Robust Symbol Timing Synchronization for OFDM Systems Using PN Sequence

A. M. Khan, Varun Jeoti, M. A. Zakariya, and M. Z. Ur Rehman

***Abstract*—This paper presents the symbol timing synchronization for OFDM receivers using PN sequence of values 1 or -1. The proposed design preamble is based on the correlation property of Pseudo Noise (PN) codes. Simulation results show that the proposed scheme is more robust to multipath fading channel than the conventional PN-based Park method, particularly at low SNR. It helps in setting the high threshold value in timing metric estimator.**

***Index Terms*—Orthogonal frequency division multiplexing (ofdm), pn (pseudo noise), symbol timing offsets (sto) and preamble.**

I. Introduction

OFDM is considered as a current trend for wireless communication due to its high data rate transmission capability with high bandwidth efficiency [1]. OFDM transforms frequency selective channel into a non-frequency selective channel by separating the available spectrum into a number of orthogonal narrowband sub channels. OFDM introduces the Cyclic Prefix (CP),which eliminates Inter-Symbol Interference (ISI) between OFDM symbols [2].

In spite of above mentioned advantages, synchronization is still challenge in OFDM receivers. Inter-Carrier Interference (ICI) is generated in OFDM symbol due to imperfect frequency synchronization, while timing synchronization error causes ISI and destroys the orthogonality [3]. Hence, both need to be considered in OFDM receivers.

In this paper we have discussed symbol timing synchronization. Symbol timing synchronization must be performed to detect the starting point of each OFDM symbol (with the CP removed), which facilitates obtaining the exact samples. In general, STO estimation can be implemented either in time or frequency domain.

Mainly there are two types of STO methods: I) Cyclic Prefix (CP) and II) Training Symbol (TS). In CP based method, cyclic prefix is used to correlate with the last part of data symbol, while in TS based method, training symbols is used for symbol synchronization in the receiver. In contrast with CP, it involves overhead for transmitting training symbols, but it does not suffer from the effect of the multi-path channel [4]. This paper covers the TS based method for symbol timing estimation.

For correct timing estimation of OFDM symbol, different TS based methods have been proposed. The well-known frequency and time synchronization technique is proposed by Schmidl and Cox [5]; where two identical halves of training sequence are used, but Schmidl has high Mean Square Error (MSE). In [6], Minn has proposed identical preambles in time domain with opposite signs. Wang in [7], discussed a new method for STO estimation in two steps, but it has high complexity. An improved PN based preamble design is proposed by Ren [8], where constant envelop preambles approach is used. Similarly a robust joint estimator for timing and frequency offsets is discussed by Yang in [9]. Another attempt has been made by Park in [10], where he achieved impulse like timing response. It is assumed to be the better estimator because of its correct timing point index at 0. But on the other hand, it has been observed that peak of the timing metric (Park) degrades at low SNR and sometimes it reaches below the threshold value. Hence to rectify this problem we have proposed a preamble scheme that has PN sequence of values 1 and -1, which performs better at low SNR.

This paper is organized as follows. In Section II, OFDM system model is explained. Section III is divided into two subsections: Section III-A describes Schmidl timing estimator and Section III-B introduces Park timing estimator. In Section IV, proposed symbol timing synchronization technique is presented. Section V explained the methodology. Results and analysis are discussed in Section VI and conclusion of the work is presented in Section VII.

II. System Model

Consider the general case of linear, dispersive and noisy OFDM system. We use the standard complex-values baseband equivalent signal model. The n^{th} received sample has the standard form

$$y[n] = \sum_{m=0}^{L-1} h[m] x[n-m] \tag{1}$$

where $h[n]$ is channel impulse response [11], which has L number of channel . $x[n]$ is the time-domain OFDM signal expressed by

$$x[n] = \sum_{k=0}^{N-1} c_k e^{j\frac{2\Pi kn}{N}} \tag{2}$$

where N is number of subcarrier and c_k's are the complex information symbols. At receiver, timing offsets is modeled as a delay in the received signal and frequency offsets is

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modeled as phase distortion of the received data in the time domain. These two uncertainties and AWGN $w[n]$ yields received signal

$$r[n]=y[n-n_{\varepsilon}]e^{i(2\Pi\theta_{\varepsilon}n+\Phi)}+w[n] \tag{3}$$

where n_{ε} is the integer-valued unknown arrival time of a symbol, θ_{ε} is the frequency offset and is Φ the initial phase. Therefore the goal of timing synchronization is to estimate the n_{ε}.

