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Time and Frequency Synchronization in OFDM System

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Abstract

Orthogonal frequency division multiplexing (OFDM) is one of the multicarrier modulation techniques, which transmits data in very high rate and efficiently mitigates the effects of multipath distortions as well as loss in bandwidth efficiency. However, OFDM systems are very sensitive towards synchronization error. Synchronization of an OFDM signal is required to find the symbol timing and carrier frequency offset (CFO). Before demodulation of subcarriers, either from explicit training data or using cyclic prefix of the OFDM signal we can get synchronization at receiver. After demodulation of the OFDM subcarriers, information about the synchronization can be obtained from training symbols embedded into the regular data symbol pattern. The estimation of synchronization error can be performed depending on the type of the training data. In this paper, it is focused on preamble based training data following IEEE802.11a preamble structure of the WLAN system and cyclic prefix based training data. According to the preamble structure of IEEE 802.11a Wireless Local Area Network (WLAN) standard, the problem of synchronization is solved. The OFDM system is modelled by using LTE standards as it is more popular in 4G mobile communications. And the synchronization is being tested in simulation by using preamble structure of IEEE 802.11a in preamble based synchronization and by using cyclic prefix in cyclic prefix based synchronization.

Keywords

Carrier frequency offset, cyclic prefix based synchronization, IEEE 802.11a, LTE, OFDM, and Preamble based synchronization and STO.

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1. Introduction

Orthogonal Frequency Division multiplexing (OFDM) is a parallel data transmission technique that can efficiently mitigate the effects of multipath distortions and the loss in bandwidth efficiency. Basically, OFDM is one of the multicarrier modulation (MCM) techniques which transmit the signal through multiple carriers by converting wideband channel into multiple narrowband sub-channels where each sub-channel experiences flat fading. And also in single carrier system, all the data present in single carrier may be lost, whereas in multicarrier transmission data may be lost in one or two subcarriers, but not the whole data stream. Thus, OFDM offers several advantages over conventional modulation techniques [1]-[3]. However, OFDM transceiver requires a bank of sinusoidal oscillators for modulation and demodulation with precise phasing to maintain minimum crosstalk between sub-channels. In addition, the coherent demodulation process becomes bulky and expensive due to the increase in the number of sub-channels. The concept of OFDM is first introduced by Robert W.Chang in 1966 which gives bandwidth efficiency without ISI and ICI with bank of oscillators at the modulator and demodulator [4]. In 1971, a digital implementation of OFDM system was suggested by Weinstein and Ebert which replaces the bank of sinusoidal oscillators with IDFT and DFT to perform modulation and demodulation respectively. In addition, when the number of sub-channels is large, FFT algorithm can be implemented for faster and more efficient digital computation. OFDM has gained an increased interest during the last few years as a multicarrier transmission modulation technology [5]-[7]. Consequently, it has become a mature technology in both wired and wireless communication applications and standards such as ADSL, VHDSL, DAB, DVB-T, WLAN IEEE 802.11 a/g/n standards, 3GPP LTE and 4G LTE-Advanced. However, OFDM system is highly sensitive towards synchronization errors due to the nonidealities between the transmitter and receiver oscillators as well as the detection for the starting of the packets at the receiver [6]. Synchronization is one of the important tasks performed at OFDM receivers. Synchronization of an OFDM signal is required to find the symbol timing and carrier frequency offset [8]. Finding the symbol timing for OFDM signal means estimation of detecting the start of symbol [9]. OFDM systems are very sensitive towards carrier frequency offsets, because they can only tolerate offsets which are a fraction of subcarrier spacing without a large degradation in system performance. The carrier frequency offset (CFO) causes due to mismatch of RF oscillator frequency at the transmitter and the receiver, and also due to Doppler shift [10]-[11]. The frequency offset causes two problems, one is the reduction of amplitude of the signal and the other is introduction of ICI. The estimation of synchronization error can be performed depending on the type of the training data [12]. The known pilot data or training data can be used for synchronization by inserting in various location of the signal. This method is known as data-aided synchronization. In this method the known pilot data may be one or two OFDM symbols. And also it gives efficient synchronization if the known pilots are used as preambles in IEEE802.11a standard packet structure of the OFDM based WLAN system [13]. So we can also name this method as preamble based synchronization. On the other hand, the cyclic prefix can be used as training or pilot data and this method is known as non-data aided synchronization or cyclic prefix based synchronization.

2. Synchronization in OFDM System

A. Preamble based synchronization

The synchronization algorithm which uses the structure of preamble is more efficient and more popular, because IEEE802.11a standard provides detail preamble structure of WLAN system. Before going to detail of synchronization preamble used in IEEE 802.11a is shown in figure "2".

The MAC protocol of IEEE 802.11 is essentially a random access network, so the receiver does not know exactly when a packet starts [14]. The task of the receiver is to detect first the start of an incoming packet. Packet detection is the task to find an approximate estimate of the preamble for an incoming packet data. As it is the first synchronization algorithm which is performed, so the rest of the synchronization process is dependent on good packet detection performance. In General, packet detection can be explained as a binary hypothesis.

Null Hypothesis: H_0

Alternative Hypothesis: H_1

The actual test is usually the form of test whether a decision variable m_n exceeds predefined threshold "Th".

$H_0 : m_n < Th \rightarrow Packet\ is\ not\ present$

$H_1 : m_n \geq Th \rightarrow Packet\ is\ present$

The performance of the packet detection algorithm can be summarized with two probabilities:

P_D : The probability of detecting a packet when it is truly present.

