsilon)(n+\delta)/N} + w(n) \qquad (3)$$

Normalized carrier offset can be given as, $\epsilon = \frac{\Delta f}{B/N}$

where, $\Delta f = \frac{v}{c} f_c$ is the carrier frequency offset caused due to Doppler frequency shift or it can be represented as the difference between carrier frequencies generated at the transmitter and receiver where, v represent velocity of receiver, c as the speed of light, f_c as carrier frequency. B represents total bandwidth, N is total number subcarriers, $r(n)$ represents n^{th} received sample, $X(k)$ represents data transmitted on the k^{th} subcarrier, $H(k)$ represents the channel coefficient across k^{th} subcarrier, $w(n)$ represents n^{th} noise sample.

3. PROPOSED METHOD

In this paper, we focus on preamble-aided method since it gives a more accurate estimation performance in both continuous and burst mode type transmission. Here we have proposed low complexity timing estimator which has smaller estimator MSE not only in low frequency offset condition but in the high frequency offset as well. The samples of the proposed preamble can be generated similar to the preamble structure of [9] except later half is not conjugated so that it will be employed as [6] preamble as well which will filter out unnecessary peaks. This preamble structure can be given as follows:

$$P_{pro} = \left[A_{N/4} B_{N/4} A_{N/4} B_{N/4}\right] \qquad (4)$$

where, B is time reversed and complex conjugated version of A. The proposed structure takes the advantages of the both preamble [6] and [9]. It has two identical halves as well as symmetrical property.

For proposed method the timing metric is calculated in two steps. First step is similar to given by [9]:

$$M_x = \frac{|P_x(d)|^2}{(R_x(d))^2} \qquad (5)$$

where,

$$P_x(d) = \sum_{n=1}^{N/2} r(d-n).r(d+n) \tag{6}$$

and

$$R_x(d) = \sum_{n=1}^{N/2} \left| r(d+n) \right|^2 \tag{7}$$

The Fig.4(a) shows the timing metric calculated by Eq.(8) under no channel impairment conditions. The metric shows largest peak corresponding to the full symbol match which occurs at the correct starting point while two minor peaks which are $N/4$ samples away before and after the correct symbol starting point. The $P_x(d)$ is designed such that, sum of the pairs of product is maximum in M_x at the exact starting point while at the other points values are almost zero but due to symmetric structure of preamble there are some of the other peaks are also generated at each $N/4$ samples apart from the major peak. These minor peaks are due to partial symbol match. These minor peaks will be hindrance in finding the correct symbol time in ISI channel. In order to filter out peaks other than the desired one we multiply the proposed metric with [6] timing metric because the value of this metric is very low in that region. Now we can present the second step of the proposed timing metric as follows,

$$M_{pro} = M_x . M_y \tag{8}$$

where,

$$M_y = \frac{\left| P_y(d) \right|^2}{\left(R_y(d) \right)^2} \tag{9}$$

$$P_y(d) = \sum_{n=0}^{N/2-1} r*(d+n).r\left(d+n+\frac{N}{2}\right) \tag{10}$$

and

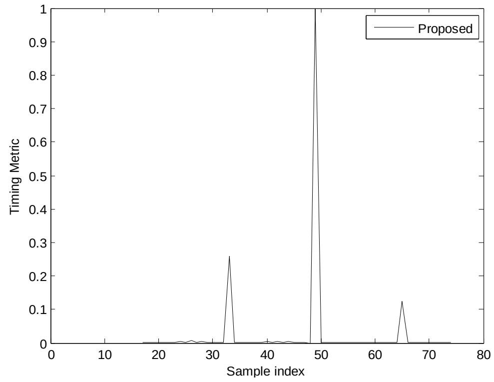
$$R_y(d) = \sum_{n=0}^{N/2-1} \left| r\left(d+n+\frac{N}{2}\right) \right|^2 \tag{11}$$

As we can see that proposed timing metric is based on autocorrelation technique applied twice in different ways hence the name is double autocorrelation technique. The Fig.3 shows the test vector used for testing the timing metric of the proposed method, where 32 samples of zeros are sent prior to preamble. Cyclic prefix of 16 samples as *B* is followed by preamble of 64 samples after that data is transmitted. This structure represents the scenario of typical burst packet transmission. From the test vector structure we can see that the start of the symbol is 49th sample. Fig.4(a) shows timing metric performance plot of the proposed method under no channel distortion, where we can see that major peak at the right after the cyclic prefix at 49th sample which is the starting point of symbol.

