Analysis of LTE-Advanced Uplink System for the Effect of Carrier Frequency Offset and Ratio of Peak to Average Power

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Abstract: Broadband communication is one of the high demanding requirements of today's world, where LTE-Advanced does not only focuses on the further enhancement of their data rates but also on reducing the total cost of the system with greatest throughput and performance. In achieving the high throughput LTE-Advanced has to suffer a major problem of power degradation and its effect on the continual disturbance in offset of carrier frequency(CFO). These problems of power(PAPR) and Carrier offset can be minimized if the control over higher carrier aggregation be achieved, which will increase the LTE-Advance system performance significantly.
This paper investigated the effect of power ratio (peak to average) and offset of carrier frequency in LTE-Advance Uplink system's performance and proposed a novel technique using the partial transmit sequence and pilot symbols by applying proposed phase sequence generation method to reduce the ratio of peak power to the average power without having the effect on the frequency offset of carrier. The implemented technique maintained the low PAPR by 4db (76%) with perfect orthogonality among carriers without effecting the carrier frequency offset and reducing the complexity of the system.

Index Terms- Carrier Aggregation, LTE-Advance, Peak to Average Power Ratio(PAPR), Carrier Frequency Offset(CFO)

I. INTRODUCTION

At the establishment of wireless communication, Telco companies focused typically just on voice and data (short text-based messages) transmission due to low-speed wireless connection but in the last few years, the demand for broadband access has increased considerably. This broadband service is changing the world by offering great quality of service for the next generation multimedia Triple – Play (Real time audio and Real time HD (high-definition) video, high speed data, mobile TV etc.) applications. So the need of time demands of advancement in broadband services and exploration of new technologies, establish the engineers and scientist to further work on broadband wireless access technologies.

LTE-Advance requirements is set according to (IMT-Advanced) to achieve equal or even improved data rates than IMT-Advance requirements. So further work on LTE-Advance is being done by researchers to increase the capacity of wireless networks as well as to achieve overall better performance with lower cost.

3GPP proposed LTE to use SC-FDMA in its uplink transmission as multiple access technique where as OFDM in downlink. OFDM is best solution in frequency selective channel. It avoids channel fading by Parallel transmission of data over multiple subcarriers. But the issue with OFDM is its high PAPR. In OFDM all the subcarriers add up after passing through IFFT block, if this addition is coherent it leads to high PAPR and the composite time domain signal appears as Gaussian noise. This signal with high PAPR can be handle in downlink by a node B but in uplink case, user equipment usually has limited battery power. With limited battery power it is not possible to allow high PAPR signals in Uplink. So SC-FDMA is preferred solution over OFDMA in LTE Uplink.

II. LITERATURE REVIEW

LTE-Advance fulfills the requirement of IMT-advance by using bandwidth greater than 20 MHZ (contiguous or non-contagious spectrum). To achieve higher data rates with greater efficiency, following changes with the LTE-Advanced radio interface are require [1]:

- Carrier Aggregation enabled the Wider Bandwidth
- Enhanced Multiple Access Technique (Clustered SC-OFDMA) and Enhanced Multiple Antenna Transmission (MIMO) enabled the efficiency

LTE-Advanced is designed to fully utilize the extended 100MHZ Bandwidth with backward LTE compatibility (up to 20 MHz), to acquire such high bandwidth LTE-Advanced uses carrier aggregation proposed by IMT-Advanced. In carrier aggregation, Multiple carrier components (can be of different bandwidths, up to 20 MHz) are combine to provide over all bandwidth (p to 100 MHz). At the same time individual carrier component allow LTE users to remain using spectrum separately. [2]

Single Carrier FDMA is generally used in LTE-Advance uplink system which is based on OFDMA with pre-DFT coding technique. In SC-FDMA data is divided into multiple parallel sub carriers and each subcarrier is primarily coded with M-DFT. Orthogonality between subcarriers are maintained by inserting the cyclic prefix and guard interval. The subcarrier mapping can be localized or distributive. LTE and LTE-Advanced uses localized mapping.