P_{FA} : The probability of the test incorrectly decides that, a packet is present, when actually there is none.

The little P_{FA} can be tolerated to guarantee good P_D .

There are different methods to find packet detection in WLAN. They are

a) Received signal energy detection
b) Double sliding window packet detection
c) Using preamble for packet detection

a) Received signal energy detection:

The simplest algorithm to find the start edge of the incoming packet is to measure the energy of the received signal. When there is no packet being received, the received signal r_n consists of only noise $r_n = w_n$. When the packet starts, the received energy is increased by the signal component $r_n = s_n + w_n$, thus the packet can be detected with a change in the received signal energy level. The decision variable m_n is then the received signal energy accumulated over some window of length *L* to reduce sensitivity to large individual noise samples.

$$m_n = \sum_{k=0}^{L-1} r_{n-k} r_{n-k}^{*} = \sum_{k=0}^{L-1} |r_{n-k}|^2 \qquad (1)$$

Calculation of m_n can be simplified by noting that it is a moving sum of the received signal energy. This type of sum is also known as sliding window. The rationale for the name sliding window is that at every instant of time *n*, one new value enters the sum and one old value is discarded.

$$m_{n+1} = m_n + |r_{n+1}|^2 - |r_{n-L+1}|^2 \qquad (2)$$

Thus the number of complex multiplications is reduced to one per received sample. However, to store all the values of $|r_n|^2$ inside the window, more memory is required. By using received signal energy packet is detected. This simple method suffers from a significant drawback, i.e. the value of the threshold depends on the received signal energy.

b) Double Sliding Window:

The double sliding window packet detection algorithm calculates two consecutive sliding windows of the received energy. The basic principle is to form the decision variable m_n as a ratio of total energy contained inside the two windows.

Figure “3” shows the windows A and B and the response of m_n to a received packet. The windows A and B are considered stationary relative to the packet that slides over them to the right. It can be observed that when only noise is received, the response is flat since both windows contain ideally the same amount of noise energy. When the packet edge starts to cover the window ‘A’, the energy in the window ‘A’ gets higher until the point where it is totally contained inside the start of the packet. This point is the peak of the triangle shaped m_n and the position of the packet corresponds to this sample index as shown in figure “3”. After this point window B starts to also collect signal energy, and when it is also completely inside the received packet, the response m_n is flat again. The packet detection is declared when m_n crosses over the Threshold value “Th”.

In Double sliding window algorithm value of m_n does not depend on the total received power. After getting the peak, the response levels off to the same value as before the peak, although the received energy level is much higher. The presence of peak refers to the presence of required Packet .Using the algorithm of double sliding window, which is a good approach, if the receiver does not have additional information about the received data. However, more can be done, if the receiver does have additional information about the received data.

$$a_n = \sum_{m=0}^{M-1} r_{n-m} r_{n-m}^{*} = \sum_{m=0}^{M-1} |r_{n-m}|^2 \qquad (3)$$

$$b_n = \sum_{l=0}^{L} r_{n+l} r_{n+l}^{*} = \sum_{l=0}^{L} |r_{n+l}|^2 \qquad (4)$$

$$m_n = \frac{a_n}{b_n} \qquad (5)$$

c) Using Preamble Structure:

The preamble of IEEE 802.11a has been designed to help the detection of the start edge of the packet. The standard of IEEE 802.11a gives guidelines on how to use the various segments of the preamble to perform the necessary synchronization functions. The preamble structure of the WLAN enables the receiver to use a very simple and efficient algorithm to detect the packet. The approach of Schimdl and Cox [15] is presented below for acquiring symbol timing, but the general method is applicable to packet detection. This method resembles the double sliding window algorithm, but it takes advantage of the periodicity of the short OFDM training symbols at the start of the preamble. This approach is the delay and correlate algorithm.

The figure “4” shows two sliding windows P and Q. The P window is a cross correlation between the received signal and a delayed version of the received signal, hence the name is delay and correlate. The delay z^{-D} is equal to the period of the start of the preamble.

The Q window calculates the received signal energy during the cross correlation window. The value of the Q window is used to normalize the decision statistic, so that it is not dependent on absolute received power level.

$$P_n = \sum_{k=0}^{L-1} r_{n+k} r_{n+k+D}^{*} \qquad (6)$$

$$Q_n = \sum_{m=0}^{L-1} r_{n+k+D} r_{n+k+D}^{*} \qquad (7)$$

$$m_n = \frac{|P_n|^2}{|Q_n|^2} \qquad (8)$$

Symbol timing synchronization:

The estimation of symbol timing is obtained using auto-correlation of received signal [16]-[17]. The auto-correlation of received signal can be expressed as:

$$R_{rr}(m) = \sum_{k=m}^{m+D-1} r(k)\, r^{*}(k+D) \qquad (9)$$

When this auto-correlation function will give maximum value, then the peak will be detected which gives the estimation of the start of the data symbols as shown in figure “5”.

Frequency synchronization:

In a typical wireless communication system, the signal to be transmitted is up converted to a carrier frequency prior to transmission. The receiver is expected to tune the same carrier frequency for down-converting the signal to baseband, prior to demodulation. Because of the device impairments, the carrier frequency of the receiver need not be same as the carrier frequency of the transmitter. When this happens, the received baseband signal, instead of being centred at DC (0MHz), will be centred at a frequency δf_c .

