Journal of Network Communications and Emerging Technologies (JNCET) www.jncet.org
Volume 2, Issue 2, June (2015)

Suppression of CFO Effect in LTE Uplink Transmission: A Survey

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Abstract – The third generation partnership project (3GPP) Long Term Evolution (LTE) is the latest technology to tackle the increased need for mobile broadband services. Single-Carrier Frequency-Division Multiple Access (SC-FDMA) technology is being used for uplink (UL) transmission. In this system, the orthogonality between subcarriers is disrupted due to the presence of Carrier Frequency Offsets (CFOs) that tend to Multiple Access Interference (MAI) and Intercarrier Interference (ICI) among various users. This paper surveys the dilemma of CFO by screening the various suppression techniques for frequency offset in LTE uplink.

Index Terms – CFO ; LTE Uplink; Kalman Filter; MMSE.

1. INTRODUCTION

The existing global telecommunications networks are being transformed into an integrated system with the revolution of wireless and will provide a wide range of frequent communications services to the various customers anywhere in fixed or motion. It provides evolutionary paths for people to communicate, as it blends mobility with communication. This desirable characteristic of mobility gives rise to many challenges that are encountered in a wireless medium. These challenges take place at different layers of the theoretical model of OSI.

A certain quality of service (QoS) must be satisfied in order to have a reliable communication in speedy and error-free transmission. To maintain the QoS, the available bandwidth is being shared by different users at the same time. Hence, a variety of multiple access techniques are used to share the allocated spectrum among a range of different mobile users in the most ingenious manner. First-generation (1G) cell-phone system uses Frequency Division Multiple Access (FDMA), where each user is given a definite uplink and downlink frequency channel. The combination of TDMA and FDMA is the basis of 2G cellular systems where eight timeslots are given to each frequency channel where seven slots are reserved for phone calls and one slot for signaling data. The Code Division Multiple Access technique (CDMA) is a channel access method based on spread spectrum and is used in 3G.The Orthogonal Frequency Division Multiple Access (OFDMA) scheme is an advanced new version of FDMA. In OFDMA, every node has a variety of sub-carriers that offers different data rates having distinct quality of service among various users. The provision of sub-carriers differs from user to user as it is depends on the condition of radio channel and traffic load [1].

3GPP Long Term Evolution (LTE) is the evolution of the 3GPP UMTS standard, aiming at providing higher system capacity, better spectrum efficiency, as well as more robust performance in challenging wireless channels.SC-FDMA has been chosen for high data-rate LTE uplink communication systems. Furthermore, on comparison with OFDM system, it has an advantage of low Peak to Average Power Ratio (PAPR).However, SC-FDMA system is also susceptible to CFO, comparable with other OFDM based systems which is generally, occurs due to Doppler shift and oscillator mismatch [15]. During uplink communications, the combination of various signals from different users comprises the received signal, in which every user has distinct CFO. Therefore, the numerous CFOs of the received signals will disrupt the orthogonality between the various subcarriers. Consequently, the generation of ICI and MAI into the received signals will occur. Thus the performance of the system will be sincerely degraded.

The paper is structured as follows-Section II provides a system model comprising LTE UL system. Section III deals with the impairments of SC-FDMA system .In section IV, different techniques to mitigate the impairments have been discussed. Finally, conclusions are drawn in section V.

2. SYSTEM MODEL

Fig.1 demonstrates the blocks of SC-FDMA uplink communication system. Within SC- FDMA communication system, the transmitter of the system transforms a binary input data to a series of modulated subcarriers. The subcarriers are further partitioned into numerous other sub-channels. From single user data symbols are transmitted on one sub-channel, instead of being modulated on all available subcarriers. The transmitter next groups the modulation symbols {xn} into blocks each containing N symbols. Hence, to modulate the SC-FDMA subcarriers, the first step includes an N-point DFT that generates a representation of frequency domain Xk of the input symbols. There is a transformation of these input symbols into frequency domain by using DFT, which can be expressed in an equation. The DFT equation is represented as [2], [3]:

$$X_k = \sum_{k=0}^{N-1} x_n e^{-2\pi jkn/N} \qquad (1)$$

where, k= 0, 1……N-1

Furthermore, an M-point IFFT is also carried out to produce the time-domain samples, then cyclic prefix is added followed by the parallel to serial converter then DAC is performed and finally transmit over RF subsystems [2].