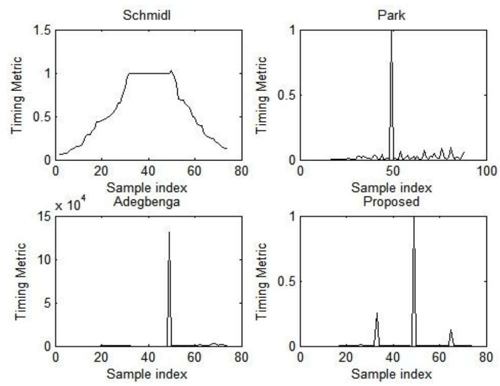
Zeroes	*B*	*A*	*B*	*A*	*B*	*data*

Fig.3 Test vector structure for testing the timing metric

In order to see performance of proposed method, we implemented the algorithm and obtained the timing metric in various channel conditions with low and high CFO scenarios. Fig.4(b) shows the comparison between preamble aided timing estimators under ideal channel conditions with 64 subcarriers and 16 cyclic prefix. As from Fig.3 we can see that correct symbol starting index is 49 while in Schmidl's method [6] we can see that the plateau starts at the sample 33, which is the starting point of the CP, and the plateau goes till the sample 49, which is the start of the symbol. This causes uncertainty in finding exact starting point. Although Schmidl's method gives an idea to take average of two 90% maximum point to estimate the correct starting point but it still not ensures the exact staring point. In [9] we can see that it has impulse shape timing metric at the exact symbol starting point but at other points it has some small peaks as well. In [12] timing metric is formed after the frequency offset correction of the received signal so it has impulse shape at exact starting point but its performance is not so good in the presence of high CFO.



(a)



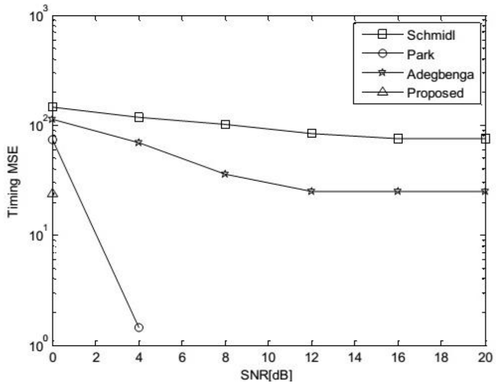
(b)

Fig.4 (a). Proposed timing metric under ideal channel condition (b). Comparison of the timing metric of estimators under ideal channel condition

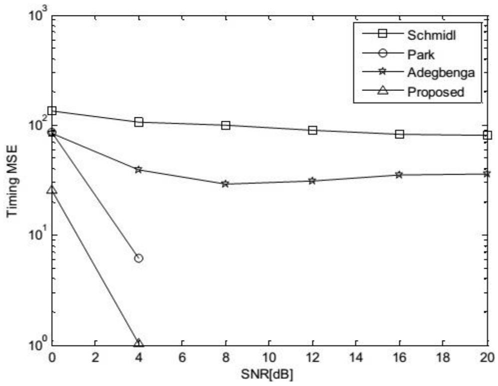
4. SIMULATION RESULTS

We compared the performance of the proposed method by computer simulations and compared the results with Schimdl's method [6], park's method [9] and Adegbenga's method [12]. QPSK sub-carrier modulation is used with a normalized frequency offset ϵ = 0.1 and 0.5, FFT size N = 64 and cyclic prefix length $N_g = 16$, sampling time of input signal t_s = 0.05μs, Doppler frequency shift Δf = 200Hz. We have considered different types of channel conditions such as ideal, AWGN, Rayleigh fading ISI channel and HIPERLAN/2 indoor channel A [9]. We have performed simulation in the presence of CFO so that we can check the robustness of proposed method with previous works.

We have compared the MSE of the timing offset estimation of the proposed method with the previous methods. For AWGN channel the proposed method achieves an ideal timing accuracy with zero timing mean-square-error (MSE) at low CFO of 0.1 as shown in Fig.5(a). For the same case timing MSE of Park's method [9] is fractional at moderate SNR and shown to be significantly better than Schmidl's method [6] and Adegbenga's method [12] at higher SNR. In Fig.5(b) we can see that at high CFO of 0.5, the performance of proposed method is still superior to others.