Let the transmitted signal be $s(n)$, then the complex baseband representation of the pass band signal is

$$y(n) = s(n)e^{j2\pi f_{tx} nT_s} \quad (10)$$

Here f_{tx} is the transmitter carrier frequency.
After the receiver down converts the signal with a carrier frequency f_{rx} , the received baseband signal ignoring noise can be represented as

$$r(n) = s(n)e^{j2\pi (f_{rx}-f_{tx})nT_s} \quad (11)$$

$$= s(n)e^{j2\pi\delta f_c nT_s} \quad (12)$$

$$\delta f_c = f_{rx} - f_{tx} \quad (13)$$

Where $r(n)$ is the received signal, $s(n)$ is the transmitted signal and δf_c is the frequency offset.
Let preamble period is D then

$$r(n+D) = s(n)e^{j2\pi\delta f_c (n+D)T_s} \quad (14)$$

$$r(n)r^*(n+D) = s(n)e^{j2\pi\delta f_c nT_s} s^*(n+D)e^{-j2\pi\delta f_c (n+D)T_s} \quad (15)$$

The auto-correlation function can be written as :

$$R_{rr}(n) = \sum_{n=0}^{N+D-1} r(n)r^*(n+D) \quad (16)$$

$$= \sum_{n=0}^{N+D-1} s(n)e^{j2\pi\delta f_c nT_s} s^*(n+D)e^{-j2\pi\delta f_c (n+D)T_s}$$

Finally the frequency error estimator can be formed as

$$CFO_{Est} = -\frac{\measuredangle R_{rr}(n)|_{peak}}{2\pi DT_s} = \hat{\delta} f_c \quad (18)$$

B. Cyclic prefix based synchronization

The synchronization using cyclic prefix method is similar with the preamble based method. Only the difference is that extra training symbols are not used for synchronization. The cyclic prefix of the OFDM signal can be used for finding the symbol timing offset (STO) and carrier frequency offset (CFO). This method reduces the over head of the bits. But the accuracy comes in preamble based synchronization than cyclic prefix based synchronization as more number of samples is used for correlation in case of preamble based synchronization.

Symbol timing synchronization:

The copy of the cyclic prefix is available at the end of the OFDM symbol, so that the auto-correlation of the cyclic prefix with its copy decides the start of the OFDM symbol. The maximum value of auto correlation function detects the peak and gives the information about the start of the next symbol as shown in figure “6”.
The estimation of symbol timing is obtained using auto-correlation of received signal. The auto-correlation of received signal can be expressed as:

$$R_{rr}(l) = \sum_{l=0}^{N_{CP}} r(n - N_{CP} + l)\, r^*(n - N_{CP} - N + l) \quad (19)$$

Where, $N \rightarrow Symbol\ length\ \ i.e\ \ 0 < n < N-1$
$N_{CP} \rightarrow Cyclic\ prefix\ length$
$l \rightarrow autocorrelation\ variable$

Frequency synchronization:

The received signal with carrier frequency offset δf_c is expressed as

$$r(n) = s(n)e^{j2\pi\delta f_c nT_s} \quad (20)$$

From the auto-correlation function of received signal in Equation “20”, it can be written as

$$R_{rr}(l) = \sum_{l=0}^{N_{CP}} s(n - N_{CP} + l)e^{j2\pi\delta f_c (n-N_{CP}+l)T_s} s^*(n - N_{CP} - N - l)e^{-j2\pi\delta f_c (n-N_{CP}-N+l)T_s}$$

$$= \sum_{l=0}^{N_{CP}} |s(n - N_{CP} + l)|^2 e^{j2\pi\delta f_c NT_s} \quad (21)$$

Therefore estimated CFO can be expressed as:

$$CFO_{Est} = \frac{\measuredangle R_{rr}(l)|_{peak}}{2\pi NT_s} = \hat{\delta} f_c \quad (22)$$

C. Comparison

CP based synchronization enables the time and frequency offset estimation with the redundant information present in cyclic prefix without additional pilots. Therefore the overall information rate increases. But due to the correlation of less number of samples the estimation of synchronization error cannot give good result. Therefore to enhance the performance we need to use some pilots for estimation of synchronization error.

The estimation of synchronization error due to time and frequency offset using pilots as redundant information gives better result than the CP based synchronization, but the information rate decreases due to the overheads of redundant information.

The pilots can be chosen as one OFDM symbol following single window sliding method or two

OFDM symbols following double sliding window method. More OFDM symbols used as pilot give better performance in synchronization. So to get better synchronization we have to compromise with information rate or vice versa.

The known pilot structure can be chosen using the preamble structure of the OFDM signal in IEEE802.11 standard of WLAN system. Therefore, the synchronization is easier due to the known pilots or preambles at the OFDM receiver.

In this paper, the OFDM system is modelled by using LTE standards as it is more popular in 4G mobile communications and the synchronization is being tested in simulation by using preamble structure of IEEE 802.11a [18].

3. Results and Discussion

Figure "1" shows the flow diagram for simulation.
Figure "7" shows the simulation result for the double sliding window technique with SNR 18dB in AWGN channel. In this example, the A and the B windows have a length of 64 samples. The triangle shape can clearly be observed beginning from sample number 1710 and ending around sample number 1774. These two numbers are the outer edges of the two windows when the timing metric reaches its peak. The start of the packet is sample number 1710 and the packet has detected at sample number 1740 which is the peak of the triangle.

From Figure "8" and "9", we observed that the frame synchronization error probability of occurrences spans less samples in case of SNR of 18dB compared to SNR of 3dB for same value of number of samples or symbol length (L) and CFO.

That is increase in SNR gives better frame synchronization.

