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PERFORMANCE IMPROVEMENT FOR LTE-OFDM SYSTEM WITH MIMO BEAMFORMING

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ABSTRACT

An LTE multiuser multiple input multiple output - orthogonal frequency division multiplexing (MIMO-OFDM) channel is often affected by inter-symbol interference (ISI), peak to average power ratio (PAPR) and the frequency offsets. In order to attain maximum performance of the system with reduced errors, the capacity of the channel is maximized by modified waterfilling algorithm, power leakage, carrier frequency and sampling frequency offsets are reduced using the energy ratio algorithm keeping the false alarm minimum with respect to the receiver power ratio and detection probability. The PAPR effect is minimized by a group pilot concept of modified SLM where cyclic shift of pilots for each distinct mapping in the SLM system is executed and at the receiver a minimum distance vector routing is evaluated to evade explicit transmission of SI and detects the accurate phase set used in the transmitter.

Keywords: MIMO-OFDM, inter-symbol interference, peak to average power ratio, power leakage, carrier frequency offset, sampling frequency offset.

I. INTRODUCTION

The Third Generation Partnership Project (3GPP) has regulated Long Term Evolution (LTE) as an advancement of 3G systems to meet the necessities of expanding the data rate; high portability and low latency for a data capacity of 20MHz. Researchers is in constant invention of the higher generation modes of communication. The off-late 4G technology of LTE is designed to provide up to ten times the speed of 3G networks with “anytime, anywhere” data, voice and multimedia can be rendered to users with higher data rates [1]. Due to their superior performance, Multiple Inputs Multiple Outputs (MIMO) Orthogonal Frequency Division Multiplexing (OFDM) modulation have been considered in 3GPP LTE/LTEA, Worldwide Interoperability for Microwave Access (WiMAX) and high speed WLAN. In general the transmitted signals of the OFDM systems are subjected to high peak – to – average power ratio that leads to inter-symbol interference and inter-carrier interference when passing through nonlinear power amplifier but the OFDM is one that eliminates complex equalization methods [2].

IJARSE
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Here, a low complexity subcarrier allocation is carried out for MIMO – OFDM using zero–forcing beamforming (ZFBF). It reduces the total transmit power with respect to the data rates of the users. In a multiuser MIMO (MU-MIMO) system, ZFBF removes multiuser interference and subcarrier allocation in both frequency and spatial domains [3]. A study on various proposals for PAPR reduction is done which includes: tone reservation [4] – [6], companding [7], tone injection [8], active constellation extension [9], [10], interleaving [11], [12], partial transmit sequence [13] – [15], and selected mapping (SLM) [16]-[19]. Of all these, even though the complexity of SLM is high it is most commonly used because of its distortion less nature. The main disadvantage of the traditional SLM technique is the use of multiple Inverse Fast Fourier Transforms (IFFTs). These problems are addressed in [17]-[19] where a low complexity architecture of SLM is dealt that converts the frequency domain phase rotations to time domain operations (i.e.,) the IFFTs are replaced by conversion vectors in [17] acquired by taking IFFT of the phase rotation vectors and the conversion vectors of [18] are indicated as perfect sequences in [20].

The practical usefulness of these time-domain approaches as an alternative to the traditional SLM method however depends on the time-domain equivalent operations having a low computational complexity. As a result, only a limited selection of sequences can be applied [21]. Furthermore, since the adopted sequences are not randomly generated, but are somewhat correlated due to the low-complexity requirement, the frequency-domain equivalent phase rotations are not truly random, and thus, a substantial degradation of the PAPR reduction performance occurs [18]. An SLM-OFDM system at the transmitter requires the exact information of the phase set. The side information (SI) is usually either transmitted at the loss of data rate explicitly or is avoided at the cost of computational complexity using Blind SLM (BSLM) technique. In this work we propose a new technique called group pilot based SLM system that evades the need of SI with low complexity. It comprises of cyclic shift of pilots for each distinct mapping in the SLM system and at the receiver calculates a minimum distance vector routing to evade explicit transmission of SI and to detect the accurate phase set used in the transmitter. The bit error rate (BER) performance is estimated with AWGN channels.

