

# Timing Error Estimation in OFDM Based wireless Communication System Using Matched Filter

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**Abstract** – In Orthogonal Frequency Division Multiplexing (OFDM) System time and frequency synchronization are important issues to be solved. This project is focused on time synchronization of OFDM system. Timing synchronization means estimation of timing error followed by correction of timing error. Timing error if present causes misalignment of FFT window and if timing synchronization is not performed with sufficient accuracy, the orthogonality among the sub-carriers is lost, and the communication system suffers from intersymbol interference (ISI) and intercarrier interference (ICI). For the timing error estimation in OFDM system the training symbols with good autocorrelation properties are required. Matched filter can then be used for estimation of the error by performing matched filtering between received signal and the training signal generated at the receiver. In this project the performance of matched filter based timing error estimator will be verified in MATLAB using some parameters like probability of correct detection, mean square error etc. Also BER analysis will be done.

**Keywords** — Carrier Frequency, Orthogonal Frequency Division Multiplexing, Timing Estimation.

## I. INTRODUCTION

In orthogonal frequency division multiplexing (OFDM) systems, time and frequency synchronization are important issues to be solved [2]. If these tasks are not performed with sufficient accuracy, the orthogonality among the sub-carriers is lost, and the communication system suffers from intersymbol interference (ISI) and intercarrier interference (ICI). Several techniques have been proposed recently for OFDM timing and frequency synchronization. Since received cyclic prefix is usually affected by ISI, the performance of this estimator depends on the channel. To avoid this problem in timing synchronization, the method in [2] uses a training symbol with two identical halves in time domain. However, the timing metric used in [2] suffers from broad autocorrelation function (ACF), which may result large timing estimation error. This blurry ACF can be eliminated and, hence, timing offset estimation error can be reduced by designing a special training symbols which give more sharper timing metric trajectory [6] [7]. It is well known that pseudo-noise (PN)-sequences have good autocorrelation properties. Therefore, many authors have proposed the use of time domain PN-sequence as preamble in OFDM systems. [8] In this paper, we propose a method which uses the Schmidl and Cox's training symbol generation [2]. Therein, two identical halves in time domain are generated by transmitting PN sequence on the even frequencies, while zeros are transmitted on the odd frequencies. As a difference, instead of correlating two identical halves with each other in the receiver [2] our proposal utilizes matched filter (MF) for time and frequency synchronization. [1]

The rest of the paper is organized as follows. The proposed time synchronization methods are described in Sections II. In Section III simulated results are compared with theoretical ones in additive white Gaussian noise (AWGN) channel for verifying obtained results.

## II. TIME SYNCHRONIZATION METHOD

A block diagram of the typical OFDM system is shown in Fig.1. Therein, input data bits are first encoded, interleaved and mapped to data symbols, each of which modulates a different subcarrier. In the proposed scheme, the transmitter transmits every now and then a PN-preamble, whose length is  $L$ . This PN-sequence is then zero padded such that zeros are placed on the odd frequencies after serial-to-parallel (S/P) conversion. Therefore, the total length of the PN-preamble is  $2L$ , which is equal to the number of subcarriers ( $N_c$ ). Multicarrier modulation is performed by taking the inverse fast Fourier transform (IFFT) of data symbols. The discrete time baseband OFDM signal can be expressed as

$$s(n) = \frac{1}{\sqrt{N_c}} \sum_{k=0}^{N_c-1} D(k) e^{j2\pi kn/N_c}, \quad (1)$$

Where  $D(k)$  is a data symbol which modulates  $k$ th subcarrier. When the number of subcarriers is sufficiently large,  $s(n)$  approximates a complex Gaussian process with zero mean and variance  $2 s = E\{|s(n)|^2\}$ . An OFDM symbol has a useful symbol period  $T_u$  and preceding each symbol is a cyclic prefix of length  $T_{cp}$ , which is longer than the channel impulse response so that there will be no ISI. The baseband signal is digital-to-analog (D/A) transformed and up-converted to the radio frequency (RF) and then transmitted through the channel.