Figure "10" shows root mean square error for carrier frequency offset (CFO) of 0.5 ppm decreases faster for symbol length of 1024 with increase in SNR than the symbol length of 512.That means increase in number of samples per symbol decreases frequency offset error.

Figure "11" shows bit error rate(BER) decreases with increase in signal to noise ratio(SNR) and BER vs. SNR performance of symbol length of L=1024 is better than L=512, i.e. increase in samples or symbol length gives better BER performance.

Figure "12" shows that the performance of BER vs. SNR in preamble-based synchronization is better than CP-based synchronization which is discussed in above comparison.

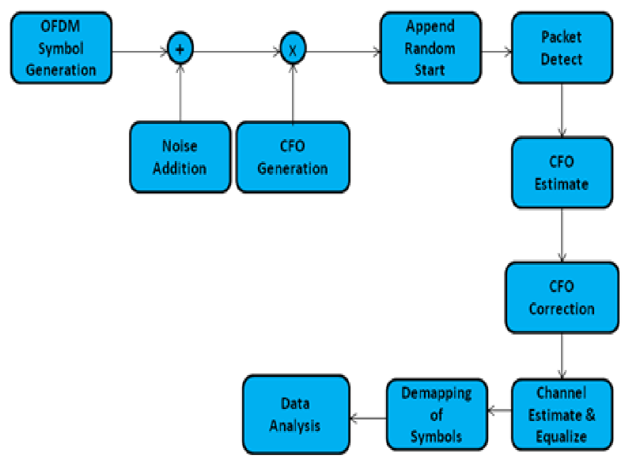

Figure 1: Simulation Flow diagram

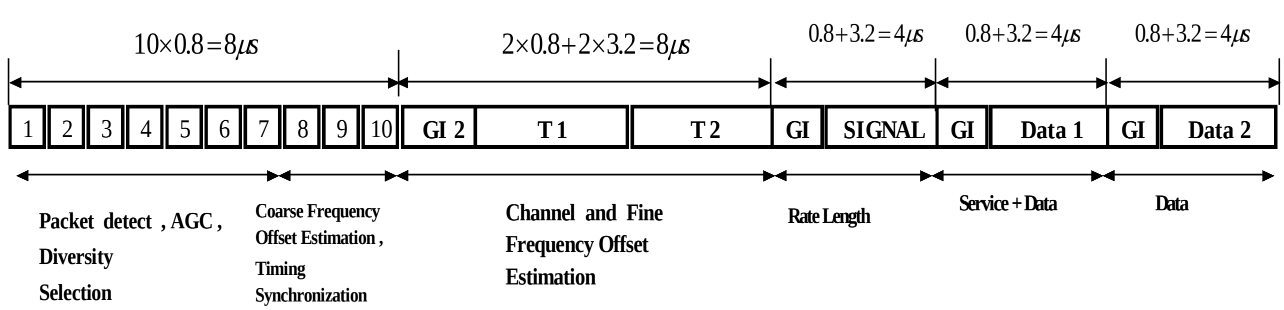

Figure 2: IEEE 802.11a Packet structure

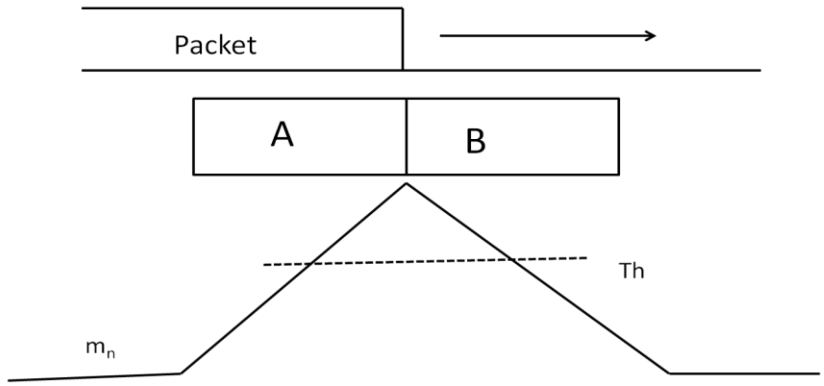

Figure 3: Double sliding window

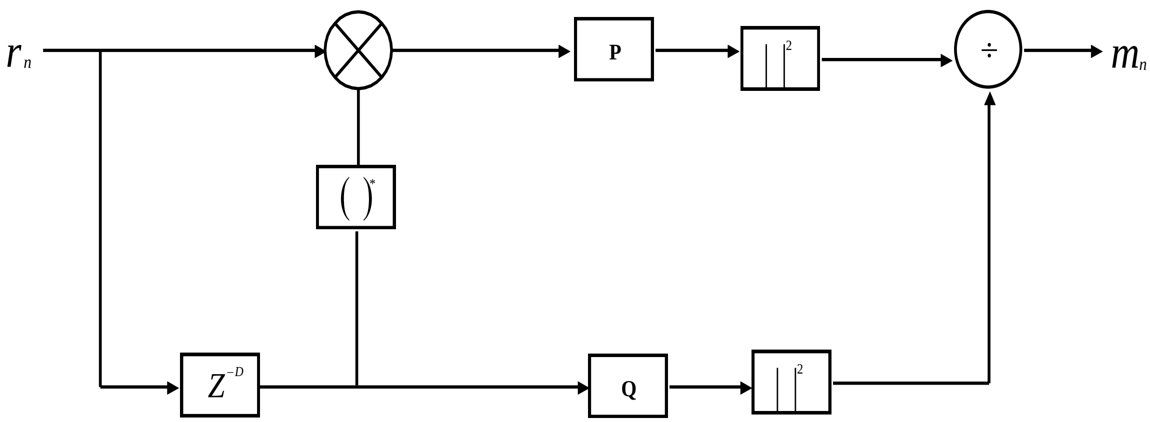

Figure 4: Signal flow structure of Delay and Correlate Algorithm

