International Journal of Current Engineering and Technology
E-ISSN 2277 – 4106, P-ISSN 2347 – 5161

Available at http://inpressco.com/category/ijcet

Research Article

A Comparative performance analysis of CFO Estimation in OFDM Systems for Urban, Rural and Rayleigh area using CP and Moose Technique

Mohd.Tavfeeq†*, Ashish Xavier Das† and A.K.Jaiswal†

†Department of Electronics and Communication Engineering, SHIATS India

Accepted 25 Aug 2015, Available online 31 Aug 2015, **Vol.5, No.4 (Aug 2015)**

Abstract

Orthogonal frequency division multiplexing (OFDM) is a most efficient and well-known modulation technique for transmission of digital data with high data rate. It is a multicarrier modulation technique where available spectrum divides into number of carriers and each one being orthogonally modulated by a low data rate stream .OFDM system is most effective technique for overcome the problem of multipath fading, immunity to delay spread Increasing signal to noise ratio (SNR) with negligible Inter carrier interference (ICI) and Inter symbol interference (ISI).but High peak to average power ratio(PAPR) and frequency offset is main problem with OFDM that degrade the performance of system. One of the main reasons for ICI is loss of synchronization caused by frequency offset between oscillators at the transmitter and the receiver. This causes the carriers to lose orthogonality, so they cannot be completely separated at the receiver. As a consequence, ICI lowers the signal-to-noise ratio (SNR) and increases the error probability. In this paper we are trying to investigate and estimate the effects of carrier frequency offset on OFDM system using Cyclic prefix and Moose method for two different channel model like Urban, rural and Rayleigh channel model.

Keywords: *Orthogonal frequency division multiplexing, Carrier Frequency offset, cyclic prefix and Moose.*

1. Introduction

As high data rate transmission is one of the major challenges in modern wireless communications, there is a substantial need for a higher frequency bandwidth. Meanwhile, with the increase of data rate the distortion of the received signals caused by multipath fading channel becomes a major problem. Orthogonal Frequency Division Multiplexing (OFDM) gives higher bandwidth efficiency by using the orthogonality principle and overcomes the effect of multipath fading channel by dividing the single high data rate stream into a several low data rate streams. OFDM is a multicarrier transport technology for high data rate communication system (Bingam *et al* 1990). The OFDM concept is based on spreading the high speed data to be transmitted over a large number of low rate carriers. The carriers are orthogonal to each other and frequency spacing between them are created by using the Fast Fourier transform (FFT). OFDM is being used in a number of wired and wireless voice and data applications due to its flexible system architecture. Some examples of current OFDM applications are DAB (digital audio broadcasting), HDSL (High-Rate Digital Subscriber Line), VHDSL (Very High-Rate Digital Subscriber Line), ADSL (Asymmetric DSL), HDTV-Terrestrial (High Definition TV-T), IEEE 802.11 and Hiper LAN/2, GSTN (General Switched Telephone Network), Cellular Radio and DVB-T (digital video broadcasting-terrestrial)(Nee *et al*,2000) However, despite all these advantages, OFDM has some drawbacks including its higher peak to average power ratio and suffers higher sensitivity to Carrier Frequency Offset (CFO). There are two main causes of CFO. The first is a frequency mismatch between the local oscillators at the transmitter and receiver which results in residual CFO at the receiver after the down-conversion process. The second cause is the Doppler shift which is a result of the relative motion between the transmitter and receiver present in mobile environments. CFO is a major drawback in OFDM systems which disturbs the orthoganality among the sub-carriers and consequently introduces Inter-Carrier Interference (ICI). CFO also increases the Bit Error Rate (BER) and degrades SNR of the signal (Jungwon L *et al* 2004). By estimating the CFO at the receiver, the loss in performance due to the CFO can be significantly reduced. Many methods have been proposed in the literature to estimate and compensate for the CFO. CFO estimation techniques can be broadly classified into Pilot-aided schemes and non-pilot aided (blind)

*Corresponding author **Mohd.Tavfeeq** is a Student; **Ashish Xavier Das** is working as Assistant Professor and **A.K.Jaiswal** as HOD

estimation schemes. Pilot assisted methods use well defined pilot symbols to aid in the estimation of CFO. This method is popular and capable of achieving very quick and reliable estimates, though there is a loss in data rate and spectrum efficiency of the system. Blind (non-pilot aided) methods exploit the structural and statistical properties of the transmitted signals. Though these techniques preserve the data rate, they lead to processing the received data to multiple times, which causes delay in decoding (Zhang *et al*, 2007).