Access to static spectrum is the principle approach for wireless communication. MIMO is utilized to expand the overall bitrate through transmission of two or more different data flow on two or more different antennas using the same channel in both time and frequency and separated only through the different reference signals in order to be received by two or more antennas. Here fixed channels are assigned to primary users (PUs) or licensed users and secondary users (SUs) or unlicensed are prohibited to use those channels even when left free or unoccupied. The idea of LTE, WiMAX and other 3GPPs was to achieve more efficient use of the radio frequency spectrum. It allows the SU to use the spectrum when PU is idle and also that the SU should detect the very weak signals transmitted by the PU so as to abandon the occupied shared band of the spectrum. The time taken to detect the spectrum is called as quiet periods. Energy detection is done followed by feature detection to find out whether it is the PU or noise which is the source of energy.

Various factors are to be noted if the SU should detect the PU's emergence and stop its communication leaving the band such as the degradation of signal in the secondary network may occur when the SU receiver and SU transmitter loses its synchronization during quiet periods and for real-time applications, degradation in the quality of service (QoS) may take place as the throughput reduces to zero during the sensing intervals [22]. Other parameters that influences the receiver error count are phase noise (PN), carrier frequency offset (CFO),

IJARSE
ISSN (O) 2319 - 8354
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sampling frequency offset (SFO) and narrowband interference (NBI). Not only the primary signal but also the above parameters are causes for the error count and based on the estimation and compensation of residual errors, the characteristics of the receiver may change from one to another. The traditional spectrum monitoring methods that depends on the sensing of the quiet periods (QPs), processes the received time domain samples to study a particular aspect of the PU. To enhance the system throughput, the QPs are to be eliminated throughout the monitoring phase. Indeed for the SU, signal construction can occur without including the QPs. A technique called energy ratio (ER) is preferred that suits the MIMO-OFDM LTE system. On the transmitting end, the transmitter introduces scheduled null-tones by which the spectrum is observed during the channel's reception. This observing using OFDM detects the reappearance of the PU. The various signal chain deteriorations due to CFO, SFO, NBI and frequency selective fading channels are examined here. As this technique is carried out with respect to the signal chain, it need not wait for the decoded bits and hence produces faster response to the appearance of the PU.

II. SYSTEM MODEL

We consider a MIMO-OFDM communication system with M transmit and receive antennas and N sub-carriers as in Fig. 1. The modulated symbols form an N x 1 frequency domain data vector

$$X = [X[0], X[1], \dots X[N-1]]^T \quad (1)$$

where X[k] indicates the modulated symbol of k^{th} sub-carrier and $(.)^T$ indicates the transpose operation. To generate time domain signal vector x, an N-point IFFT is performed where the n^{th} element of x is given by,

$$x[n] = \frac{1}{\sqrt{N}} \sum_{k=0}^{N-1} X[k].\exp\left\{\frac{j2\pi nk}{N}\right\}, \qquad n = 0, 1, \dots, N-1 \quad (2)$$

The PAPR of the discrete time OFDM signal is represented as

$$PAPR(x) = \frac{\max_{0\le n\le N-1}|x[n]|^2}{E[|x[n]|^2]}, \quad (3)$$

where E[.] symbolizes the expectation operation. In general, the PAPR reduction is evaluated by means of complimentary cumulative distributive function (CCDF) which is expressed as

$$CCDF_{PAPR(x)} = \Pr(PAPR(x) > \gamma) \quad (4)$$

where the probability of PAPR of x exceeds γ a given clip level.