LTE advance uses Clustered-SC-OFDMA (NxSC-OFDMA) as its multiple access scheme in uplink transmission to utilize the carrier aggregation facility. Carrier aggregation breaks the property of single carrier nature in clustered SC-OFDMA which causes an increase in PAPR in the aggregated waveform to be transmitted. Carrier frequency offset is challenging problem for all OFDM based multiple access schemes. Likewise clustered SC-OFDMA in LTE-Advanced uplink system also suffers with carrier frequency offset. CFO causes serious interferences which will degrades systems performance significantly. Carrier Frequency offset can be reduce to implement some frequency synchronization techniques. But to handle these techniques are very difficult in case of uplink transmission due to random nature of users. Each users suffers with different CFO and the alignment of one user's CFO misalign the others. [4]

In order to fulfill IMT-Advance requirement LTE-Advance system adopted the carrier aggregation, which uses LTE Release 8 standard independently for each carrier component. As LTE-Advance uses clustered SC-FDMA in uplink so the physical layer processing (Scrambling, Modulation, DFT-Precoding, Sub-carrier Mapping and IFFT Modulation) for each component carrier is performed independently as described in figure 1:

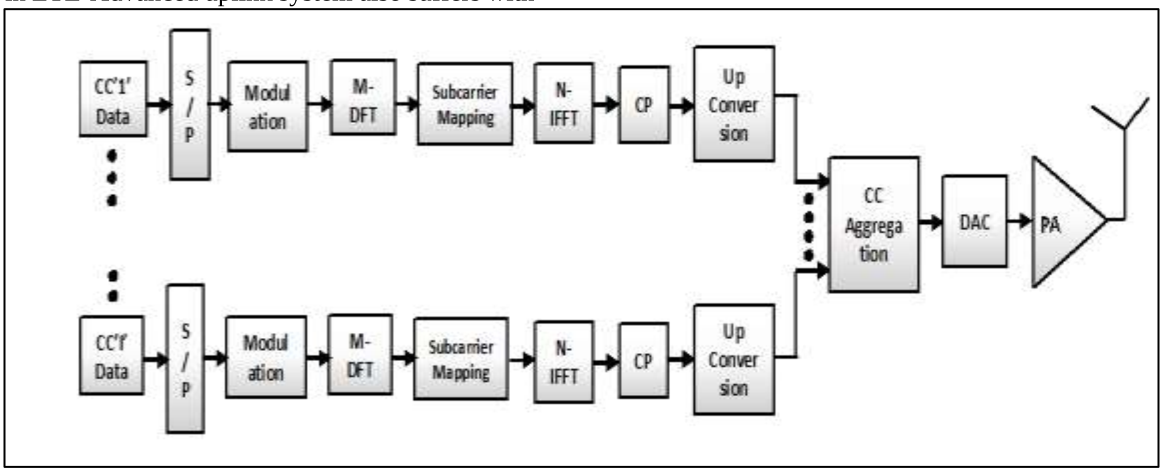

Fig 1. LTE-Advanced Uplink Transmitter

Ratio of Peak to Average Power (PAPR) is having significant importance in wireless communication, as it effects the transmission power directly. When data is transmitted from the user equipment to EnodeB, user equipment needed a power amplifier to boost that signal to such extent that it can easily be picked by network. In any Transmission system power amplifier consumes sufficient energy so it should be design in such a way to absorb less power and provide the user equipment battery with long time. In choosing amplifier design, Power amplifier efficiency is dependent on two factors:

- Amplifier should be capable of amplifying the peaky components of waveform. But highest signal peaks do not contain enough information.
- Average Power contains more information over time and defines the transmission speed.

For a designer of mobile devices, both transmission speed and power consumption are important so it should be taken care in amplifier design that it absorbs ass less energy as possible. Which can be possible if there is no large difference in peak and average power of signal. With less PAPR operating time of a user equipment battery may be increase at sufficient transmission speed.

Similar to OFDMA, Clustered SC-OFDMA behaves as a multicarrier scheme. The component carriers are added coherently or non-coherently after IFFT operation, if the addition is coherent, the resultant signal may have high peaks with relatively low average power of the aggregated signal. Thus Clustered SC-FDMA has high PAPR than SC-FDMA.

Complementary cumulative Density Function Curve shows the relative power levels of any signal against their probability of occurrence. This curve is better metric for PAPR as this shows that for how much time a signal remains on same power level. [4]

Carrier frequency offset occurs mainly due to two important reason, when there is a mismatch between transmitter and receiver oscillator or due to the presence or Doppler Effect in high speed mobile environment. Due to carrier frequency offset, the received signal's frequency is shifted to that offset value. For multiple access techniques based on OFDM, the orthogonality among subcarriers is maintained if the receiver uses the same oscillator frequency as that of carrier present in received signal. The transmitter and receiver can never be oscillating at identical frequencies so there is always a slight frequency shift which causes the carrier interference. As LTE-Advance uses NxSC-OFDMA in uplink which is OFDM based technique so inherent carrier frequency offset in uplink transmission is present. This offset increases by using PAPR reduction techniques. The high PAPR occurs when the large subcarriers add up coherently, so in order to break this coherent addition reduction technique usually exploit phase shifting which leads to slightly change in the carrier frequency offset.