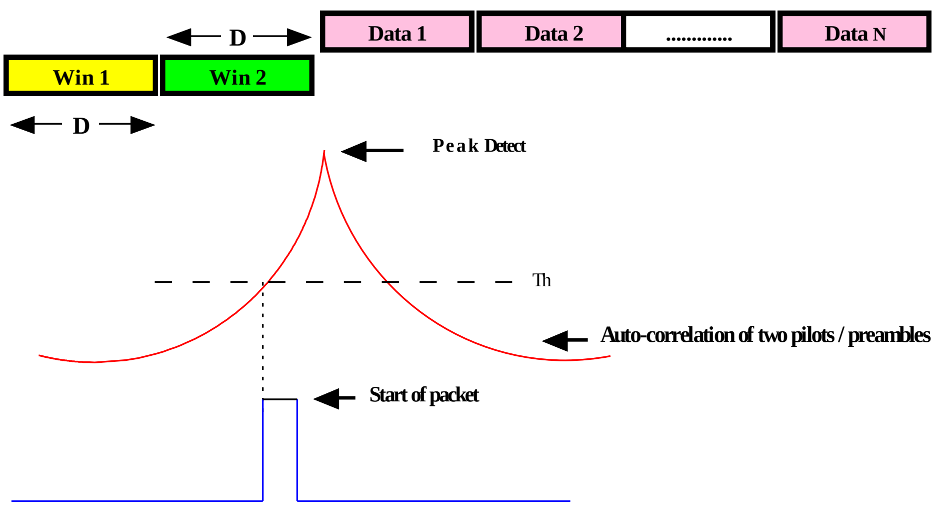

Figure 5: STO estimation using repetitive training symbol

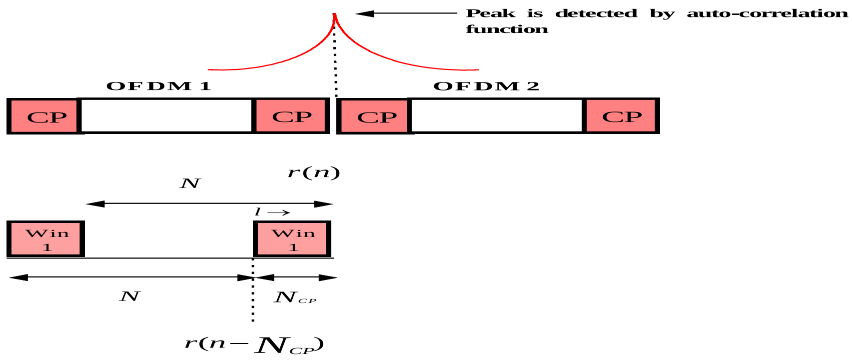

Figure 6: STO estimation using cyclic prefix

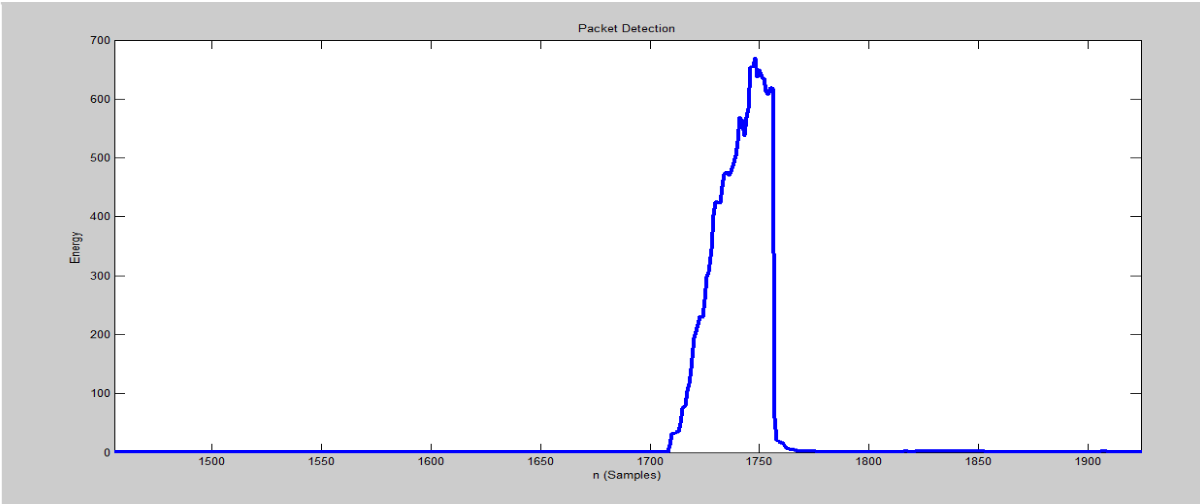

Figure 7: Packet Detection

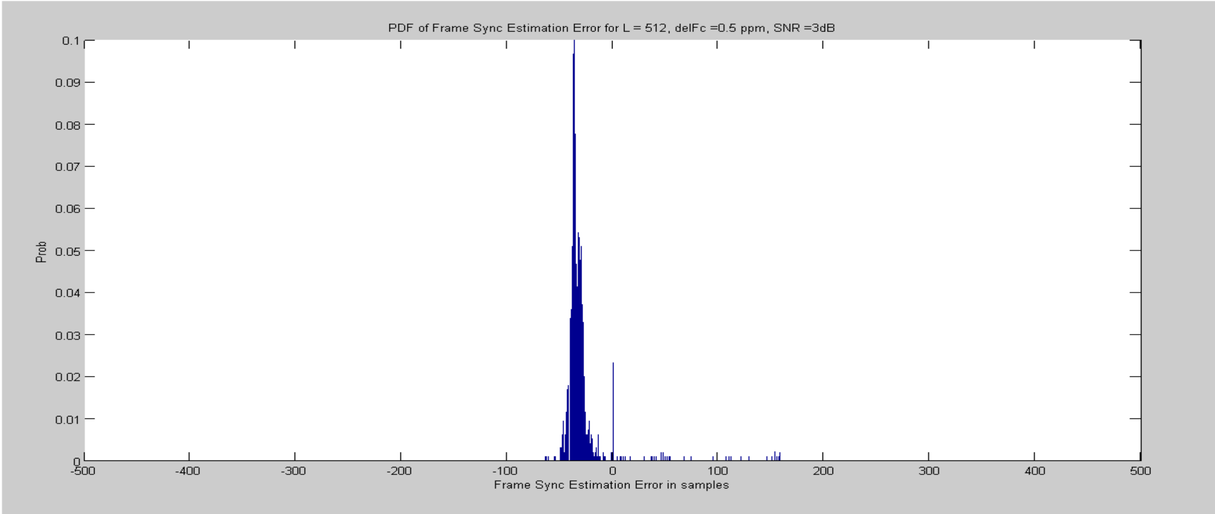

Figure 8: PDF of frame synchronization estimation error for L=512, delFc=0.5ppm, SNR=3dB

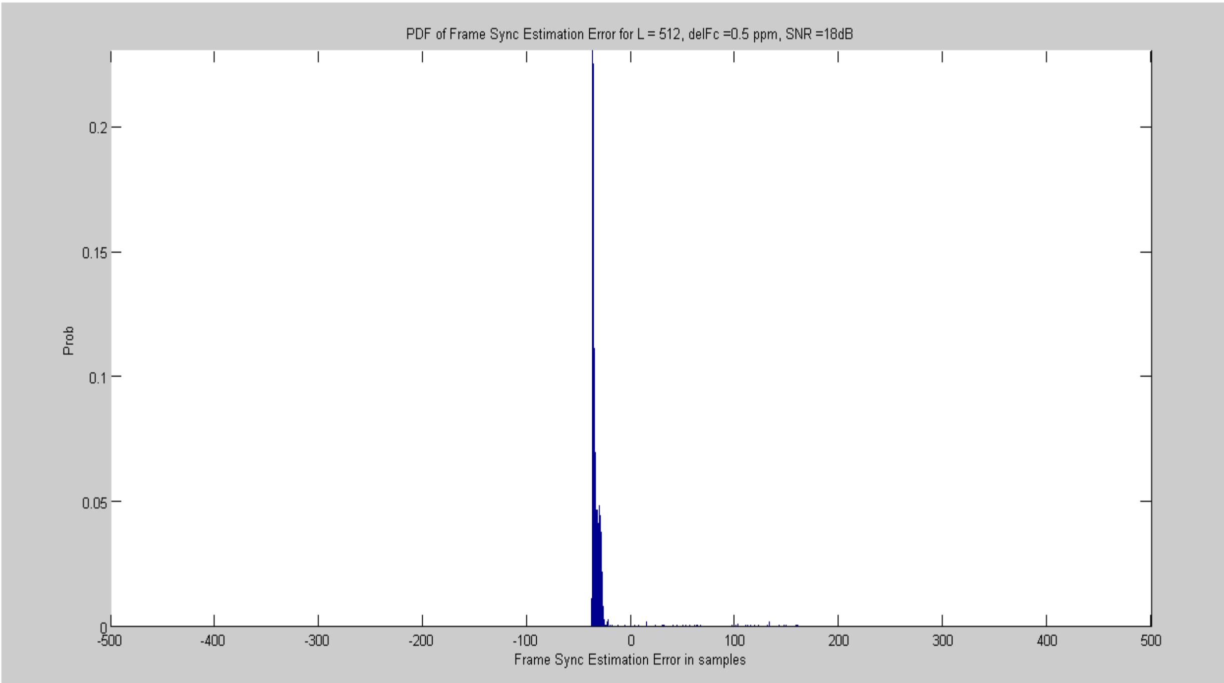

Figure 9: PDF of frame synchronization estimation error for L=512, delFc=0.5ppm,SNR=18dB