III. Conventainal Symbol Timing Sychronization Techniques

In this paper, we present two conventional types of symbol timing synchronization techniques, which are known as Schmidl and Park.

A. Schmidl's Method

In this method, Schmidl introduced a training sequence, which has identical halves in time domain. These identical halves can be generated by transmitting the zeros on odd frequencies and PN sequence on the even frequencies. Then by taking *IFFT*, we will get the similar halves in time domain. Let N be the no of *IFFT* points in one OFDM symbol. The preamble used by Schmidl is as follows

$$P_{Sch}=\left[S/N \qquad S/N\right] \tag{4}$$

where S/N represents the sample length of $N/2$. The timing metric for Schmidl's can be written as

$$M_1(n)=\frac{|P_1(n)|^2}{(R_1(n))^2} \tag{5}$$

where $P_1(n)$ is the correlation term as shown below

$$P_1(n)=\sum_{k=0}^{N/2-1} r(n+k)^*(n+N/2+k), \tag{6}$$

$R_1(n)$ is energy term which can be expressed

$$R_1(n)=\sum_{k=0}^{N/2-1} \left|r(n+N/2+k)\right|^2 \tag{7}$$

and $r(n)$ is the received signal. In this technique, timing metric gives the plateau whose length is equal to length of CP. Plateau gives high MSE and ambiguity to find exact starting of point *FFT* symbol [12].

B. Park's Method

In Park method, zeros are transmitted on odd frequencies and real value of PN sequence is transmitted on even frequencies, therefore the basic form training sequence is similar to Schmidl. But Park achieves the impulse like timing response.

Park introduced the following pattern for preambles

$$P_{Park}=\left[S/4 \quad S(-n)/4 \quad S^*/4 \quad S^*(-n)/4\right] \tag{8}$$

where $S/4$ represents the sample length of $N/4$ and $S(-n)/4$ is the symmetric to $S/4$.

While $S^*/4$ and $S^*(-n)/4$ are the conjugate of $S/4$ and $S(-n)/4$ respectively. The timing metric for Park is expressed as

$$M_2(n)=\frac{|P_2(n)|^2}{(R_2(n))^2} \tag{9}$$

where $P_2(n)$ is the correlation term as shown below

$$P_2(n)=\sum_{k=0}^{N/2} r(n-k)(n+k) \tag{10}$$

and $R_2(n)$ is energy term which can be expressed

$$R_2(n)=\sum_{k=0}^{N/2} \left|r(n+k)\right|^2 \tag{11}$$

IV. Proposed Symbol Timing Sychronization Technique

The proposed method significantly improves the timing metric peak of the original Park method, particularly at low SNR. The peak of the Park's timing metric degrades at low SNR and sometimes it reaches below the threshold value.

Hence to rectify this problem we have proposed a preamble scheme that has PN sequence of values 1 and -1, which performs better at low SNR.

A. Design of Proposed Preamble

In the proposed method, pattern of preamble can be expressed as

$$P_{Pro}=\left[S/4 \quad S/4 \quad S^*/4 \quad S^*/4\right] \tag{12}$$

where $S/4$ represents the sample length of $N/4$ and (*) denote the conjugate. The preambles $S/4$ are generated by taking the *IFFT* of PN sequence of values 1 to -1. It means that at each frequency one of the BPSK point is transmitted. The timing metric used for proposed preamble is same as Park method, as shown in equation (9).

Fig. 2 shows the comparison of preambles between Park's and proposed method.

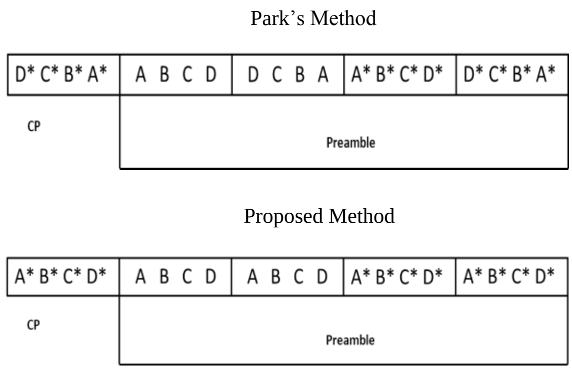

Fig. 1. Comparison of preambles between park's and proposed methods.

