Performance Analysis of PAPR Reduction in MIMO OFDM System Using Modified M-2-M Constant Modulus Algorithm

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Abstract - Orthogonal Frequency Division Multiplexing (OFDM) is most commonly preferred in digital communication for high data rate transmission. OFDM system has a main shortcoming of high peak to average power ratio (PAPR) value [1]. As survey and studied in literatures PTS and SLM are the most suitable methods to overcome the problem of high PAPR. Major limitation of this scheme is PAPR. But by going through block level approach we can further reduce PAPR, which is MCMA (Modified Constant Modulus Algorithm). In this paper, new algorithms are proposed by mapping of phase rotation factor, by the mapping of M-ary data points to the 2M constellation points of 2M-ary modulation scheme using two phase rotation factors (1, j), and hence it is known as "M-2M Mapping" scheme. With this property, the proposed algorithms can reduce half of the computational complexity compared with the conventional algorithms. Simulation results demonstrate that the proposed algorithm can provide significant computational complexity reduction with good performance.

***Keywords*—Orthogonal Frequency Division Multiplexing (OFDM), Peak-to-Average Power Ratio (PAPR),M-2M Mapping, Selected Mapping (SLM), Modified Constant Modulus Algorithm (MCMA).**

I. INTRODUCTION

OFDM (Orthogonal Frequency Division Multiplexing) is now a days widely used for wireless applications since it provides high data rate and also improves the spectral efficiency [1]. OFDM is a multicarrier digital communication technique in which the all available bandwidth is divided into many small streams of low data rate and then they are modulated with various different sub-carriers. One of the main shortcomings of OFDM is high PAPR (peak to average power ratio) [5]. To overcome this problem and to obtain efficient output power, generally the high power amplifier (HPA) is set to near the saturation region. The high PAPR mainly causes nonlinearity in the amplifier behavior. Due to this it works in the linear portion with large head-room and this tends to very inefficient amplification. So, it is customary to reduce the PAPR for making the system with fewer losses. The detailed analysis is given in the next sections.

In high-speed wireless communication, combining MIMO and OFDM technology, OFDM can be applied to transform frequency-selective MIMO channel into parallel flat MIMO channel, reducing the complexity of the receiver, through multipath fading environment can also achieve high data rate robust transmission. Therefore, MIMO-OFDM systems obtain diversity gain and coding gain by space-time coding, at the same time, the OFDM system can be realized with simple structure. Therefore, MIMO-OFDM system has become a welcome proposal for 4G mobile communication systems. The basic structure of MIMO OFDM system model is shown in figure 1.

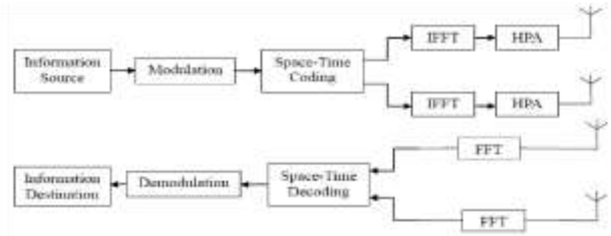

Figure 1. Basic Structure of MIMO OFDM System

At the transmitting end, a number of transmission antennas are used. An input data bit stream is supplied into space-time coding, then modulated by OFDM and finally fed to antennas for sending out (radiation). At the receiving end, incoming signals are fed into a signal detector and processed before recovery of the original signal is made.

OFDM signal generated by an N point Inverse Fast Fourier Transform (IFFT) in the transmitter, and the Fast Fourier Transform (FFT) can be used at the receiver to reform the signal. Now if the input complex-valued data of N subcarriers as: $X_N = X_K, K = 0,1,2 \ldots\ldots N-1$ is used to form with each of the symbol modulating the corresponding subcarrier from a set of opted orthogonal set, the discrete-time OFDM symbol can be written as:

$$x(n) = \frac{1}{\sqrt{N}} \sum_{k=0}^{N-1} X_k e^{j\frac{2\pi}{NL}kn}, 0 \le n \le NL-1$$

Where; X_K is the symbol carried by the K^{th}sub-carrier, L is the oversampling factor. An OFDM signal contains an "N" number of independently modulated subcarriers, which can be given a very large PAPR when added up coherently.