Ibrahim Abdullah et al, explained Many techniques for reducing PAPR in [5]. These techniques are grouped into two general classes according to their process of generation and results:

- Techniques which causes signal distortion
- Techniques which uses scrambling

According to [5] for PAPR reduction one of the most effect technique is signal scrambling using partial sequence transmission in which actual data is divided into small random pieces and then multiply each piece of data with different weights(phases) iteratively to get optimum result. The model for Conventional Partial Transmit sequence for the V sub-blocks of equal size and without any gap in between them is given by [5]

$$\hat{X} = \sum_{v=1}^{V} b_v X_v \tag{1}$$

Where, $b_v = e^{-j\varphi_v}$,
$\varphi_v \epsilon\, [0, \quad 2\pi]$ *and*
$v = \{1,2, \ldots \ldots .., V\}$
v represents weight factor to change the phase. Xt (Time-domain signal) can be generated from Xv by applying IFFT on Xv. Weight factor v can be represented through matrix B as shown in equation (2):[6]

$$B = \begin{bmatrix} b_1 \;, b_1 \;, b_1 \;, \ldots . b_1 \\ . \\ . \\ b_M \;, b_M \;, b_M \;, \ldots . b_M \end{bmatrix} \tag{2}$$

Where each row of B representing the same phase values and optimization parameter bˆ can be suitably selected by the criteria given in (3): [5]

$$\hat{b} = argmin(max_{1 \le n \le N} \left| \sum_{v=1}^{V} b_v X_v \right|^2 \tag{3}$$

Where, to get the maximum value of $\hat{b}, argmin(.)$is applied as decision criterion. Due to the shifting of phases, this method will introduce frequency offset effect in carrier frequency and in return systems performance effected significantly. We can use the DMRS sequence to analyze and reduce the carrier frequency offset effect. [6].

III. Mathematical Modelling of Proposed Technique

This paper proposes a modified Phase Transit Technique with random change in phase sequence. The mathematical model for the proposed scheme is given as:

A. Mathematical Modeling for LTE-Advance Uplink System

LTE-Advanced uplink uses clustered SC-FDMA. By considering the physical structure of LTE uplink consider there are I carrier components in LTE-A uplink system and each carrier component is consist of M subcarriers. Let x_m be the data stream after the modulation block (constellation Mapping=QPSK/8PSK/QAM) of the Uplink system. Modulated data symbols from x_m can be represented as:

$$x_{i.m} = \sum_{i=1}^{I-1} \sum_{m=1}^{M} x_{i,m} \tag{4}$$

The M-point DFT based output can be achieved by pre-coded DFT-operation based modulated symbols $x_{i.m}$ as:

$$X_{i,l} = \sum_{m=0}^{M-1} x_{i.m} e^{-j\frac{2\pi ml}{M}} \tag{5}$$

Where length of DFT is represented by l=0, 1,…..M-1.

Every user is assigned the resources by subcarrier mapping block. As LTE-Advanced uses localized subcarrier mapping so each user occupies M consecutive subcarriers. Guard bands are left on both side of the consecutive subcarriers. The mapped frequency domain symbol after zero padding is given as:

$$Z_{i,k} = \begin{cases} X_{i,l} & 0 \le k = l \le M-1 \\ 0 & M \le k \le N-1 \end{cases} \tag{6}$$

Each subcarrier after mapping will pass through IFFT block. The time domain signal after IFFT block is represented as

$$z_{i,k} = \frac{1}{N} \sum_{n=0}^{N-1} Z_{i,k} e^{j\frac{2\pi nk}{N}} \tag{7}$$

Where k=0, 1,2,…………, N-1. K is the length of IFFT.
Results of IFFT blocks are sampled values of complex envelop. These complex envelop of SC-FDMA symbols are separate for each component carrier in LTE-Advanced. So the overall aggregated symbol complex time domain envelop can be obtained after addition of the complex envelop of each i-CC together and is given as:

$$s_{agg,k\,(n)} = \frac{1}{\sqrt{N}} \sum_{i=0}^{I} \sum_{k=0}^{N-1} z_{i,k} \tag{8}$$