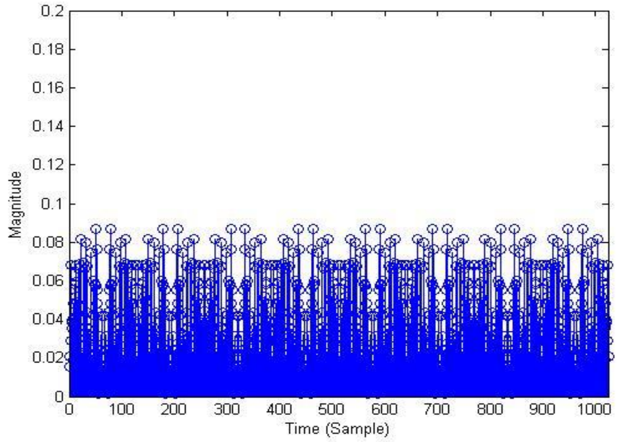

Fig. 2. Park's time domain preambles.

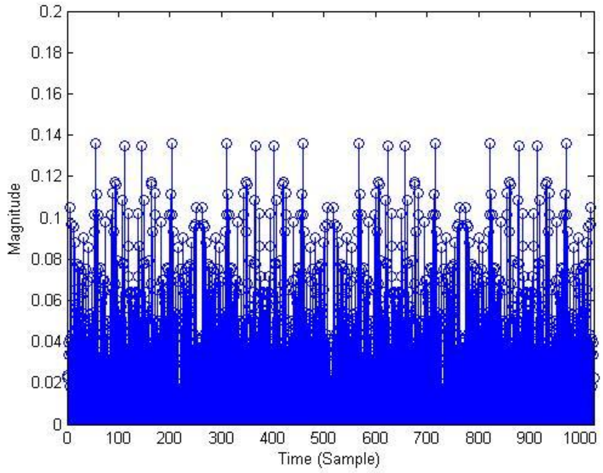

Fig. 3. Proposed time domain preambles.

V. Methodology

In time synchronization, two different types of training symbol are applied on a same timing estimator (Park). In first type of training symbol a real value of PN sequence is transmitted on even frequencies and zeros are transmitted on odd frequencies. While in second type of training symbol one of the point of BPSK constellations (1 or -1) is transmitted on each frequency. In this paper, we have estimated the peak of the timing metric for various values of SNR, particularly at low SNR. We also measure the difference of primary and secondary peaks. The OFDM simulations parameters are shown in Table I.

TABLE I: OFDM Parameters

No of *FFT* points (N_{fft})	1024
Length of Cyclic Prefix (N_g)	256
Total no of Subcarriers (N_{ofdm})	1280
Frequency Offset	0.1

VI. Results and Analysis

Time domain preambles for Park and proposed schemes are shown in Fig. 2 and Fig. 3 respectively. For simulation HYPERLAN/2 indoor channel model is used where 1024 subcarriers are used for data and 256 are used for cyclic prefix. It is shown that the average amplitude of proposed preambles is higher than the conventional preambles for Park. This is because; we have proposed PN preambles values 1 or -1 in frequency domain.

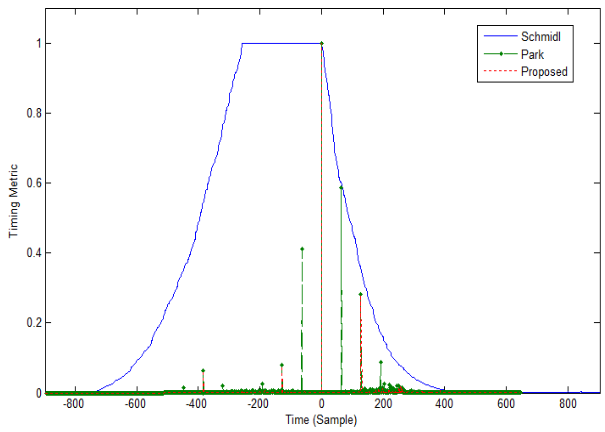

Fig. 4. Comparison of timing metric schmidl, park and proposed method.