Further, one can also define PAPR for continuous time and discrete-time signals [6]. For a continuous-time OFDM signal, it can be defined at an instant as the ratio of the maximum power to the average power as:

$$PAPR\ [s(t)] = \frac{t \in \max_{[0,T_s]} |s(t)|^2}{E\{|s(t)|^2\}}$$

Where s (t) is the time-continuous type OFDM signal & in case of a discrete-time type signal, sampling is generally placed at a rate of Nyquist-rate to estimate true PAPR. But these samples which are taken here need not to be compulsorily overlapped with the time-continuous signal's peaks. To accurately estimate of PAPR, one need to perform oversampling of given OFDM signal. PAPR with oversampling factor L is given as [6];

$$PAPR[oversampling] = \max_{k \in [0,NL]} \frac{|x(k/L)|^2}{E\{|x(k/L)|^2\}}$$

Where, E [.] denotes the expected value, basically shows average power of the signal and x (k/L) are samples of the OFDM signal with oversampling and defined as:

$$x[k/L] = \sum_{n=0}^{N-1} s_n e^{i2\pi kn/N}$$

Where k=0, 1,……, LN-1. For the value L=1, the samples are called Nyquist-rate samples. PAPR with rate of Nyquist-rate sampling is:

$$PAPR[Nyquist - sampling] = \max_{k \in [0,NL]} \frac{|x(k/l)|^2}{E\{|x(l)|^2\}}$$

The rest of this paper is presented as follows. In Section II illustration of various PAPR reduction techniques. In Section III theoretically comparison of different PAPR reduction techniques including the advantages and disadvantages of these techniques are given. The next part concludes and gives the briefs about the future possibilities to this work for implementations.

Statistically it can be possible to characterize the PAPR using Complementary Cumulative Distribution Function (CCDF). CCDF is a most common type of way to evaluate the PAPR by estimating the probability of PAPR, when this exceeds a particular level. The CCDF equation of the PAPR of OFDM signals with small subcarriers is written as:

$$CCDF = P(PAPR > PAPR_0) = 1 - (1 - exp(PAPR_o))^N$$

This equation is interpreted as the probability that the PAPR of a block symbol exceeds some threshold level $PAPR_O$.

PAPR is a measure of the envelope variations of a multicarrier signal and is used as FOM or figure of merit. Since OFDM signal consists of a number of independent modulated symbols, the sum of independently modulated subcarriers may have large amplitude fluctuations which causes in a large PAPR.

II. EFFECTS OF PAPR

As PAPR increases it results in the following effects [21]:

• Large dynamic range of the D/A and A/D converters will be required; if it is not increased then the peak values could be clipped, results in signal distortion.

• If A/D and D/A converters with large working ranges are taken, quantization noise will also increase and performance will degrade.

• Furthermore, the selection of power amplifier and up-converters will also be crucial when PAPR problem occurs. The working range of Power amplifier & up converters is required, so that the nonlinear distortion would not be introduced which results in decreasing the power efficiency of Power amplifier.

III. PAPR REDUCTION TECHNIQUES

PAPR reduction techniques can be mainly divided into two types. These are signal scrambling techniques and signal distortion techniques [24].

The signal scrambling techniques are classified as:

- Block Coding Techniques (CMA)
- Selected Mapping (SLM)
- Partial Transmit Sequence (PTS)
- Interleaving Technique
- Tone Reservation (TR)
- Tone Injection (TI)

The Signal Distortion Techniques are classified as:

- Peak Windowing
- Envelope Scaling
- Clipping

IV. PROPOSED PAPR REDUCTION TECHNIQUES

It has been in literature that PTS and SLM are the two better techniques, which can be used for reduction of high PAPR. Since in most of the literature they are used for getting good results, also without affecting the other parameters. In this paper we are proposing a new method for both PTS and SLM, by the introduction of a new mapping scheme, using MCMA which does not requires SI information.

In this paper we are proposing a new mapping scheme for CMA as well as SLM which basically maps M-ary data points to the 2M constellation points of 2M-ary modulation scheme using two phase rotation factors (1, j), and hence it is known as "M-2M Mapping" scheme. Mainly we have made changes in the S/P & P/S conversion blocks. The proposed mapping scheme completely eliminates the requirement of SI, like MPSM-PTS [28].