It has been seen that the pilot tones normally applied in wireless OFDM transmission for synchronisation and channel estimation purposes can be used in PAPR reduction too. A write up on examinations of their utilization is introduced in [19]. The authors propose to control with the pilot symbols by choosing those of their qualities that limit PAPR of the entire OFDM symbol. A set of orthogonal pilot successions is proposed in [19] so blind identification can be performed at the receiver in view of the orthogonality of the symbols on the pilot tones and

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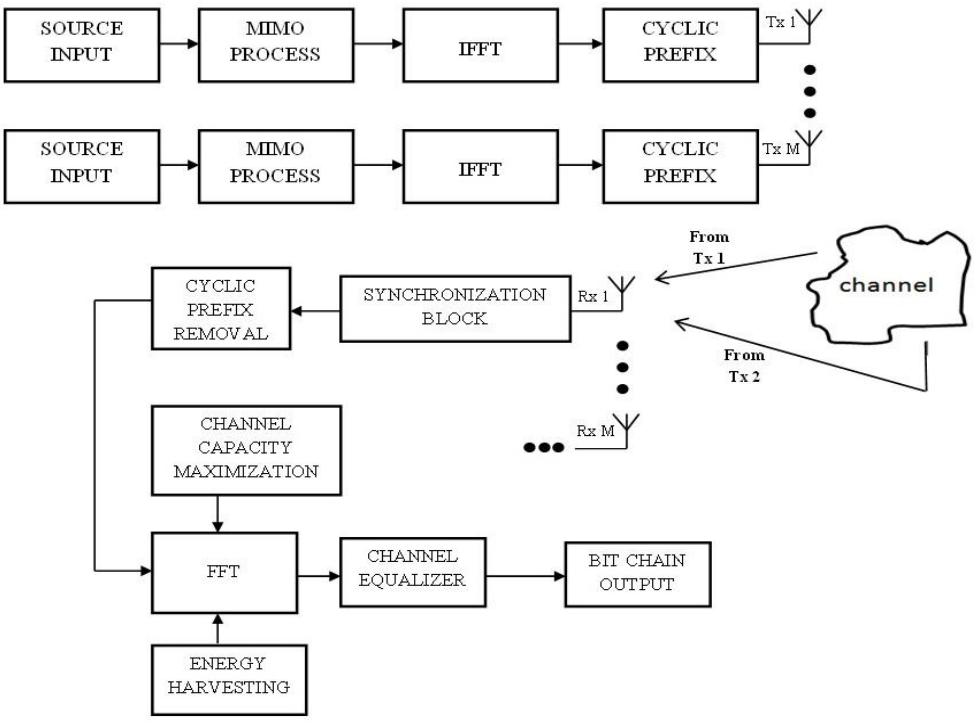

Fig. 1. MIMO-OFDM system model for performance improvement

no SI must be transmitted to the receiver. Applying pilots to the PAPR minimization, which is proposed in this paper, varies from that depicted above and is theoretically very simple.

Based on the MIMO-OFDM technique, to reliably reproduce the transmitted signal, the receiver has to be synchronised with the transmitter in frequency, phase and time in communication system. The mismatch between the transmitter and receiver sampling clocks and their reference frequency in an OFDM system leads to frequency offset. The sampling clock errors occur in two ways:

1. Gradual variation in the sampling time leads to rotation of sub-carriers and resulting loss of signal to noise ratio (SNR) due to inter carrier interference (ICI) and
2. Loss of orthogonality due to the energy spread and adjacent sub-carriers among the sub-carriers.

Defining a normalized sampling error as

$$t_\Delta = \frac{T' - T}{T} \tag{5}$$

where T is the transmit sampling period and T′ is the receive sampling period. Power is approximated as

$$P_{t_\Delta} \approx \frac{\pi^3}{3}(Kt_\Delta)^2 \tag{6}$$

where k is the sub-carrier index. Therefore the degradation increases with the square of the sub-carrier index K and the offset t_Δ. An OFDM system with large number of sub-carriers is very sensitive to sampling offset. In the next section let us see in detail about the above mentioned techniques and view the simulation and results obtained on its basis.