The complex passband signal after pulse shaping (root raised cosine) is given as:

$$s_{agg,k(t)} = e^{j2\pi Fit} \sum_{n=0}^{N-1} s_{agg,k(n)} \,.\, r(t - nT) \tag{9}$$

Fi=Up sampling Factor
T=Sampling Rate.
Peak to average power ratio for NxSC-FDMA signal can be find as:

$$PAPR = \frac{max\left|s_{agg,k}[n]\right|^2}{E\left[\left|s_{agg,k}[n]\right|^2\right]} \tag{10}$$

Ratio of peak to average power(PAPR) is the function of aggregated SC-FDMA symbols which are random in nature so PAPR is also be treated as random variable in nature and we can show the PAPR variations through complementary cumulative distribution function (CCDF).

$$CCDF = \Pr\,(PAPR > PAPR_0) \tag{11}$$

Where, $PAPR_0$ represents the threshold value of PAPR.

B. Mathematical Modelling of Proposed PTS In N-SC-FDMA Systems for PAPR Reduction

This technique is proposed by using Conventional PTS for OFDM with some modifications to reduce its complexity. Consider we have M partitions of final aggregated signal after carrier aggregation and a modified phase sequence with N random values is generated. Random values are chosen from {1

-1} with phase factor is W=2. The proposed phase sub-sequence is given as:

$$\hat{B} = \begin{bmatrix} b_{1,1} & b_{1,2} \ldots\ldots & b_{1,N} \\ b_{2,1} & b_{2,2} \ldots\ldots & b_{2,N} \\ & \vdots & \\ b_{M/2,1} & b_{M/2,2} \ldots\ldots & b_{M/2,N} \end{bmatrix}_{\frac{M}{2}XN} \quad (12)$$

Where, M/2 represents the periodic frequency of change in phase sequence as shown in equation (12). In this proposed technique each row of phase vector consists of different random values of {-1 1} so PAPR reduces more as compared to the conventional PTS. The proposed PTS uses an interleaved sequence:

$$\hat{b} = \left[b_{1,1} \quad b_{2,1} \ldots . \quad b_{1,\frac{N}{D}}, , , , , b_{1,1} \quad b_{2,1} \ldots \ldots . \quad b_{1,\frac{N}{D}} \quad , \right]_{1XN} \quad (13)$$

$$D = VW^{\frac{M}{2}-1}, \quad V=1, 2 \ldots\ldots\ldots. \frac{N}{W^{\frac{M}{2}-1}} \quad (14)$$

Where, V represents each iteration of phase change and D represents the total number of sub-phase sequences. After generation the phase sequence is extended to D rows as follow.

$$\hat{B} = \begin{bmatrix} b_{1,1} & b_{1,2} \ldots\ldots & b_{1,N} \\ b_{2,1} & b_{2,2} \ldots\ldots & b_{2,N} \\ & \vdots & \\ b_{\frac{M}{2},1} & b_{\frac{M}{2},2} \ldots\ldots & b_{\frac{M}{2},N} \\ b_{\frac{M}{2}+1,1} & b_{\frac{M}{2}+1,2} \ldots\ldots & b_{\frac{M}{2}+1,N} \\ b_{\frac{M}{2}+2,1} & b_{\frac{M}{2}+2,2} \ldots\ldots & b_{\frac{M}{2}+2,N} \\ & \vdots & \\ b_{\frac{M}{2}+D,1} & b_{\frac{M}{2}+D,2} \ldots\ldots & b_{\frac{M}{2}+D,N} \end{bmatrix}_{\frac{M}{2}+DXN} \quad (15)$$

The figure2. shows the block diagram of the proposed PTS technique:

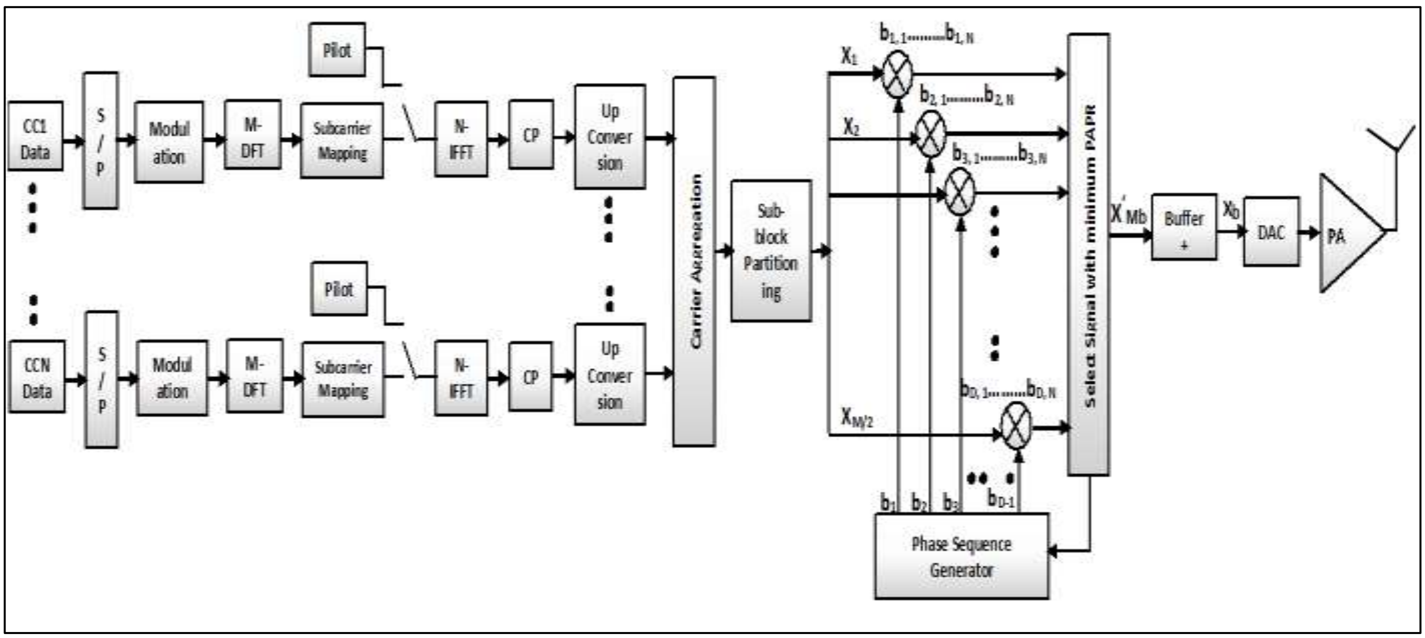

Figure2. Proposed Phase Transmit Sequence

The transmitted symbol can be expressed using PTS as:

$$\hat{x}_b = \sum_{v=1}^{M} s_{agg,k\,(v)} b_v \quad (16)$$

By applying the (16) on new generated phase sequence for M=4

$$\hat{x}_b = \hat{x}_{1,q} b_{p,q} + \hat{x}_{2,q} b_{p+1,q} + \hat{x}_{3,q} b_{p+2,q} + \hat{x}_{4,q} b_{p+3,q} \quad (17)$$

Where p=1, 2, …….. , D-1, q=1, 2, ………., N

If D increases, the number of partitions increases in a similar way and PAPR reduction increases at the cost of high complexity. The side information is needed to send to the receiver with the number of iterations.

C. CFO Estimation

As in LTE-Advance each carrier component uses the same DMRS for the channel estimation, so if there will be any carrier frequency offset effect will observe, it can be estimated through this proposed technique. Let N signals are coming at the receiver, after down conversion and ADC signal is given as:

$$r(o) = \sum_{n=1}^{N} s_{agg,k\,(o)} + w(o) \quad (18)$$

Where w(o) is the AWGN noise and $s_{agg,k\,(o)}$ signal component by kth user is given by:

$$s_{agg,k\,(o)} = e^{\frac{j2\pi\varepsilon_o o}{N}} \sum_{l=0}^{l_k-1} h_k(l) s_{agg,k}{}^{T}(o-l) \quad (19)$$

Where, hk is discrete time channel impulse response and ε_ois sub carrier spacing normalized frequency offset. The frequency estimation unit in the receiver uses r (k) sequence to compute the estimated frequency offset. This estimation is done by exploiting DMRS sequence (used as pilot reference signal). This sequence is already known to receiver and does not affected by channel except its phase. Thus estimated value of phase shift can be compensated by same phase rotation and along with the received side information.