At the receiver, discrete time baseband signal  $r(n)$  is obtained by down-converting and analog-to-digital (A/D) transforming the continuous time RF-signal. In an AWGN channel, without frequency offset,  $r(n)$  is given by

$$r(n) = s(n - \tau) e^{j\varphi} + \eta(n), \quad (2)$$

where  $\tau$  is the propagation delay,  $\varphi$  is the carrier phase and  $\eta(n)$  is AWG noise with zero mean and variance  $2 = E\{| \eta(n) |^2\}$ . Cyclic prefix cannot be removed until the receiver has knowledge about frequency, phase, and symbol synchronization (Fig. 1). In this section, we concentrate on timing synchronization where the starting point of the OFDM symbol is estimated. After cyclic prefix removal, multicarrier demodulation is performed by taking the fast Fourier transform (FFT). Then the received information symbols are demapped to bits which are de-interleaved and decoded.

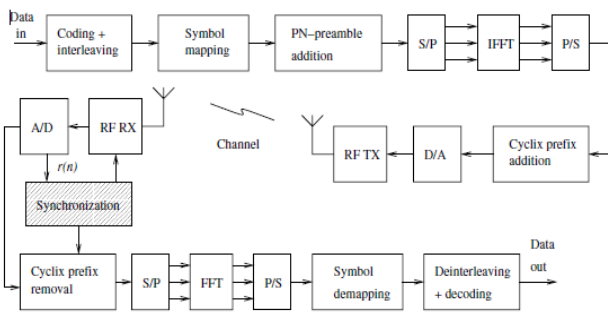


Fig.1. A block diagram of the OFDM system

### A. Time Domain MF Synchronizer

Fig. 2 shows the block diagram of the non coherent MF timing synchronizer implemented in time domain. The sampled signal  $r(n)$ , from A/D converter (Fig. 1), has signal-to-noise-ratio (SNR) =  $\frac{2}{s} / \frac{2}{s}$ .

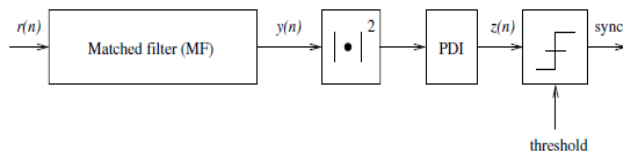


Fig.2: Noncoherent MF time synchronization unit in time domain.

The signal  $r(n)$  is then passed through MF whose impulse response  $h(n)$  is complex conjugated, time reversed and delayed version of one half of the  $sPN(n)$ , i.e.,  $h(n) = s^*PN(L-n)$ . When the preamble signal  $sPN(n)$  is filtered using this MF, then two identical sharp ACFs occur as can be seen from Fig.3. This is because the transmitted preamble consisted of two identical halves. Post detection integration (PDI) can be used to combine these two ACFs and time synchronization is made from this combined signal shown in Fig. 4. As a reference, timing metric of the Schmidl and Cox's method is shown in Fig. 5. By comparing these figures, it can be seen that the proposed scheme provides sharper timing metric. Next, the theoretical synchronization probabilities for the proposed method are presented. When  $sPN(n)$  and  $h(n)$  are not synchronized, then the output of the MF ( $y(n)$ ) is (if an ideal ACF is assumed) complex valued Gaussian distributed random variable with zero mean and variance equal to  $L/2$  per I and Q branch. Therefore, the decision variable  $z(n)$  after magnitude squaring and PDI follows the central chi-square distribution with 4 degrees of freedom and the probability of false alarm (PFA) is

$$P_{FA} = \exp\left(\frac{-T_H}{L\sigma_\eta^2}\right) \sum_{k=0}^1 \frac{1}{k!} \left(\frac{T_H}{L\sigma_\eta^2}\right)^k, T_H \geq 0. \quad (3)$$

From which the detection threshold  $TH$  can be calculated in order to obtain the desired PFA. In the synchronous code phase position decision variable  $z(n)$  is characterized by the non central chi-square distribution and the probability of detection (PD) is