IJARSE
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ISSN (P) 2319 - 8346

III. PEAK TO AVERAGE POWER RATIO IN MIMO-OFDM

Let us now consider two signals x(t) and y(t) as the real and imaginary parts of a complex baseband output signal $\tilde{S}$ with an interval of t ϵ [0,Ts] as

$$\tilde{S} = x(t) + jy(t) \tag{7}$$

$$= \frac{1}{\sqrt{N}} \sum_{k=0}^{N-1} A_k \, e^{\frac{j2\pi kt}{T_s}} \tag{8}$$

where T is the time period of the OFDM system and A_k is the complex data of the K^{th} sub-carrier. According to Nyquist rate OFDM has maximum spectral efficiency and it constrains the overlapping of bands in channels. The use of IFFT makes its implementation simple and less complex. Perfect synchronisation of transmitters and receivers is also obtained using zero forcing beamforming (ZFBF). High PAPR is the main drawback of this multicarrier modulation that leads to two major problems; it increases the complexity of analog to digital and digital to analog convertors and reduces the efficiency of the RF power amplifiers.

A discrete time baseband OFDM has PAPR defined as the ratio of the maximum power of peak to the average power of the OFDM signal.

$$PAPR_{db} = 10 log_{10} \left\{ \frac{P_{peak}}{P_{avg}} \right\} \tag{9}$$

Here P_{peak} is the maximum power for one OFDM frame and P_{avg} is the average power consumed by each frame.

1. Traditional SLM Technique

The OFDM data symbol X_n (similar to that of equation (1)) in a traditional SLM method is multiplied symbol-wise by one of the U pseudorandom phase mask M_u where,

$$X_n = [X_{1,n}, \dots, X_{N,n}]^T$$

$$M_u = [M_1^u, \dots, M_N^u]^T, \qquad (u = 1, \dots, U)$$

where, $\qquad M_i^u = \exp(j\varphi_{i,u})$

Taking these as vector products $X_n \otimes M_u$ the OFDM symbol time domain representation is

$$x_n^u = F^{-1}(X_n \otimes M_u), \qquad u = 1, \dots, U \tag{10}$$

where F^{-1} is the IFFT matrix operation and on computing U such vectors, x_n^u is transmitted which presents the lowest PAPR value. This corresponds to the index u* for which $\max(x_{i,n}^u)$ for (i = 1,…,N) and (u = 1,…,U) evaluates the lowest value. Hence this index u* should be transmitted as an extra message keeping in mind to detect the OFDM data symbol effectively, in the simplest form.

Examining a simple case where the pilot tones are placed on a set of sub-carriers whose indices belongs to a set $\Upsilon = \{i_1, \dots, i_M\}$ where M is the number of pilot tones applied. Therefore at n^{th} time period the OFDM data blocks are divided into blocks of data and pilot symbols (Xn and Pn).

$$X_n = [X_{1,n}, \dots, X_{N,n}]^T$$

$$P_n = [P_{1,n}, \dots, P_{N,n}]^T \tag{11}$$

where X_n and P_n are estimated by

IJARSE
ISSN (O) 2319 - 8354
ISSN (P) 2319 - 8346

$$X_{i,n} = \begin{cases} D_{i,n} & \text{for, } i \in \{1,..,N\}\backslash\Upsilon \\ 0 & \text{for } i \in \Upsilon \end{cases} \tag{12}$$

$$P_{i,n} = \begin{cases} 0 & \text{for, } i \in \{1,..,N\}\backslash\Upsilon \\ B_{i,n} & \text{for } i \in \Upsilon \end{cases} \tag{13}$$

where $D_{i,n}$ (from QAM or QPSK) and $B_{i,n}$(from BPSK or QPSK) are the data and pilot symbols of the ith subcarrier of the nth OFDM symbol (i = 1 ,…, N). The pilot symbols in general need not be the same at each time period n, hence it can be represented as the index n.