IV. SIMULATIONS AND RESULTS

For simulation, we have used MATLAB. Initially LTE-Advanced Uplink system is simulated over MATLAB with OFDMA and SC-OFDMA. Then the uplink system is simulated with Clustered SC-OFDMA and Proposed Technique for PAPR Reduction. Following are the parameters that set for the Modelling of LTE and LTE-Advanced Uplink:

Parameter	Specification
Modulation	QPSK, 16-QAM, 64 QAM
Spacing of Subcarrier	15KHz
Subcarrier Mapping	Localized
Channel Type	AWGN
CP Type	Normal
No. of Subcarrier Per Component Carrier	1200
FFT Length	2048
Transmission Bandwidth Per Component Carrier	20MHz
Up-Sampling Factor	4
Pilot Sequence	DMRS

Table 1. LTE-Advance Uplink Modelling Parameters

Comparison of PAPR In LTE With OFDMA And SC-FDMA

Initially LTE-Advanced system is simulated with OFDMA and SC-OFDMA. Result shows that the PAPR is less in SC-OFDMA than OFDMA. The figure shows the result:

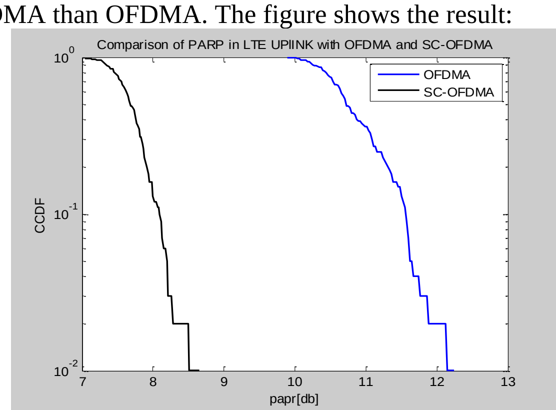

Figure 3. PAPR comparison in LTE OFDMA and SC-OFDMA

Comparison of PAPR In LTE With Different Modulation Scheme

In order to achieve higher data rate, higher modulation schemes are used which significantly increases the PAPR. Following figure shows the simulations results:

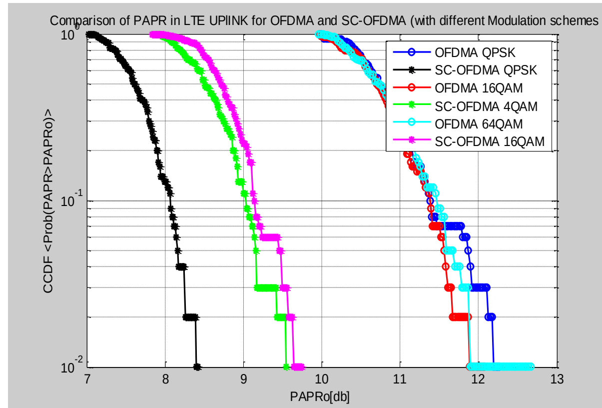

Figure 3. PAPR comparison in LTE with different Modulation Schemes

Comparison of PAPR In LTE And LTE-ADVANCED

Due to the clustered SC-OFDMA, Single carrier property breaks and results in Large PAPR. The simulation results show high PAPR in LTE-Advanced.

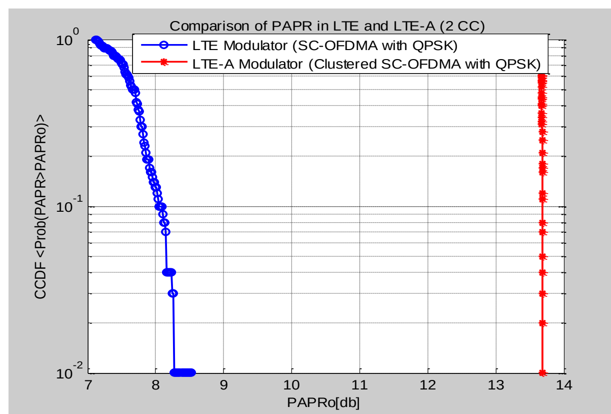

Figure 4. PAPR comparison in LTE and LTE-Advanced

Comparison of PAPR In LTE and LTE-ADVANCED

Result shows that the PAPR becomes worst in clustered SC-FDMA even than OFDMA which seriously degrades the performance of Power amplifier and needed high power consumption.