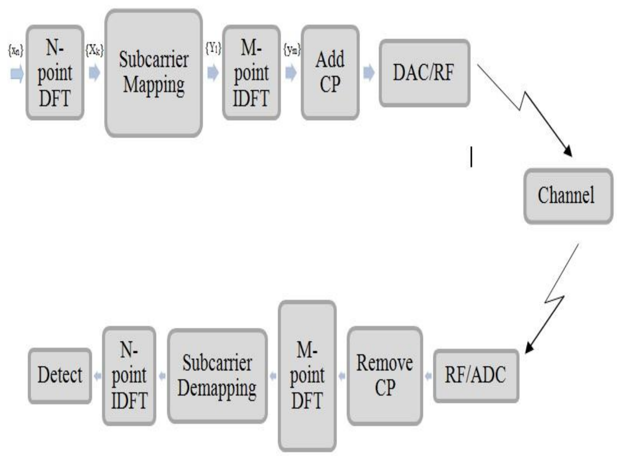

Figure 1 Structure of transmitter and receiver in SC-FDMA systems

The Inverse discrete Fourier transform IDFT equation is given as [2], [3]:

$$y_m = \frac{1}{M} \sum_{m=0}^{M-1} Y_l e^{2\pi jkm/M} \qquad (2)$$

where, m= 0, 1 ……M-1

Also x_n (n = 0, 1. . . N−1) characterizes modulated input symbols and X_k (k = 0, 1 . . . N −1) characterizes M samples of the DFT of x_n. Also, Y_l (l = 0, 1 . . . M −1) characterizes the frequency domain samples after subcarrier mapping and y_m (m = 0, 1 . . . M −1) characterizes the transmitted time domain channel symbols obtained from the inverse DFT (IDFT) of Yl [3].

Subcarrier mapping is the process of mapping the constellation mapped data onto the available subcarriers. There are mainly two types of subcarrier mapping methods, namely: Distributed Mapping mode and Localized Mapping mode.

In distributed mapping, there is a process of assigning the DFT outputs to subcarriers over the whole bandwidth discontinuously [13]. In other words, the constellation mapped data are mapped on to equally spaced subcarriers, while zeroes are mapped on to the unused carriers in between them. In localized mapping, there is a mapping of the DFT outputs to a set of successive sub-carriers thus restraining them to a part of total bandwidth of the system.

Prior to transmission, two other signal processing operations are performed by transmitter. The use of a Cyclic Prefix is an efficient method to avoid Inter Block Interference (IBI) between two successive blocks. To minimize out of band signal energy the transmitter also executes pulse shaping. In receiver side, the received signal is converted into the frequency domain using DFT, and then demapping of the subcarriers followed by the frequency domain equalization. Finally, by using IDFT, decoding and detection, the equalized symbols are converted to the time domain.

3. IMPAIRMENTS

In 3GPP LTE uplink, SC-FDMA is being used as it provides more robustness in contrast to OFDMA, but Carrier Frequency Offsets (CFOs) also exist in SC-FDMA alike OFDMA [8], that is the main reason for Multiuser Access Interference (MAI) as well as Inter Carrier Interference (ICI).

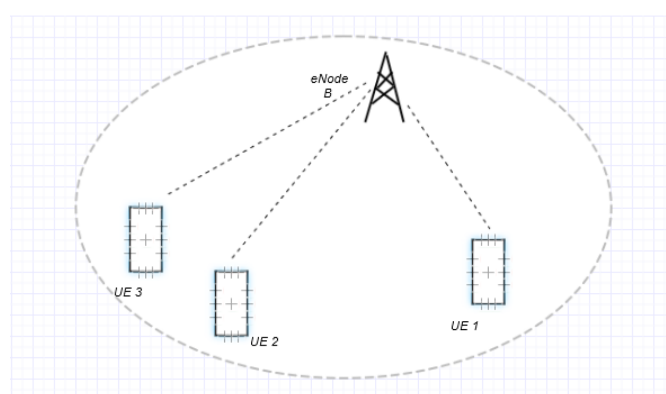

Figure 2 LTE Uplink Interference Scenario

The first UE 1 is interfered by the second UE 2 and third UE 3 in the same cell. Because of this intervention the first UE 1 suffers from ICI and MAI which can degrade the system performance [6].