2. Modified SLM with Group Pilot Concept

Modifications to the original SLM method of OFDM where the pilot tones are applied is stated where U pilot sequence P_n^u is transmitted for every time period instead of a single sequence P_n. The candidates U are evaluated by the transmitter for nth time sequence as

$$x_n^u = F^{-1}(X_n \otimes M_u + P_n^u)\ , \qquad u = 1 ,…, N \tag{14}$$

And the mask M_u is obtained by

$$M_i^u = \begin{cases} exp(j\varphi_{i,u}) & \text{for, } i \in \{1,..,N\}\backslash\Upsilon \\ 0 & \text{for } i \in \Upsilon \end{cases} \tag{15}$$

Henceforth the pilot symbols are involved in the evaluation of the OFDM time samples sequence as OFDM is modified only at the positions of the user data. The quantity of various pilot tones is equivalent to the quantity of various masks, if the pilots are transmitted in an adequately powerful way; it conveys the side information in the meantime.

At the receiver FFT is carried out after the cyclic prefix is removed giving rise to a frequency domain vector sequence

$$R_n = [R_{1,n}\ , \dots\ , R_{N,n}]$$

where

$$R_{i,n} = \begin{cases} D_{i,n}\, M_{i,n}^{u*}\, H_{i,n} + N_{i,n} & \text{for, } i \in \{1,..,N\}\backslash\Upsilon \\ B_{i,n}\, H_{i,n} + N_{i,n} & \text{for } i \in \Upsilon \end{cases} \tag{16}$$

and $N_{i,n}$ is the Gaussian noise sample on the ith FFT output sequence for the nth OFDM symbol. These complex samples belong to ϒ that consists of the pilot symbols. It is also corrupted by additive white Gaussian noise (AWGN) so the transfer function of the channel is estimated, derived and tracked. An OFDM frame structure consists of a preamble and OFDM user symbols. If suppose the preamble occupies the full OFDM symbol's length, then this frame came be used to find the initial channel transfer function coefficients and it can be suitably preselected to include a low PAPR value since such an OFDM symbol is fixed. Using the pilot symbols the channel transfer function is subsequently tracked and if required, interpolation in both frequency and time axis is carried out on them. Hence using the group pilot concept of SLM PAPR reduction is applied effectively.

IJARSE
ISSN (O) 2319 - 8354
ISSN (P) 2319 - 8346

IV. FREQUENCY OFFSET ERROR REDUCTION

Another drawback in OFDM system is that it is very sensitive to frequency errors and leads to offset problems such as CFO, SFO and NBI. On the transmitter end the incoming data from source is first segmented into blocks, randomized, sent into the channel for encoding and are separately interleaved. The data is then modulated in the constellation mapper. The OFDM frame in the frequency domain is formed by putting together the modulated data, the preambles that are used in time and frequency domains of the OFDM frame or one or more training symbols and the modulated pilot symbols which are used for synchronization by the receiver block. Inverse of these blocks are applied at the receiver. The cyclic prefix is removed after the time synchronization and frequency synchronisation. The processes involved in time synchronisation is: frame detection, starting time of the symbol, SFO estimation and compensation and in frequency synchronisation: CFO estimation and correction.

To make sure the SU can use the same spectrum as that of PU, the same pilot symbols are transmitted to the receiver end of the SU while the sub-carrier data are allocated based on the time and frequency of the various users. Usually by accumulating the reserved tone's energy, the primary signal power and the secondary noise power are estimated. If the primary power exceeds a predefined threshold, then this primary power can be identified. The neighbouring sub-carriers might produce spectral leakage which will affect the energy of the reserved tones so this approach does not assure of the PU detection. A better decision making criterion is proposed here which has an effective resistance to this power leakage thereby overcoming CFO and SFO.