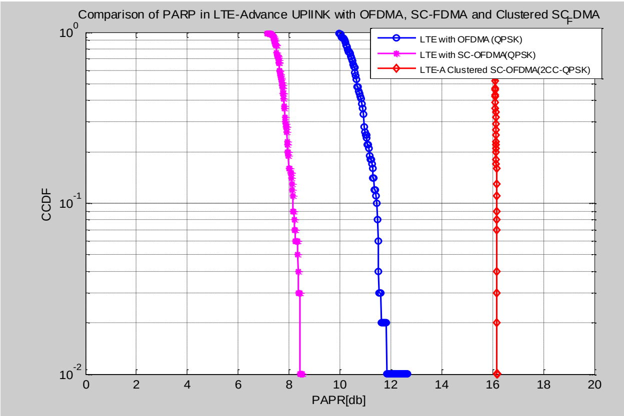

Figure 5. PAPR comparison in LTE and LTE-Advanced

Comparison of PAPR With Increasing CC

As the number of aggregated component carrier's increase, the chances for subcarrier coherent addition increases proportionally. Figure shows the Simulation Result.

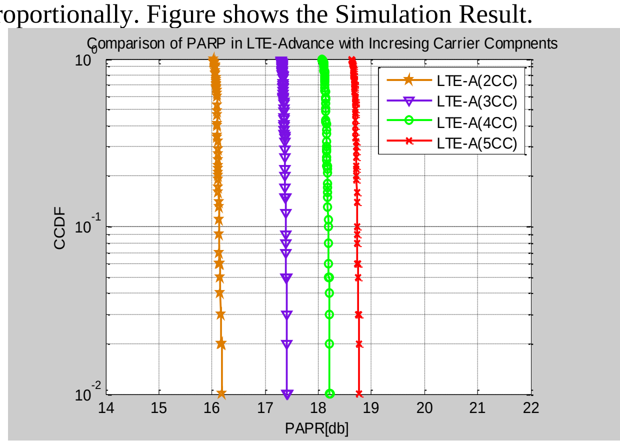

Figure 6. PAPR comparison in LTE-Adva with different CC

Comparison Of PAPR With LTE-A And Proposed Technique

By using the Low complexity PTS, PAPR reduces 4db with two component carriers. Figure shows the result of simulations.

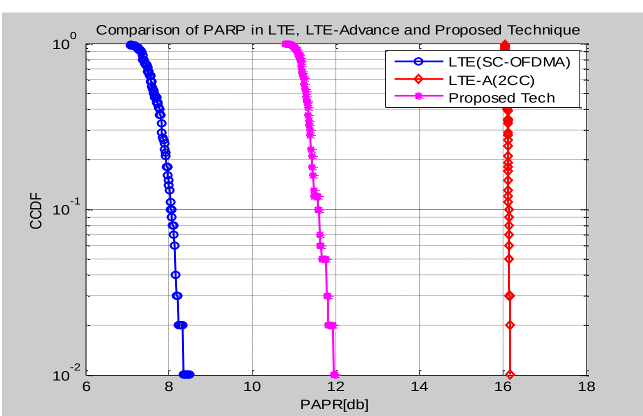

Figure 7. PAPR comparison in LTE-Advanced with Proposed Technique

Comparison of PAPR In LTE-A And Proposed Technique With Different CC

Proposed Technique Reduces PAPR inLTE-Advanced with 2 component carriers by 4db, 3 CC by 3db, 4CC by 2db and 5CC by1.5 db. Figure shows the Simulation Results.

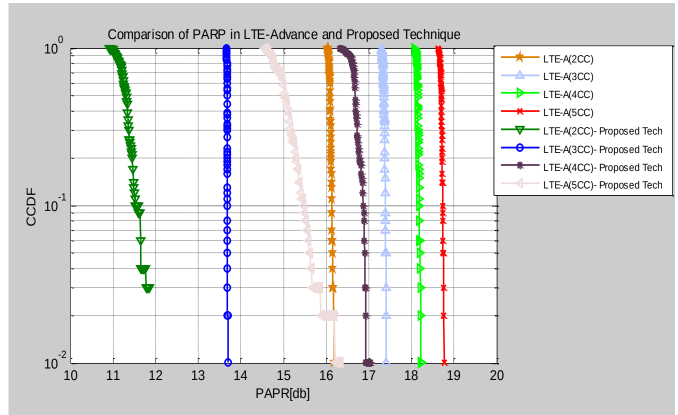

Figure 8. PAPR comparison in LTE-A with Proposed Technique (Different CC)

Carrier Frequency Offset Without Using Proposed Technique

Constellation diagram shows the frequency offset in Received signal.