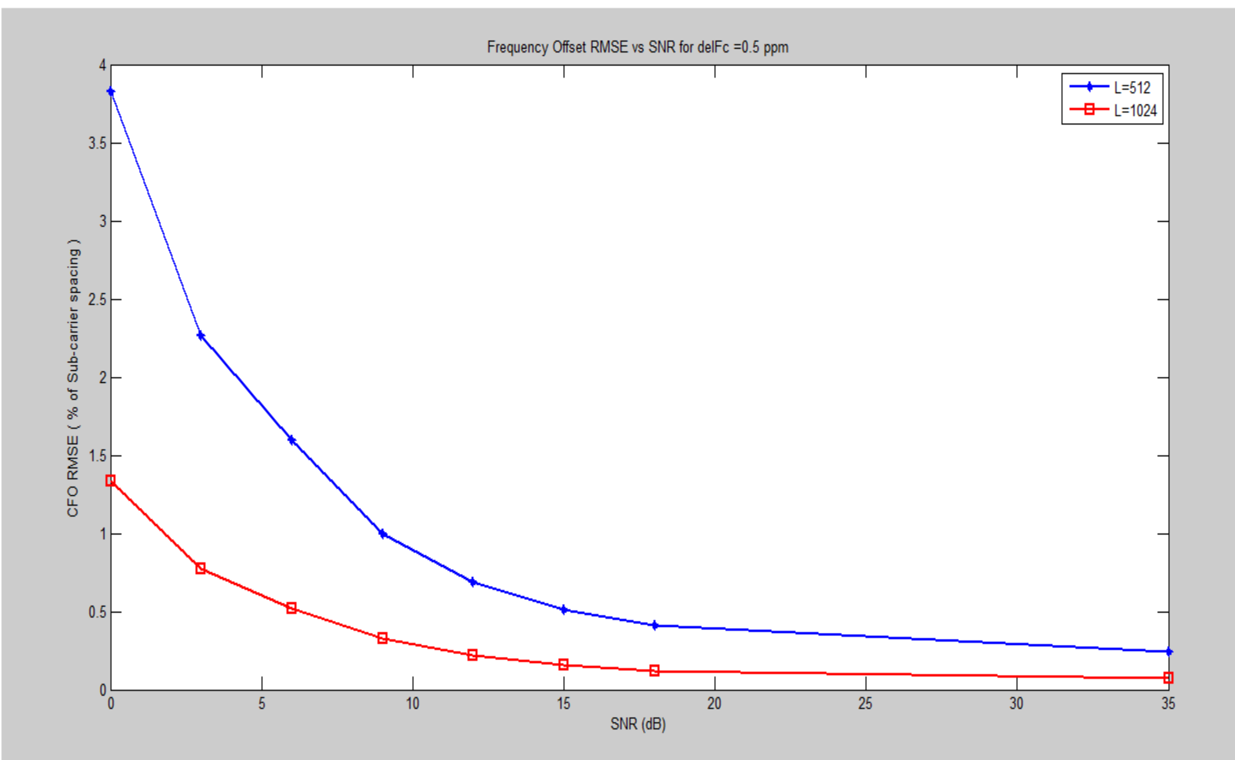

Figure 10: Frequency offset RMSE vs. SNR for L=512 &1024, deFc=0.5 ppm

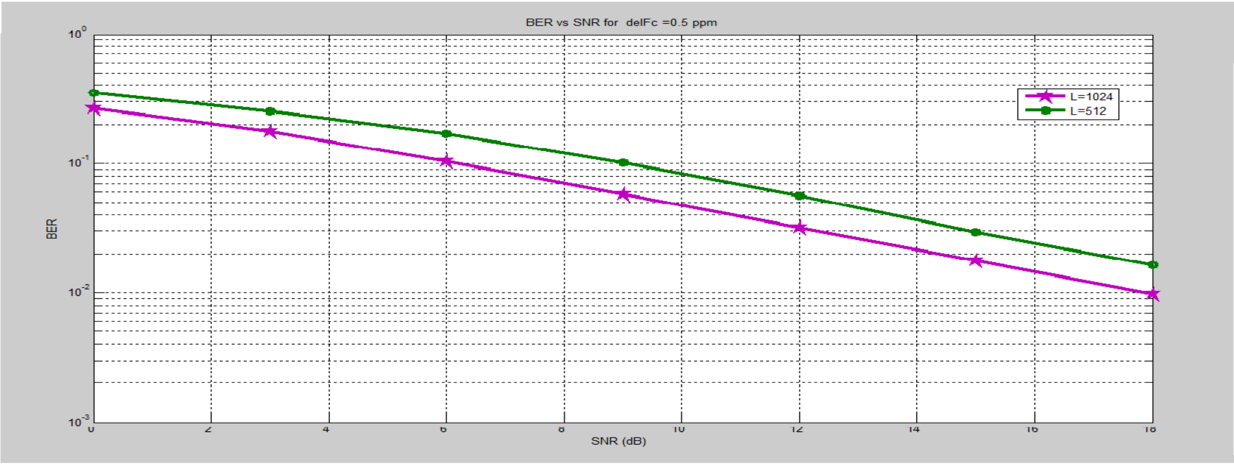

Figure 11: BER vs. SNR for L=512 and 1024 for delFc=0.5ppm

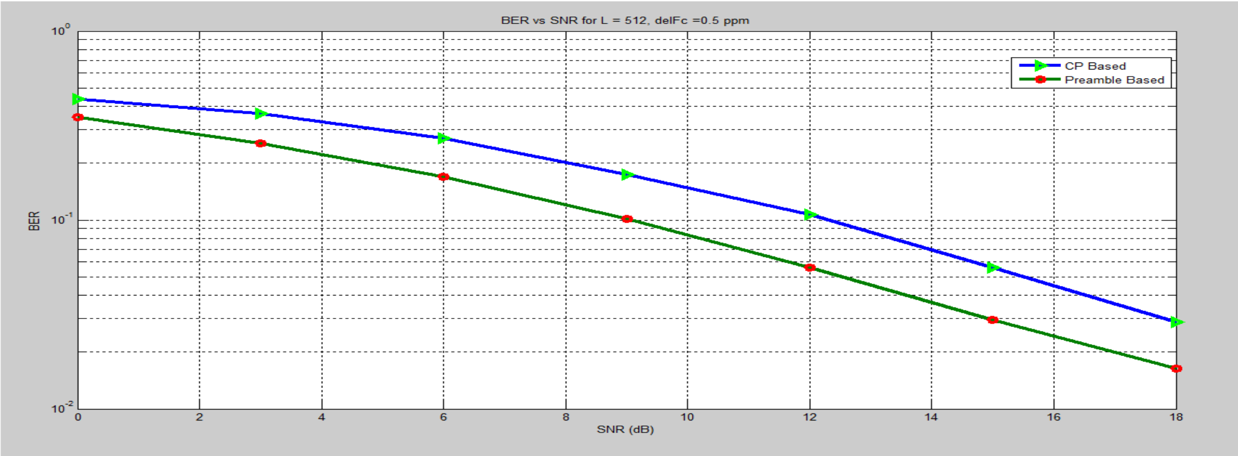

Figure 12: BER vs. SNR comparison in CP & Preamble based synchronization

4. Conclusion and Future Work

Like other communication systems there are many problems in synchronization should be taken into consideration in OFDM system. Depending on the information rate cyclic prefix based synchronization should be used, and for better performance in synchronization the pilot based or preamble based synchronization can be implemented. The well known preamble structure of IEEE802.11a can be used for preamble based synchronization. By using correlation the exact FFT window of OFDM data field can be found easily from the peak detection.

More robust algorithms need to be implemented for synchronization which gives better performance with more information rate and less computation. In this paper cyclic prefix based synchronization is providing more information rate but less performance and poor synchronization due to the correlation of less number of samples, so this is need to find the path which will give better performance for cyclic prefix based synchronization.

References

[1] Ye (Geoffrey) Li,Gordon Stuber, "Orthogonal Frequency Division Multiplexing For Wireless Communications," Springer publisher,pp.245-269,2006.

[2] T. Hwang, C. Yang, G. Wu, S. Li, and G. Y. Li, "OFDM and its wireless applications: A survey," IEEE Trans. Veh. Technol., vol. 58, pp. 1673–1694, May 2009.

[3] Shinsuke Hara and Ramjee Prasad," Multicarrier Techniques for 4G Mobile Communications", pp. 27-50, Artech House Publishers, Norwood, Massachusetts, 2003.
[4] P.Moose, "A technique for orthogonal frequency division multiplexing frequency offset correction," IEEE Transactions on communications, vol.42, No. 10,pp. 2908-2914,1994. doi:10.1109/26.328961.
[5] J.J.Van de beek, M.Sandell, M.Isaksson,and P.O.Borjesson, "Low complex frame synchronization in OFDM system," IEEE International Conference on Communications, pp.982-986, Nov. 1995.
[6] A.Peled and A. Ruiz, "Frequency domain data transmission using reduced computational complexity algorithms," in Proc. IACASSP, pp.964-967, April 1980.