A technique called the energy ratio algorithm is depicted in Fig. 2. In the monitoring phase the primary signal appears after some time, after removing the cyclic prefix and performing frequency domain conversions on the received signal at the secondary receiver, a sequence of complex samples is formed by combining the reserved tones from various OFDM symbols. Two back to back sliding windows of equal sizes are passed in time direction over the reserved tones. The energy of the samples under one sliding window is calculated and the ratio of the two energies is observed as the decision making variable and this is why it is named so.

Processing of the reserved tones begins from the sensing phase, i.e., during the sensing and monitoring phase the decision variable is estimated but only in the monitoring phase it yields decisions. If the decision denotes the PU is inactive during the sensing phase then both the windows are flooded with just noise and error signals. In the monitoring phase the secondary user presumes that due to the appearance of the primary user there occurs a power change on the reserved tones, if X_k is greater than threshold and the band should be cleared or the secondary user can continue their transmission. If there is no primary user in the band then the energy of the window will consist of the noise and erroneous signals only. But if the primary user is appears, then the first window will sustain the unwanted signals without primary user interference whereas the second window will have both. Hence a spike is produced when a primary user is detected by the decision variable.

IJARSE
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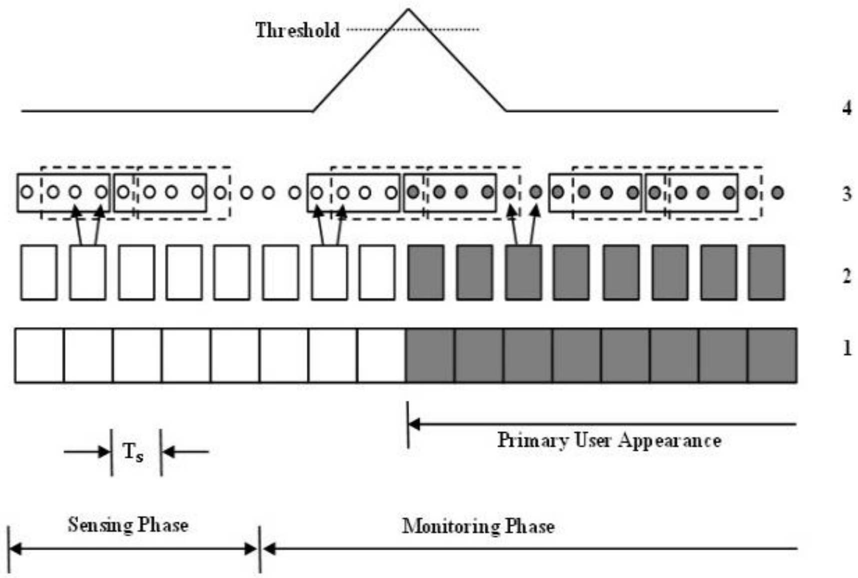

Fig. 2 Process of the Energy ratio algorithm

1) OFDM blocks in time domain, 2) Samples in frequency domain, 3) Reserved tones with sliding windows $N_{RT} = 2$ and $N = 4$, 4) Decision making variable X_k

4.1 CFO Estimation and Compensation

The maximum admissible carrier frequency offset CFO_{max} between the transmitter and receiver is of a maximum CFO integer range, $\mathcal{E}_{imax} = {}^{CFO_{max}}/_{\Delta f}$ and the integer CFO range is $\mathcal{L} = [-\mathcal{E}_{imax}, -\mathcal{E}_{imax} + 1, \ldots, -1, 0, 1, \ldots, \mathcal{E}_{imax} - 1, \mathcal{E}_{imax}]$ and the training symbols are transmitted in front of the OFDM frame. A fractional CFO is estimated by maximum likelihood estimator

$$\hat{\mathcal{E}}_f = \frac{1}{2\pi D}\{\sum_{n=0}^{N_s-1} y(n)y^*(n+D)\} \tag{17}$$

where y(n) is the received signal in time domain and $D = N_s + N_g$. Autocorrelation is done such that two or more training symbols are inserted in time domain at the beginning of the frame. Compensation of CFO is carried out with a cross correlation of the transmitted training symbol after employing a progressive phase shift

$$\hat{\mathcal{E}}_i = \max_{m\in\mathcal{L}}\left|\sum_{n=0}^{N_s-1} y_{comp}(n)y_t^*(n)e^{-2jmn/D}\right| \tag{18}$$