The orthogonality of the system relies on the condition that transmitter and receiver operates with exactly the same frequency reference [10]. But if this will not happen, the perfect orthogonality of the subcarrier will be lost, which can result to subcarrier leakage, this observable fact is also known as the Inter Carrier Interference (ICI).The orthogonality of the users can be destroyed by frequency offsets, which can take place for two reasons:

1. The different local oscillators in the UEs and the BS cause a user specific carrier frequency offset which result in a continuous phase rotation of the received constellation and will introduce Inter-Carrier-Interference (ICI). ICI in the SC-FDMA will result in interference among the users.

2. The movement of the UEs relative to the fixed BS produces frequency shifts due to the so-called Doppler Effect. Since the movements and speeds occur randomly, this will increase time variations to the problem [5].

When CFO happens, there is a shift of (δf) in the received signal. If there is a frequency error which is an integer multiple I of subcarrier spacing δf, then there is a shift of δf *I in the received frequency domain subcarriers.

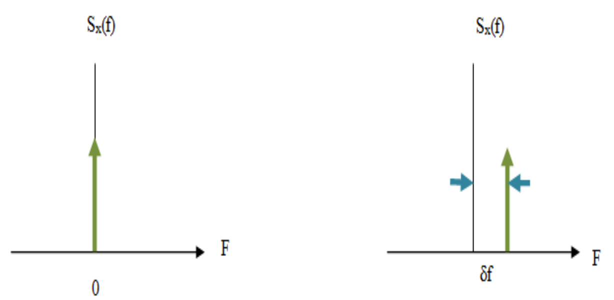

Figure 3: Frequency Offset (δf)

Therefore, a difference occurs between the carrier frequencies that are generated in the receiver with the one that is generated in transmitter and this difference can be defined as frequency offset.

$$\delta f = f_c - f_c' \quad (3)$$

Where f_c is the carrier frequency in the transmitter and f_c' is the carrier frequency in receiver.

Hence, the normalized CFO (ε) is defined as follows [2]:

$$(\varepsilon) = \frac{\delta f}{\Delta f} \quad (4)$$

Where, Δf is the subcarrier spacing.

4. TECHNIQUES FOR CFO SUPPRESSION

CFO can produce Intercarrier Interference (ICI) which can have much worse effect than the noise in the system. Hence, various CFO estimation and suppression algorithms have been proposed so far [7].

4.1. SINGLE USER DETECTOR

The CFOs compensation for each user is performed at the base station and the sampled series is counterbalanced within the time domain, and afterward a separate DFT is performed for each user. Consequently several DFT blocks are needed for each user. It can completely eliminate ICI. But before DFT, the frequency compensation for each user can enhance the offsets of frequency in the data of the other users also thereby degrading the system performance. Moreover, to detect the information symbols a separate block i.e. DFT block is required in this detector for each user that causes complexity of the system much enhanced [3].

4.2. CIRCULAR CONVOLUTION DETECTOR

The CFOs compensation can be performed within frequency domain, to reduce the amount of DFT blocks. After the process of demapping, circular convolution is done. At last, an N-point IDFT is done then after demodulation, decoding processes are carried out at the receiver.

The circular convolution detector gives improved performance as compared with the single-user detector with lesser complexity. However, large MAI induces error in the system.

4.3. SELF CANCELLATION TECHNIQUE

The variation between the coefficients of ICI of the two successive subcarriers is very minute. This makes the origin of ICI self-cancellation technique. In this scheme, one data symbol is modulated into two successive subcarriers, instead of one subcarrier. This is the main idea for ICI cancellation in this method [4].

Therefore, if a data pair (X,-X) is modulated onto two contiguous subcarriers (t, t+1), then the ICI signals produced by the one subcarrier will be abandoned considerably by the ICI produced by subcarrier t+1. The equation can be represented as [12]:

$$Y_k = \sum_{t=0,2,4}^{N-2} X(t)[S(t-k) - S(t+1-k)] + n_k \quad (5)$$

Where n_k signifies the additive noise symbol introduced in sub-carrier k and Y_k signifies the received symbol in k^{th} subcarrier.

4.4. INTERPOLATION

In order to estimate the channel over data, it is necessary for achieving accuracy in demodulation and good performance at the receiver.

As in LTE uplink, the DMRSs (Demodulation Reference Signals) are scattered in the time frequency resource grid. Interpolation is done in time domain to estimate the channel condition for other data symbols.