There are two deleterious effects caused by frequency offset; one is the reduction of signal amplitude in the output of the filters matched to each of the carriers and the second is introduction of IC1 from the other carriers which are now no longer orthogonal to the filter. Because, in OFDM, the carriers are inherently closely spaced in frequency compared to the channel bandwidth, the tolerable frequency offset becomes a very small fraction of the channel bandwidth. Maintaining sufficient open loop frequency accuracy can become difficult in links, such as satellite links with multiple frequency translations or, as mentioned previously, in mobile digital radio links that may also introduce significant Doppler shift (Kumar *et al*,2007).

One of the main reasons for ICI is loss of synchronization caused by frequency offset between oscillators at the transmitter and the receiver. This causes the carriers to lose orthogonality, so they cannot be completely separated at the receiver. As a consequence, ICI lowers the signal-to-noise ratio (SNR) and increases the error probability.

In This paper we investigated the effects of frequency offset on OFDM system using Cyclic prefix and Moose method for two different channel models referred as Urban and Rural model and how we can estimate it so that we can compensate for its effects.

In particular, we studied the effects of ICI through Matlab simulations. We show that an error in frequency synchronization as small as 0.15% of the frequency spacing can cause significant ICI, thereby making it impossible to demodulate the signal. In order to cope with this problem, cyclic prefix and Moose techniques were analyzed.

2. Effects of frequency offset on OFDM signals

When CFO happens, it causes the receiver signal to be shifted in frequency (δF); this is illustrated in the figure 1. If the frequency error is an integer multiple I of subcarrier spacing δf, then the received frequency domain subcarriers are shifted by $\delta F \times I$ [B. Sathish Kumar *et al*, 2007].

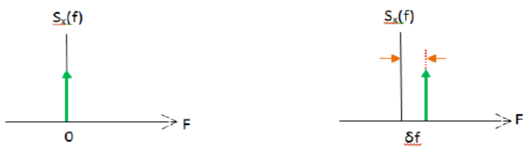

Fig.1 Frequency offset (δf)

On the other hand, as we know the subcarriers (SCs) will sample at their peak, and this can only occur when there is no frequency offset, however if there is any frequency offset , the sampling will be done at the offset point, which is not the peak point. This causes to reduce the amplitude of the anticipated subcarriers, which can result to raise the Inter Carrier Interference (ICI) from the adjacent Sub carriers (SCs). Figure 2 shows the impact of carrier frequency offset (CFO).

It is necessary to mention that although it is true that the frequency errors typically arise from a mismatch between the reference frequencies of the transmitter and the receiver local oscillators, but this difference is avoidable due to the tolerance that electronics elements have (Yong *et al* 2010].

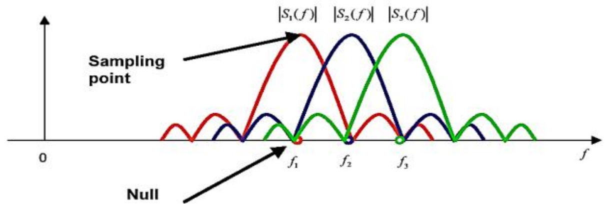

Fig.2 OFDM and the orthogonality principle

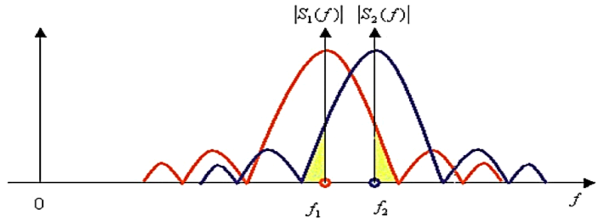

Fig.3 Illustration of ICI and carrier offset.

Therefore there is always a difference between the carrier frequencies that is generated in the receiver with the one that is generated in transmitter; this difference is called frequency offset

$$\delta F = f2 - f1$$

Where $f2$ is the carrier frequency in the transmitter and $f1$is the carrier frequency in receiver.

2.1 Carrier Frequency Offset (CFO)

The OFDM systems are very sensitive to the carrier frequency offset (CFO) and timing, therefore, before demodulating the OFDM signals at the receiver side, the receiver must be synchronized to the time frame and carrier frequency which has been transmitted. Of course, In order to help the synchronization, the signals that are transmitted, have the references parameters that are used in receiver for synchronization (Richard *et al*, 2000). However, in order the receiver to be synchronized with the transmitter, it needs to know two important factors:

(i) Prior to the FFT process, where it should start sampling the incoming OFDM symbol from.

(ii) How to estimate and correct any carrier frequency offset (CFO).