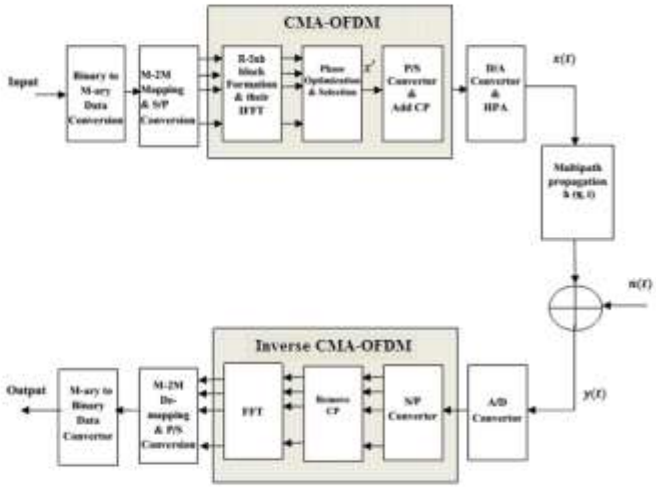

Fig. 2: Proposed system model for MCMA-OFDM

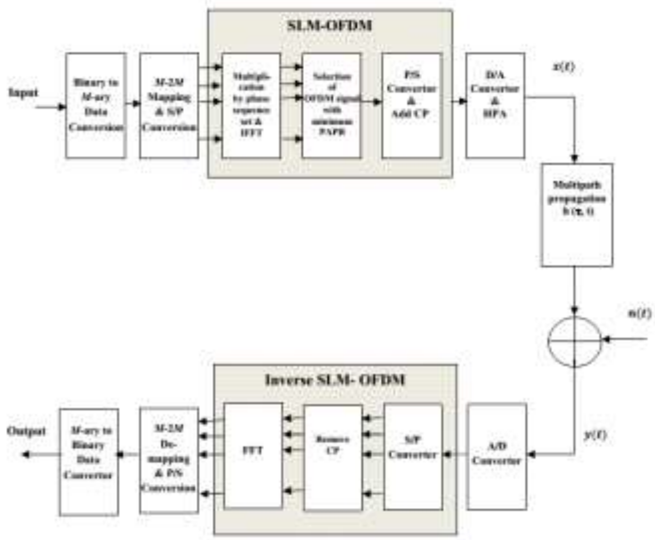

Fig. 3: Proposed system model for SLM-OFDM

4.1 SELECTIVE MAPPING

It is natural to apply SLM to each of the M antennas in MIMO-OFDM individually, a procedure called individual SLM (ISLM). For each of the parallel OFDM frames the optimum phase modification out of the possible (not necessarily the same for the parallel systems) is individually selected. Now, MV IFFT operations and M log2 V bits of side information are required. Since the worst PAPR does not exceed the threshold if all individual PAPR stay below the threshold, and the individual PAPR are distributed according to (5), we can obtain equation as:

$$\Pr(PAPR > PAPR_0) = 1 - (1 - (1 - (1 - e^{-PAPR_0})^N)^V)^M$$

4.2 SYSTEM MODEL FOR PROPOSED M-2M CMA

We have considered an OFDM system with an OFDM block with N subcarriers is transmitted from each antenna. The N subcarriers include N_u useful subcarriers surrounded by two guard bands with zero energy. The useful subcarriers are further grouped into resource blocks (RBs) each consisting of $N_b = N_u / M$ subcarriers. Data of one or more users is placed in these RBs and mapped into the space-time domain using an inverse discrete Fourier transform (IDFT) and space-time block coding (STBC). To allow channel estimation at the receivers (mobile stations), each RB also contains several pilot subcarriers that act as training symbols. The transmit signal model is illustrated in Figure 4.1.

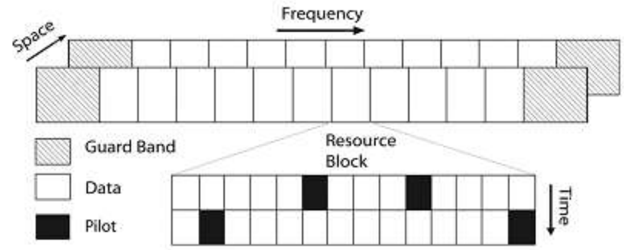

Fig 4: Data structure of an OFDM block

MIMO transmit data model in frequency domain; only a single time block from now on. The data in the -q^th RB is a matrix given as;

$$D^{(q)} \in C^{M_t * N_b},$$

It is premultiplied with a corresponding beamforming matrix given as;

$$W^{(q)} \in C^{M_t * M_t}, \text{ with } q=1,\ldots M$$

Resulting in transmit sequences;

$$X^{(q)} \in W^{(q)H} D^{(q)} ,$$

Together with guard intervals, they are collected in a matrix;

$$X \in C^{M_t * N}$$

Where, the M_t rows of this matrix represent the N symbols to be transmitted from the M_t antennas. The data model is given as:

$$X \in W^H D$$

Where; $W = \left[W^{(1)H}, \ldots\ldots, W^{(M)H}\right]$ & $D \in C^{MM_t * N}$, is a block-diagonal matrix with structure as in Figure 2, which includes guard intervals as well. Matrix X represents the spatial data in the frequency domain.