[7] Marc Engels et al., "Wireless OFDM systems, How to make them work?" The Springer International series in Engineering and Computer Science, 2002.
[8] F.Classen and H.Meyr, "Synchronization algorithms for an OFDM system for mobile communication," ITG-Fachtagung, pp.105-113, oct 1994.
[9] Daniel Landstrom, Sarah Kata Wilson, Jan-Jaap Van de Beek,Per Odling,and Per Ola Borjesson, " Symbol Time Offset Estimation in Coherent OFDM Systems," IEEE transaction on communications, Vol.50, no.4,April 2002.
[10] S. Younis, A. Al-Dweik, B. Sharif, C. Tsimenidis, and A. Hazmi, "The effect of timing errors on frequency offset estimation in OFDM systems," in Proc.IEEE ISSPIT, Bilbao, Spain, Dec. 2011.
[11] Hlaing Minn, Vijay K. Bhargava, and Khaled Ben Ben Letaief, "A Robust Timing and Frequency Synchronization for OFDM Systems", IEEE transactions on wireless communications, vol. 2, NO. 4, July 2003.
[12] Jan Jaap Van de Beek, Magnus Sandell and Per Ola Brojesson, "ML Estimation of Time and Frequency Offset in OFDM systems," IEEE Transaction on Signal Processing, Vol.45,No.7, pp.1800-1805, July 1997.
[13] Muhammad Imadur Rahaman, Suvra Sekhar Das and Frank H.P.Fitzek, "OFDM based WLAN Systems," Technical report R-04-1002; v1.2, Aalborg University, Feb 2005.
[14] IEEE-SA Standard Board, "Part-II Wireless LAN Medium Access Control (MAC) and Physical layer (PHY) specifications," 12 June 2003.
[15] T.M Schmidl, D.C.Cox, "Low-overhead, low complexity [Burst] Synchronization for OFDM", IEEE International Conference on In Communications, Vol.3, pp. 1301-1306, 1996. doi:10.1109/icc.1996.533620.
[16] Zhuo Sun*, Tao Peng and Wenbo Wang, "A novel sampling synchronization scheme for OFDM-based system with unified reference clock", EURASIP Journal on Wireless Communications and Networking, 23rd December 2012. doi:10.1186/1687-1499-2012-368.
[17] I. Diaz, L. Wilhelmsson, J. Rodrigues, J. Lofgren, T. Olsson, and V. Owall, "A sign-bit auto-correlation architecture for fractional frequency offset estimation in OFDM," in Proc. IEEE international Symposium on Circuits and Systems, pp. 3765–3768, Gannes, France, 2010.
[18] 3GPP TS 36.201: Evolved Universal Terrestrial Radio Access (E-UTRA): Long Term Evolution (LTE) physical layer: General description. 3GPP Std., 2008.

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