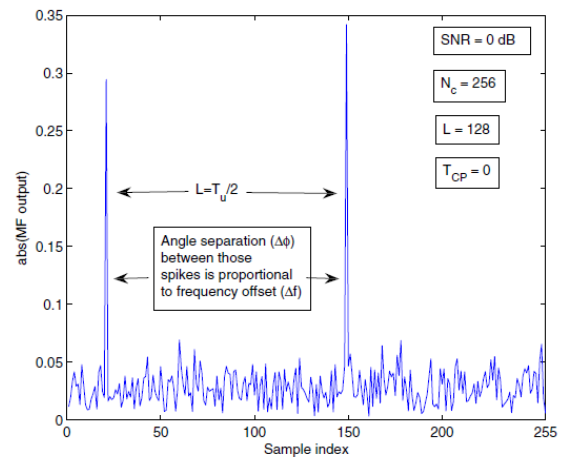


Fig.3. Magnitude squared output of the MF.

$$P_D = Q_2\left(\sqrt{\frac{4L\sigma_s^2}{\sigma_\eta^2}}, \sqrt{\frac{2T_H}{L\sigma_\eta^2}}\right). \quad (4)$$

Where  $Q(\cdot)$  is the generalized Marcum's  $Q$ -function.

When the decision is made according to the maximum selection, then the largest sample from  $L$  possible samples is selected from the set  $\{z(n)\} = [z(n) z(n+1) \dots z(n+L-1)]$ . The selected largest sample can be taken either from the "correct" ( $z(c)$ ) or from the "wrong" code phase ( $z(w)$ ). The probability of selecting the correct sample from the set  $\{z(n)\}$  is denoted by  $P_{Max} = P(z(c) > z(w)_i)$ , where  $i$  refers to all of the  $L-1$  possible false code phases. The probability  $P_{Max}$  is obtained as

$$P_{Max} = P(z(w)_i < z(c), \forall i) = \int_{-\infty}^{\infty} p(z(c)) [P(z(w) < z(c))]^{L-1} dz(c), \quad (5)$$

where  $p(z(c))$  is the probability density function (PDF) of the random variable  $z(c)$ . The probability that the maximum sample is taken from the correct time instant and, in addition, it also exceeds the threshold  $TH$  can be calculated as

$$PD, Max = P_{Max} PD, \dots \dots \dots (6)$$

which is a useful probability when both maximum selection and threshold comparison are utilized.

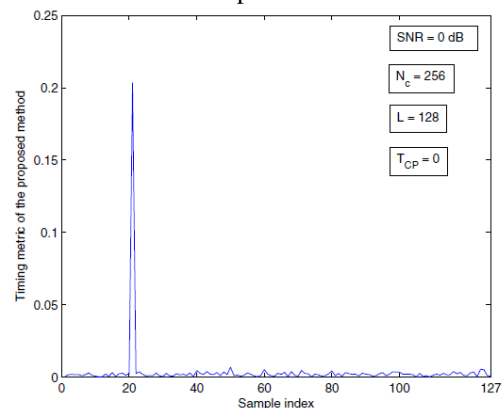


Fig.4. Noncoherently combined autocorrelation function

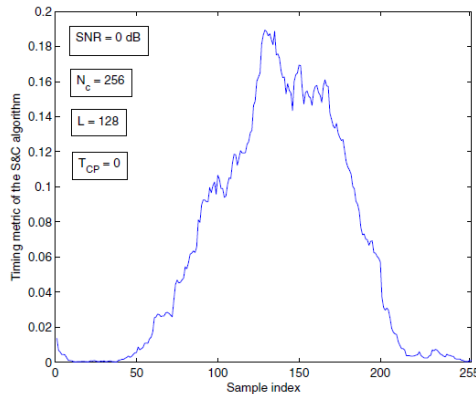


Fig.5. Timing metric of the Schmidl and Cox's method

### III. CONCLUSIONS

A Matched filter based time and frequency synchronization method for OFDM systems was proposed, which provides fast synchronization using PN-sequence preambles. The proposed method transmits a known PN-preamble in the frequency domain and it has two identical halves in the time domain. Because MF in the receiver is matched to one half of this time domain preamble, two identical autocorrelation functions are achieved from the MF output. These two autocorrelation functions are used for timing and frequency synchronization. In timing synchronization, these autocorrelation functions are combined non-coherently. In frequency synchronization, a phase difference between those is estimated. The obtained results indicate that the proposed method attains the optimum theoretical performance.

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