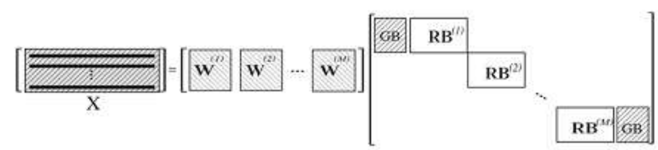

Fig 5. Beamformed MIMO transmit data in frequency domain.

The time-domain MIMO-OFDM transmit data model is obtained by taking the IDFT of the beamformed data matrix X, resulting in

$$Y = XF^H = W^H DF^H$$

Where; $F^H \in C^{N * N}$ denotes the IDFT matrix & $Y \in C^{M_t * N}$ contains the resulting transmit OFDM sequences for each of the M_t antennas. Let us further denote the time-domain data matrix $B = DF^H$, this is a full matrix. Accordingly, the beamformed OFDM block can be expressed as;

$$Y = W^H B$$

The above equation denotes the total power or energy in the data matrix D and given as;

$$P_d = \|D\|_F^2 = \|vec(D)\|^2 = \propto N_t$$

Where; $N_t = NM_t$. The function $vec(D)$ creates a column of the matrix D. N_t is the total number of subcarriers or samples to be sent from all M_t antennas, & $\propto$ is defined as the average transmit power per sample (including the zero power guard bands). If we assume that the beamforming matrix W consists of orthonormal matrices $W^{(q)}$, then applying beamforming and the IDFT does not change the total transmit power.

The IDFT operation in (4.6) leads to a large dynamic range of the resulting time-domain OFDM signal. PAPR is a common metric to measure the distortion caused by probable high peak of the OFDM signal and for a MIMO-OFDM block we can define as;

$$PAPR(Y) = \frac{\alpha N_t \|vec(Y)\|_\infty^2}{\|vec(Y)\|_2^2}$$

Clearly, the lowest PAPR is achieved for a constant modulus (CM) signal, for which the infinity norm is equal to the average power of the sequence.

The main idea in [4], [6] is to design a precoding matrix to transform the OFDM symbols Y in to a favorable signal S with lower PAPR (ideally a CM signal). This precoding matrix Ω needs to fulfill the following requirements:

1. Reduce the dynamic range of the OFDM block,
2. Preserve the beamforming property,
3. Be transparent to the receiver,
4. Not impact the bit error rate (BER).

To satisfy the second and third constraint, we are allowed to premultiply each RB, $D^{(q)}$, with a diagonal scaling matrix $\Omega^{(q)}$. To the receiver, this will appear as a fading channel effect. To not affect the BER, the scaling should be unimodular (phase only). Equivalently, a diagonal (unimodular) precoding matrix can be given as;

$$\Omega \in C^{MM_t * MM_t}$$

is applied to D. The resulting MIMO-OFDM transmit matrix (replacing) is;

$$S = W^H \Omega D F^H$$

If $\omega = vecdiag\ (\Omega)$, then the PAPR reduction problem is to design ω can be given as;

$$\min_\omega \|vec(S)\|_\infty^2 \qquad \text{s.t.} \qquad \|vec(S)\|_2^2 = P$$

Where; $P = \propto N_t$ is a fixed total transmit power. This problem is not convex because nonlinear equality constraints can rarely be expressed in a convex form. The approach in [4], [6] was to solve a series of quadratic convex sub-problems iteratively. Although this does not solve the original problem in (4.12) exactly, the results were excellent compared to other techniques, and attractive as the method is transparent to the receiver and does not distort the transmit signals. Unfortunately, this approach is yet too complex for real time applications.