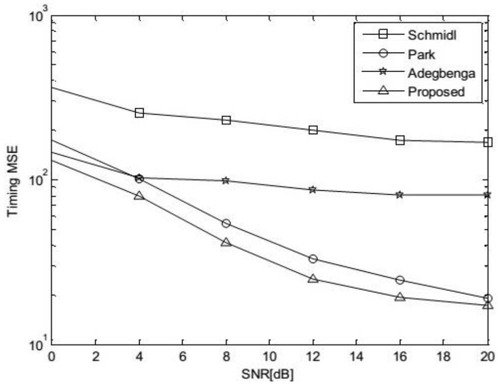
(a)



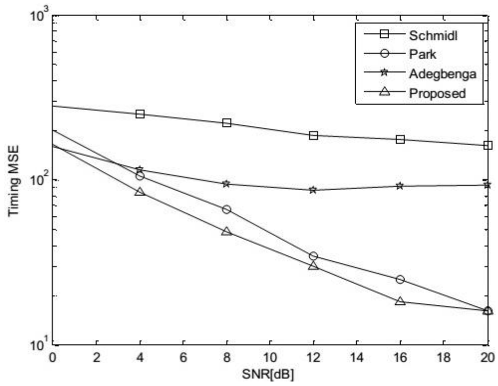
(b)

Fig.5 (a). MSE of estimators in an AWGN channel with CFO=0.1, N=64, G=16 (b). MSE of estimators in an AWGN channel with CFO=0.5, N=64, G=16

The Fig.6(a) and Fig.6(b), shows performance evaluation in Rayleigh fading ISI channel in both low and high CFO condition respectively. We have evaluated performance of the proposed method in randomly varying nature of transmission medium where we assume that magnitude of the signal will fade according to Rayleigh distribution. In this type of transmission medium basically there is no direct line of sight path exist between transmitter and receiver which will be applicable to model urban environment. Here we can see that performance of proposed method is still better than other methods in both low and high CFO condition.



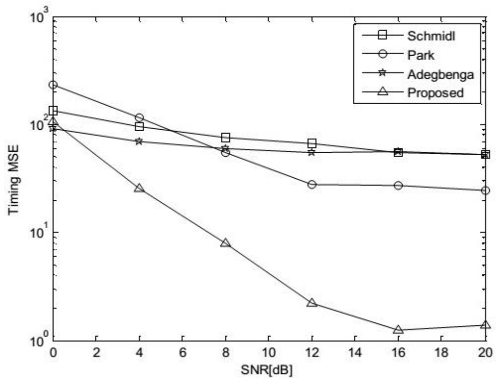
(a)



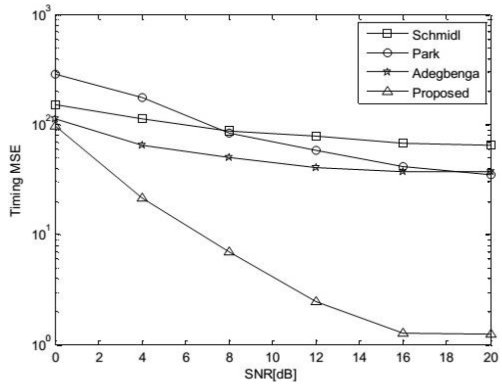
(b)

Fig.6 (a). MSE of estimators in a Rayleigh fading ISI channel with CFO=0.1, N=64, G=16 (b). MSE of estimators in a Rayleigh fading ISI channel with CFO=0.5, N=64, G=16

The Fig.7(a) and Fig.7(b) shows performance of proposed method in HIPERLAN/2 indoor channel A in low and high CFO condition respectively. HIPERLAN/2 is a version of High-Performance Radio Local Area Network (HIPERLAN) standards established by European Telecommunications Standards Institute (ETSI). It is aimed to provide fast wireless connection over different kind of networks. The operating frequency is 5GHz and it can offer a data rate up to 54Mbps. Here we can see that proposed method performs exceptionally well compared to the previous methods which show its robustness in various conditions. So from the simulation results it is verified that proposed method's timing estimation MSE is very less than other methods at all levels of SNR.



(a)



(b)

Fig.7 (a). MSE of estimators in a HIPERLAN/2 indoor channel A with CFO=0.1, N=64, G=16 (b). MSE of estimators in a HIPERLAN/2 indoor channel A with CFO=0.5, N=64, G=16

5. CONCLUSION

In this paper, we have proposed an improved robust preamble aided technique that uses only one training symbol with a simple structure having two identical parts as well as symmetrical structure to achieve robust OFDM synchronization in the time-domain. The proposed method uses double autocorrelation applied on the same preamble in two different ways to achieve the timing metric. Results show that proposed method has outperformed the existing methods in AWGN, Rayleigh fading ISI channel and HIPERLAN/2 indoor channel A without any CFO correction in received signal. Furthermore, its preamble structure is simple and compatible with current wireless networking standards which makes it a promising option for the timing synchronization of OFDM systems.

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