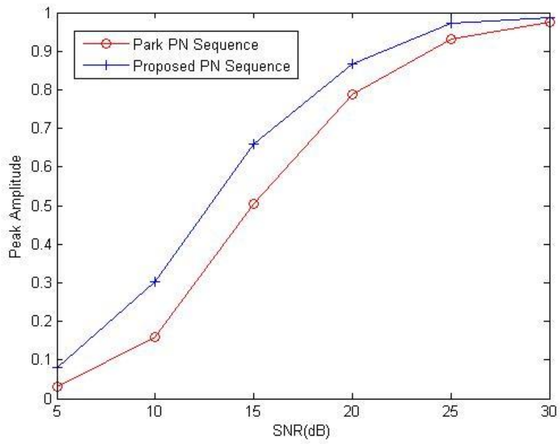

Fig. 5. Comparison of timing metric peak at various SNR.

In Fig. 4, timing metric of three techniques are compared under no noise condition, namely Schmidl, Park and proposed method. It reveals that the performance of the timing metric of Park and Proposed method is similar, as the correct timing point is indexed at 0. It is also shown that proposed method has impulse like timing metric.

We further analyze the peak of the timing metric at various SNR in Fig. 5. Simulation results have shown that the timing metric peak, in proposed technique is higher than the Park method, which helps in setting the high threshold value.

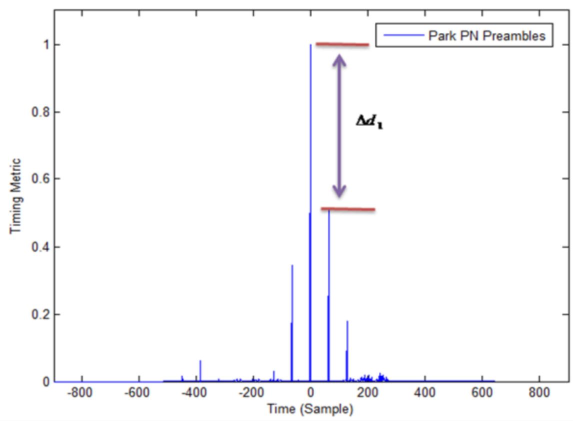

Fig. 6. Difference of primary and secondary peaks for park's preambles.

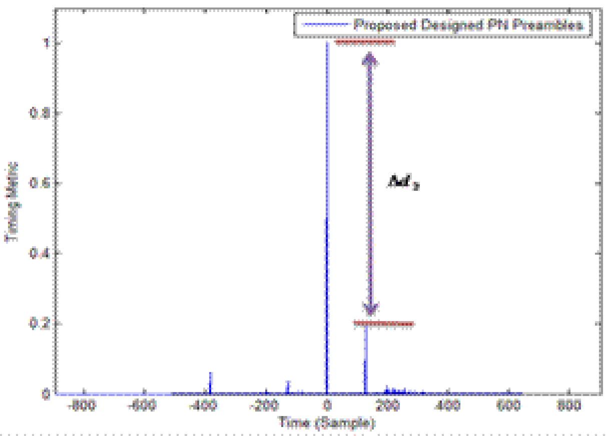

Fig. 7. Difference of primary and secondary peaks for proposed preambles.

In Fig. 6 and Fig. 7, we have shown difference of primary and secondary peaks for Park's and proposed methods respectively. It is shown that accuracy of proposed designed preambles is superior to Park's when measured in terms of primary and secondary peaks difference ($\Delta d_2 > \Delta d_1$). Therefore, the probability of false detection of STO decreases in proposed method.

VII. Conclusion

This paper presents the study of PN sequence as a preamble in OFDM receivers for time synchronization. The study suggests that the correlation property of Park PN sequence can be improved by using PN values as (1 or -1). Accordingly the proposed PN based preambles are more robust to the multipath fading channel at low SNR, which helps in setting the high threshold value in timing metric estimator.

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