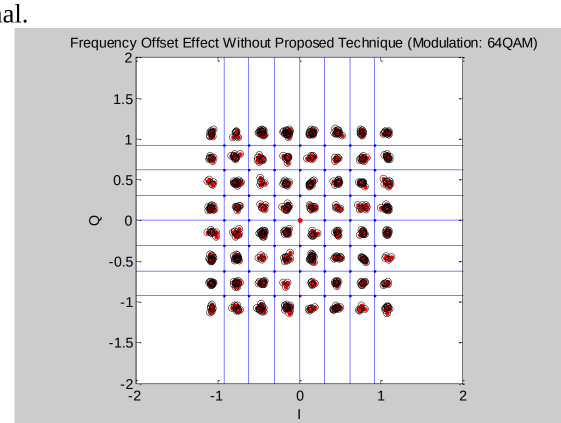

Figure 9. Constellation Diagram of Transmitted and Receive Signals

Carrier Frequency Offset with Using Proposed Technique

Constellation diagram shows that the minor frequency offset effect in proposed Technique.

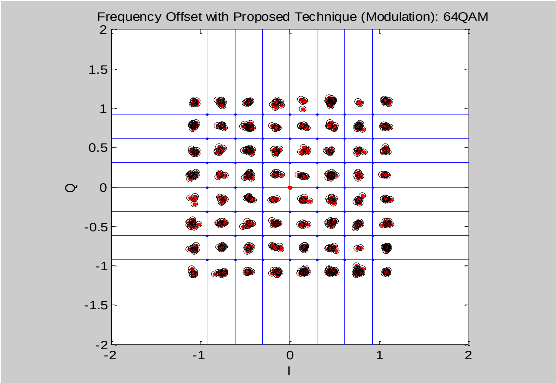

Figure 10. Constellation Diagram of Transmitted and Receive Signals

BER Plot for Proposed Technique

Bit error rate plot for modified PTS technique is shown as:

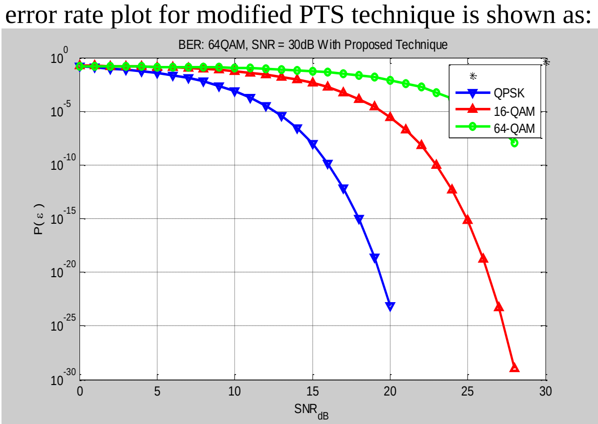

Figure 11. BER plot for Proposed Technique with 2CC

SER Plot for Proposed Technique

Symbol error rate plot for modified PTS technique is shown as:

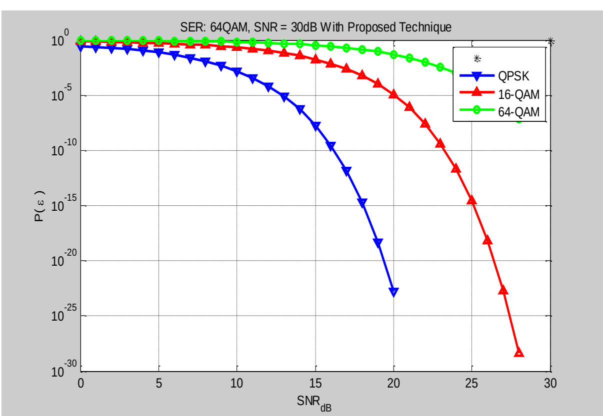

Figure 12. SER plot for Proposed Technique with 2CC

V. CONCLUSION

In this paper a low complexity PTS based PAPR Reduction Technique for the LTE-A Uplink system is presented with less frequency offset effect. The paper mainly focuses on the Reduction of PAPR in aggregated signals transmission in LTE-A Uplink with less complex and efficient method.

In this paper Conventional PTS for OFDM has been discussed and enhancement in its phase sequence generation is made to achieved the new less complex and efficient technique. Finally proposed method is simulated using MATLAB. This paper can be concluded as:

In this technique, random phase factors matrix is initially generated and then extended to multiply with the input signal. By using this technique partitions of data are condensed to half compared to C-PTS which reduces the buffer size and complexity at the cost of slight carrier frequency offset and side information burden. But this offset can be minimized by exploiting the DMRS property which is used as pilot symbol in this method. The DMRS sequence is used for the estimation of the carrier frequency offset at the output and the receiver can compensate this offset by estimated value.

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