After estimating the symbol boundaries in the receiver and when the presence of the symbol is detected the next step is to estimate the frequency offset. Figure 4 shows the block diagram of the OFDM system.

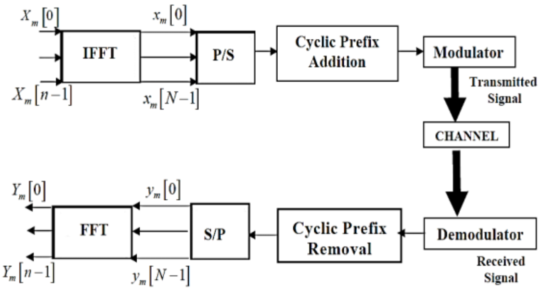

Fig.4 Block diagram of the OFDM system

In OFDM data are transmitted in blocks of length. The *Nn-th block [X(0)-------[X(N-1)]* transformed into the signal block *{X(0)-------[X(N-1)}* by the IFFT as given below.

Data at each sub-carrier (X_m) are input into the inverse fast Fourier transform (IFFT) to be converted to time-domain data (x_m) and after parallel-to-serial conversion (P/S), a cyclic prefix is added to prevent inter-symbol interference (ISI). At the receiver, the cyclic prefix is re-moved, because it contains no information symbols. After the serial-to-parallel (S/P) con-version, the received data in the time domain (y_m) are converted to the frequency domain (Y_m) using the fast Fourier transform (FFT) algorithm.

$$y[k] = \frac{1}{N} s[k]H[k]\left(\frac{\sin(\pi\Delta f)}{\sin\left(\pi\Delta f/_{N}\right)}\right) exp\left(\frac{j(N-1)\Delta f}{N}\right) + \frac{1}{N}\sum_{\substack{m=0\\m\neq k}}^{N-1} s[m]H[m]\left[\frac{\sin(\pi(m-k+\Delta f))}{\sin\left(\frac{\pi(m-k+\Delta f)}{N}\right)} exp\left(j\left(\frac{N-1}{N}\right)(m-k+\Delta f\right)\right. \quad (1)$$

If then

$$y[k] = \frac{1}{N} s[k]H[k]\left(\frac{\sin((\pi\Delta f)}{\sin\left(\pi\Delta f/_{N}\right)}\right) exp\left(\frac{j(N-1)\Delta f}{N}\right) + \frac{1}{N}\sum_{\substack{m=0\\m\neq k}}^{N-1} s[m]H[m]\alpha_0 \quad (2)$$

From equation it is clear that existence of any frequency offset and estimation of the output symbol depends on the input values. If there is no frequency offset
$\delta F = 0$
Then the received signal is$y = \frac{1}{N}\, S(k)H(k)$

Due to the frequency mismatched, the performance of an OFDM system can be reduced, this loss of performance can be compensated by estimating the frequency offset in Receiver side.

2.2 Sources of frequency offset

A few other sources can cause frequency offset, such as frequency drifts in transmitter and receiver oscillators, Doppler shift, radio propagation and the tolerance that electronics elements have in local oscillators in transmitter and the receiver. When there is a relative motion between transmitter and receiver the Doppler can happen (Zhang *et al*, 2007). It is worth to mention the radio propagation talks about the behavior of radio waves when they are broadcasted from transmitter to receiver. In terms of propagation, the radio waves are generally affected by three phenomena which are: diffraction, scattering and reflection.

2.3 Doppler Effect

The Doppler Effect (DE) defines as follows.

$$Doppler\ frequency = \frac{v.f_c}{c}$$

Where f_c is Doppler frequency, c is the speed of light, and v is the velocity of the moving receiver. (i.e. 100 km/h). The normalized CFO (ε) is defined as follows

$$CFO = \frac{Frequency\ offset}{\delta f}$$

3. CFO estimation algorithm and Techniques

CFO can produce Inter Carrier Interference (ICI) which can be much worse than the effect of noise on OFD Msystems. That's why various CFO estimation and compensation algorithms have been proposed. For showing the importance of it, it is enough to mention that, by now the researchers have proposed numerous and various CFO estimation and compensation techniques and
Algorithms,

3.1 CP based Estimation Method

Cyclic prefix (CP) is a portion of an OFDM symbol used to absorb inter-symbol interference (ISI) caused by any transmission channel time dispersion and it can be used in CFO estimation. Figure (1) shows OFDM Symbol with CP. CP based estimation method exploits CP to estimate the CFO in time domain. Considering the channel effect is minimal and can be neglected, then, the lth OFDM symbol affected by CFO can be written as

$$Y_1[n] = x(n)e^{j2\pi\varepsilon n/N} \quad (3)$$

We may now consider the corresponding CP in the OFDM symbol.