Cross correlation is repeated for every integer CFO in $\mathcal{L}$ and the maximum is looked for. The integer CFO that relates to maximum correlation is considered as the estimated CFO integer and after estimation the OFDM is compensated by phase rotation of the time domain signal by $-2\pi(\hat{\mathcal{E}}_f + \hat{\mathcal{E}}_i)n$ where the time index is denoted by n.

4.2 SFO Estimation and Compensation

The average phase difference in pilots in frequency domain between two consecutive OFDM symbols determining $y = [y_0\, y_1 \ldots y_{J-1}]^T$ where J is the number of pilots which are inserted in one preamble is first

IJARSE
ISSN (O) 2319 - 8354
ISSN (P) 2319 - 8346

determined. Then matrix X is constructed by which the pilot sub-carrier indicies x_j are properly arranged, where $x_j = 0, 1, \dots, J-1$ as

$$X = \begin{bmatrix} x_0 & x_1 & x_2 & \cdots & x_{J-1} \\ 1 & 1 & 1 & \dots & 1 \end{bmatrix}^T \quad (19)$$

And finally the carrier frequency offset $\hat{\mathcal{E}}$ and sampling (timing) frequency offset $\hat{\delta}$ is given as

$$[\hat{\delta} \quad \hat{\mathcal{E}}]^T = \frac{N_s}{2\pi(N_s+N_g)}(X^*X)^{-1}X^*y \quad (20)$$

In view of the traditional OFDM systems, CFO and SFO estimation and compensation is definitely needed and with energy ratio algorithm this evaluation becomes easy. It can provide OFDM synchronisation even with existing algorithms in an efficient manner.

V. SIMULATION AND RESULTS

From Fig.3 the result of PAPR reduction is seen. It is represented as two wave forms one without any PAPR minimization and the other using modified group pilot SLM concept. The figure shows the variations when compared between the CCDF and PAPR in dB.

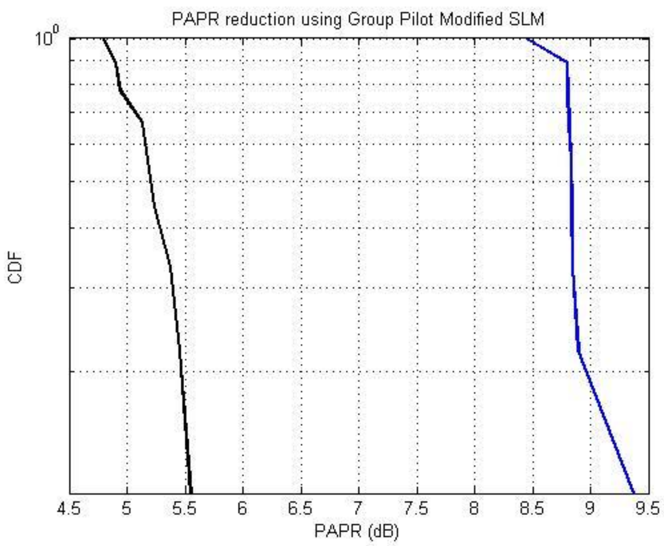

Fig. 3.PAPR reduction using group pilot modified SLM concept

The detection probabilities of various false alarms are noted in Fig. 4. Here the x-axis represents the receiver power ratio (RPR) also called as secondary to primary power ratio (SPR) which is associated to primary to secondary noise ratio (PNR) as $PNR|_{db} = SNR|_{db} - SPR|_{db}$, the PNR is the ratio on which the energy ratio algorithm is decided while for deciding the monitoring algorithm SPR is the major factor.