Formulation as a Constant Modulus Problem

Using properties of Kronecker products, we can rewrite in (4.11) as;

$$s = vec(S) = (B^* o\ W)^H vecdiag\ (\Omega) = A\omega$$

Where; $A \in C^{N_t * MM_t}$, $DF^H = B \in C^{MM_t * N}$, B^* denotes the complex conjugate of B and o denotes the Khatri-Rao product (column-wise Kronecker product). The $vecdiag\ (D)$ creates a column vector whose elements are the main diagonal of the matrix. The optimization problem (4.12) becomes;

$$\min_\omega \|A\omega\|_\infty^2 \qquad \text{s.t.} \qquad \|A\omega\|_2^2 = \alpha N_t$$

We now propose an alternative formulation of this problem, by replacing the infinity norm by the average deviation of the OFDM block from a constant modulus signal. Ideally, the resulting will be close to a CM signal, and hence have close-to optimal PAPR. The corresponding cost function is given as;

$$J(\omega) = \left\| A\omega \odot \overline{A\omega} - \propto 1_{N_t} \right\|_2^2 = \sum_{n=1}^{N_t} (\omega^H a_n a_n^H \omega - \propto)^2$$

Here the vector a_n^H , represents the n–throw of matrix A , the column vector 1_{N_t} is a vector with all entries equal to 1 and dimension N_t , and ⊙ denotes the Schur Hadamard product (pointwise multiplication).

The above formulation is similar to the well-known "CMA (2,2)" cost function for adaptive blind equalization or blind beamforming, and can be solved efficiently using available iterative algorithms. The matrix plays the role of the data matrix in the usual CMA context, whereas plays the role of the beamforming vector. The original CMA cost function is expressed in terms of an expectation operator; the present "deterministic" formulation is similar to the Steepest Descent CMA (SDCMA) [1].

The phase rotation factor is altered in our scheme mapping of M-ary data points to the 2M constellation points of 2M-ary modulation scheme using two phase rotation factors (1, j), and hence it is known as "M-2M Mapping" scheme.