$$Y_1[n+N] = x(n+N)e^{\frac{j2\pi\varepsilon n}{N}}(n+N) \quad (4)$$

$$Y_1[n+N] = x(n+N)e^{\frac{j2\pi\varepsilon n}{N}} + j2\pi\varepsilon \quad (5)$$

From equations (3) and (5), we can find that the phase difference between CP and the OFDM symbol which the victim of CFO is 2πε. Therefore, the amount of CFO can be found by the multiplication of OFDM symbol (CFO affected) with the CP and after that taking their phase angle measurements, as show below

$$\varepsilon = \frac{1}{2\pi}\arg\{\, y_1^*[n]y_1[n+N]\}\,, N = -1,-2,\ldots.-N_g \qquad (6)$$

In order to reduce the noise effect, its average can be taken over the samples in a CP interval as

$$\varepsilon = \frac{1}{2\pi}\arg\left\{\sum_{n=N_g}^{-1} .\, y_1^*[n]y_1[n+N]\right\},$$
$$N = -1,-2,-N_g \qquad (7)$$

The above equation can estimate CFO in the range of [-0.5, +0.5]. Therefore, CP results CFO estimation in the range |ε | ≤ 0.5. Hence, this technique is useful for the estimation of Fractional CFO. The drawback of this technique is that it does not estimate the integer offset.

3.2 Symbol based Estimation Method

The basis of this technique, proposed by P.H. Moose is that same data frame is repeated and the phase value of each carrier between consecutive symbols is compared. If two identical training symbols are transmitted consecutively, the corresponding signals with CFO of ε are related with each other as follows.

$$y_2[n] = y_1[n]e^{j2\pi\varepsilon} \ldots\ldots Y_2[K] = y_1[k]e^{j2\pi\varepsilon} \qquad (8)$$

In this estimation mean square error can be calculated as.

Where is the ratio of the signal to noise for the received signals, and N is the number of subcarriers (SCs). According to the paper, the limit of accurate estimation (for acquisition range) for this algorithm Acquisition Range (.15) therefore the acquisition range for subcarrier spacing is between -0.5 and 0.5, which is smaller than the value that is in the IEEE802.11a. When acquisition range goes towards the 0.5, may due to the noise and the discontinuity of the arctangent, jump to -0.5 when this occurs the estimate is no longer unbiased and in practice, it becomes useless. This estimation for the small values of CFO is conditionally unbiased. However, the big weakness for suggested algorithm in Moose's paper is its dependency to the starting point; therefore the algorithm needs to know the start point of the OFDM symbol.

4. Simulation parameter and result discussion

MATLAB simulator tool are used to estimate the Carrier frequency effect on OFDM system by cyclic prefix and Moose method. To compare CFO estimation techniques, two equations are simulated. First, by using equation [Richard Van Nee *et al*, 2000], the phase difference between CP and the corresponding rear part of an OFDM symbol. Second, using equation (8) OFDM parameters used in the simulation are given in the table below.

Table1. Simulation Parameters

Parameter	Value
Estimation technique	Cyclic prefix and Moose
Channel model	Urban and Rural
Number of Subcarrier	512
Normalized CFO()	.15
FFT size	256
Sampling time(T_S)	1/20Mhz
Doppler frequency(F_d)	200Hz
Modulation technique	QAM
SNR range	0-30 db

The effect of carrier frequency offset on OFDM system can be analyzed and estimate by using cyclic prefix and Moose estimation method for Urban, Rural and Rayleigh model on the basis of mean square error and SNR through MATLAB simulation software. Effect of Frequency offset proposed scheme can be easily checked by complementary cumulative distribution function (CCDF) plot. In this paper, we are using 512 numbers of sub-carrier, normalized CFO .15, SNR range 0-30db and modulation technique QPSK to analyzed the effect of frequency offset for Urban, Rural and Rayleigh area.

In Fig.4.1, we have seen that CCDF plot between MSE versus SNR for urban area. From figure we can simply estimate that Mean square error at 21 db SNR is approx. $10^{-6}$for Moose method whereas by cyclic prefix method MSE is approx 10^{-5}.