4.5. MMSE SCHEME

MMSE Scheme for SC-FDMA is a low complexity scheme which is done in the frequency domain. Merely a single DFT stage is requisite for every user. Furthermore, with the implementation of banded-matrix the complexity of the MMSE scheme can be further minimized. The MMSE scheme will be implemented taking both the noise and MAI into the account. This scheme will attain both equalization and CFO's compensation [9].

The MMSE estimator employs the second-order statistics to minimize the mean-square error [14]. Thus, the minimum mean square error is given by

$$min_{\hat{x}} E(\|x-\hat{x}\|^2) \quad (6)$$

Now, we have

$$E(\|x-\hat{x}\|^2) = E\big((x-\hat{x})^T(x-\hat{x})\big) \quad (7)$$

$$E(\|x-\hat{x}\|^2) = E(x^Tx - 2\hat{x}^Tx + \hat{x}^T\hat{x}) \quad (8)$$

$$E(\|x-\hat{x}\|^2) = E\|x\|^2 - 2\hat{x}^TEx + \hat{x}^T\hat{x} \quad (9)$$

Differentiating with respect to estimate of x that gives the optimal estimate. Therefore, the minimum mean square error estimate of x is

$$\hat{x}_{MMSE} = Ex \quad (10)$$

4.6. KALMAN FILTER

The Kalman filter is a block of equations that gives a proficient means to estimate the process's state in a recursive way that will result into the diminishing of the mean of the squared error. After each iteration of a Kalman filter, there is an updation of the estimate of the state vector of a system and the covariance of that vector based upon the information in a new observation.

Thus, the Kalman Filter consists of two steps:

1. The Prediction
2. The Correction

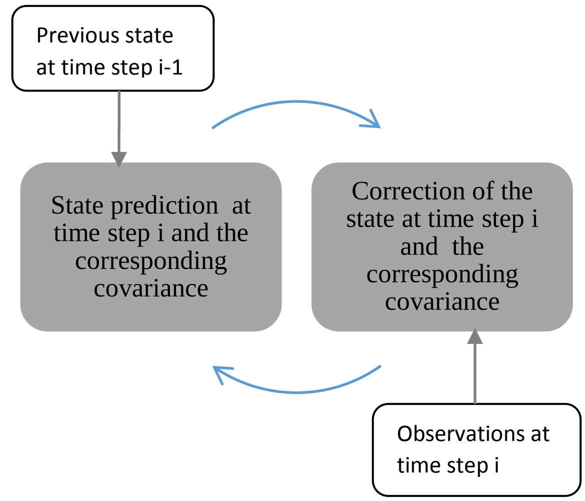

Figure 4: Circuit of Kalman Filter

In the first step the prediction of state is done within the dynamic model. It is then amended with the observation model in the second step, so as to diminish the error covariance of the estimator. Thus, the Kalman filter model assumes the true state at time i be evolved from the state at $(i-1)$ according to the following equation [11]:

$$x_i = F_i\, x_{i-1} + B_i u_i + w_i \quad (11)$$

Where F_i be the state transition model which is applied to the previous state x_{i-1}; B_i is the control-input model which is applied to the control vector u_i; w_i is the process noise which is assumed to be drawn from a zero mean multivariate normal distribution with covariance Q_i.

At time i an observation z_i of the true state x_i is made according to

$$z_i = H_i x_i + v_i \quad (12)$$

Where H_i be the observation model which maps the true state space into the observed space and v_i is the observation noise which is assumed to be zero mean Gaussian white noise with covariance R_i.

After each time, when the process is repeated using previous aposteriori estimates are used to predict the new apriori estimates. This recursive nature of Kalman Filter makes practical implementations much more feasible.

5. CONCLUSION

In this paper various techniques for suppression of CFO have been discussed by considering the SC-FDMA system model. In single user detector technique, DFT is done for every user in the base station in the time domain, but performance degradations can occur if CFO compensation is done before DFT, as it can raise frequency offset in the data. The complexity of the system caused in single user detector can be decreased in the circular convolution by reducing number of DFT blocks. But MAI is induced in this technique. Although self-cancellation scheme also perform well, but due to symbol repetitions, bandwidth efficiency is reduced to half. The Kalman filter is a mathematical recursive tool based on estimations, but it has proved accurate only for Gaussian and linear models. To elude these problems, an MMSE equalization technique is presented, which can attain CFOs compensation and equalization and all together. The hybridization of the techniques can give better results.

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