Fig. 5 examines the combined effects of the OFDM impairments such as power leakage, CFO and SFO with respect to the detection probability. The sub-carriers are sampled four by four in the spectrum and as the shape of the sub-carrier narrows down, ICI, CFO and SFO have slight degradations in their performance. By applying the window concept for CFO and SFO estimation and compensation, the power leakage to the neighbouring

IJARSE
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sub-carriers does not degrade much of the PU detection. From the figure we notice that the overall degradation due to all impairments is only 0.2dB for $P_D = 0.9$.

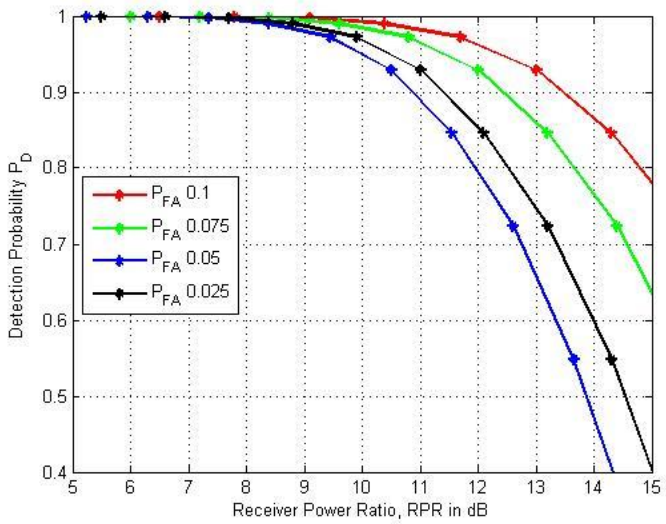

Fig. 4. Probability of false alarm detection versus receiver power ratio

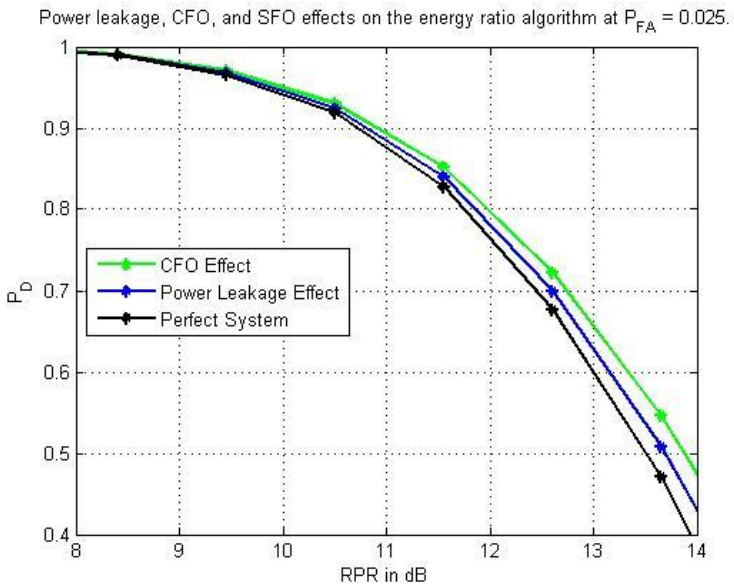

Fig. 5. Power leakage, CFO and SFO effects on the energy ratio algorithm

VI. SUMMARY AND CONCLUSION

Thus we have improved the performance of the LTE-OFDM system by implementing the pilot signals that provided proper channel estimation and synchronisation between transmit and receive blocks besides which the modified SLM technique which uses the group pilot concept minimized the PAPR value and the energy ratio algorithm designed for the OFDM system reduced the frequency and time offsets. The detection probability versus the receiver power ration was derived to estimate the minimum probability of false alarm in order to implement the algorithm in an efficient way in the reduction of power leakage and CFO.

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