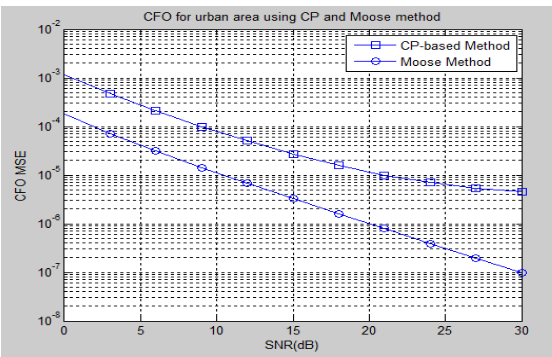

Fig 4.1 CCDF plot between CFO mean square error and SNR for urban area

In Fig.4.2, we have seen that CCDF plot between MSE versus SNR for rural area. From figure we can simply analyzed that CFO estimation performance of Moose method is more efficient and reliable than cyclic prefix technique.

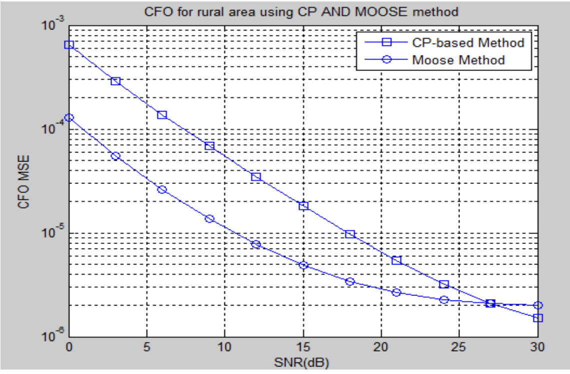

Fig 4.2 CCDF plot between CFO mean square error and SNR for rural area

In Fig.4.3, we have seen that CCDF plot between MSE versus SNR for rayleigh area. From figure we can simply estimate that Mean square error at low SNR, moose method is better but at 25 db SNR, estimation performance of Moose and cyclic prefix is mostly same.

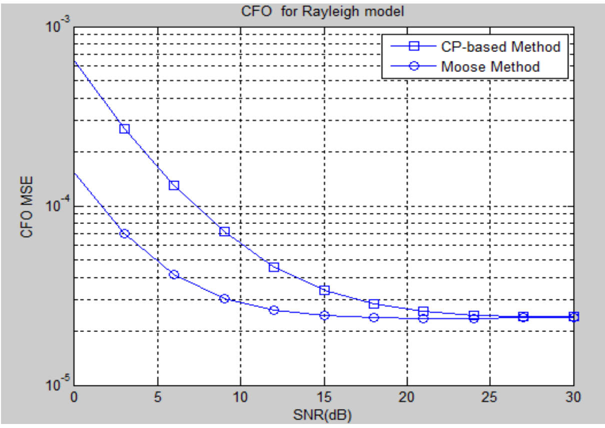

Fig 4.3 CCDF plot between CFO mean square error and SNR for Rayleigh area

After investigating the result we can simply state that overall estimation performance of Moose method for Urban, Rural and Rayleigh is better and effective than cyclic prefix method.

Conclusion

In this paper, we investigated the effects of CFO in OFDM system. From mathematical analysis and simulation results we see that CFO introduces Inter-Carrier Interference (ICI) which destroys the orthogonality of subcarriers. Two CFO estimation schemes, i.e., the CP based scheme and frequency domain based Moose scheme have also been applied to the OFDM systems. After observing the Simulation results we can conclude that overall CFO estimation performance of Frequency Domain scheme (Moose method) for urban ,rural and Rayleigh model has better than time domain CP based method in terms of normalized MSE over SNR.

References

A.C.Bingam (May 1990) Multicarrier modulation for data transmission: An idea whose time has come. *IEEE Commun. Mag.,* 28(5):5-14

Nee, R.V. and R.Prasad (January 2000), OFDM for Wireless Multimedia Communications, Artech House Publishers, Norwood, MA.

IEEE802.16 (2004) IEEE Standard for Local and metropolitan area networks Part 16: Air Interface for Fixed Broadband Wireless Access Systems

W. J. Zhang, Y. F. Guan, W. Q. Liang, D. Z. He, F. Ju, and J. Sun (Mar. 2007), An introduction of the Chinese DTTB standard and Analysis of the PN595working modes, IEEE Trans. Broadcasting, vol. 53, no. 1, pp. 8-13.

B. Sathish Kumar, K.R. Shankar Kumar, and R.Radhakrishnan (2009), An Efficient Inter Carrier Interference Cancellation Schemes for OFDM Systems, IJCSIS, Vol. 6, No. 3.

Yong Soo Cho, J. Kim, W. Young Yang, and Chung G (2010) Kang, MIMO-OFDM Wireless Communications with MATLAB (John Wiley & Sons (Asia), Singapore)

Richard Van Nee, Ramjee Prasad (2000), OFDM for Wireless Multimedia Communications, (Artech House, Boston, London)