Symbol	Phase factor sequence			
S_i	1	-1	j	$-j$
$\pm S_i^*$	1	-1	$-j$	j

Table 1: Proposed Phase factor sequence mapping

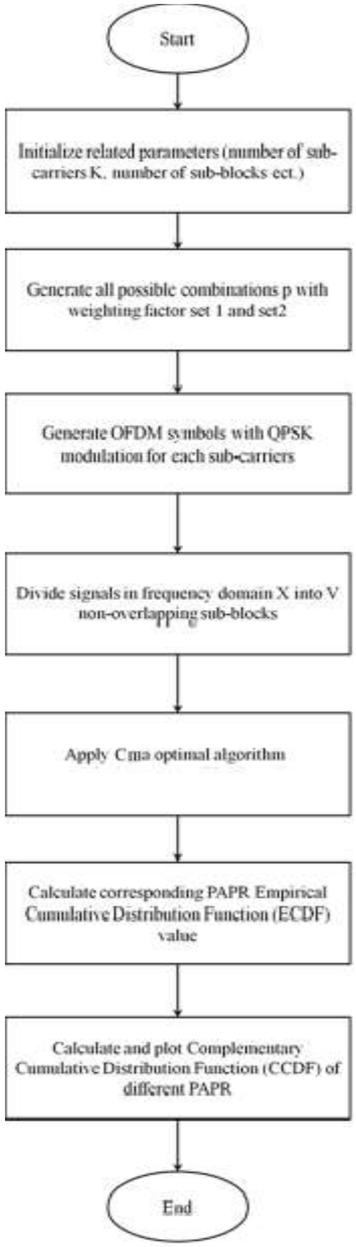

Fig 6.: Algorithm of M-2M CMA PAPR reduction performance

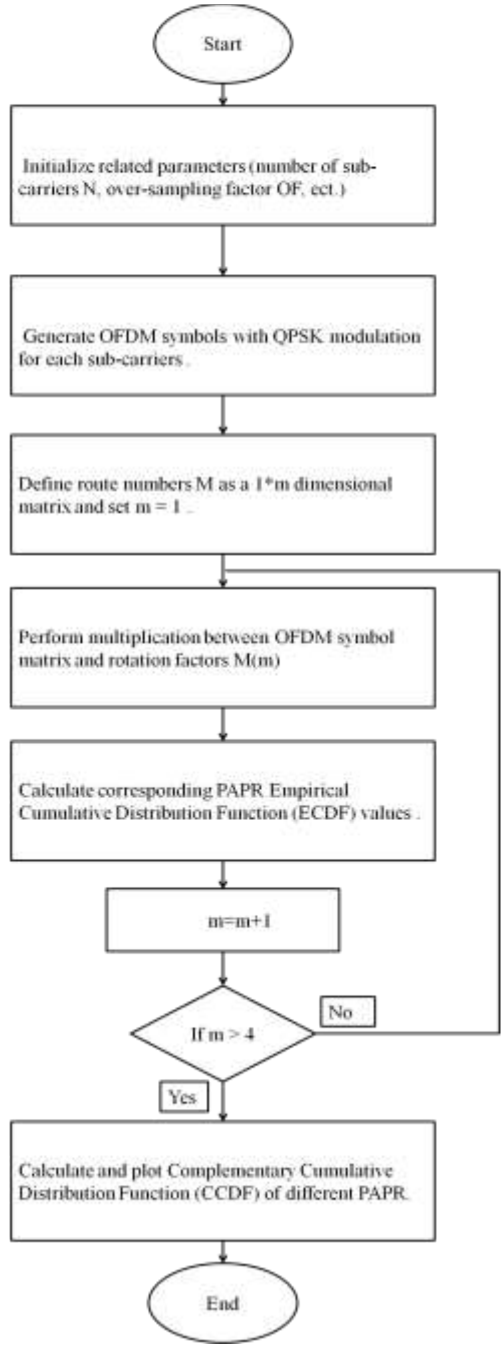

Figure 7: Algorithm of SLM PAPR reduction performance with different values of M

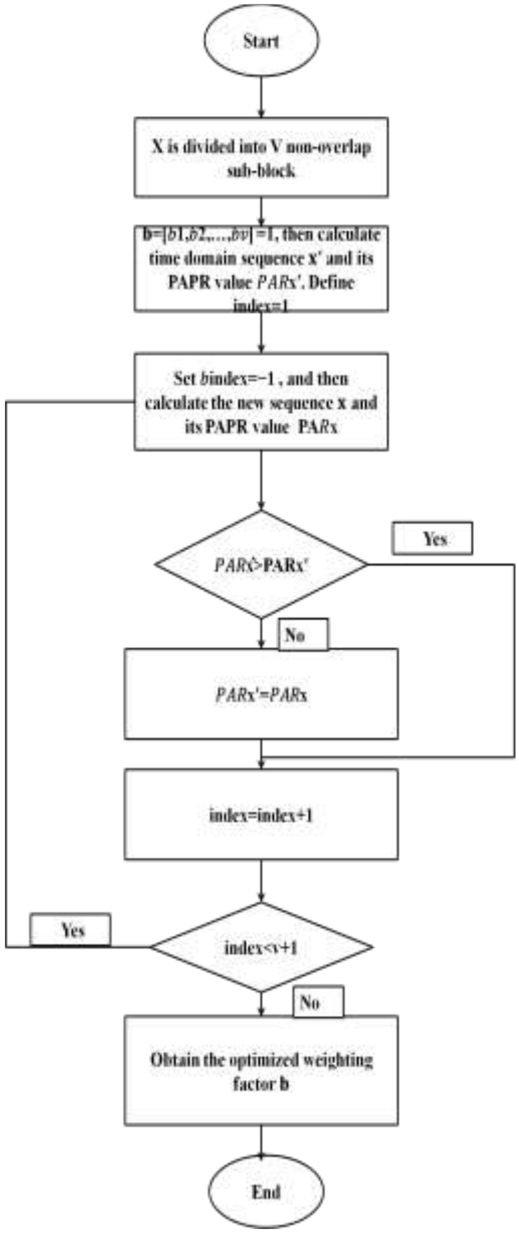

Fig 8: Flowchart of Generalized Suboptimal Iterative Algorithm.

V. SIMULATION RESULTS

In this part, an evaluation of factors which could influence the PAPR reduction performance is performed using MATLAB simulation. Based on the principles of SLM algorithm, it is shown that the ability of PAPR reduction using proposed SLM technique and proposed CMA techniques is better than normal OFDM. Also results shows that the proposed CMA technique outperforms than SLM technique. PAPR vs CCDF for SLM & CMA is shown in figure 6.In this chapter, the PAPR and error performance of all CMA based schemes under consideration are evaluated by simulations platform using MATLAB and verified with their corresponding mathematical results for 10,000 OFDM symbols are considered out of 1, 00,000.

First the simulation is done for different modulation techniques QPSK, QAM and BPSK. Results shows that the BER performance for QPSK & BPSK are better than QAM.

5.1 BER PERFORMANCE

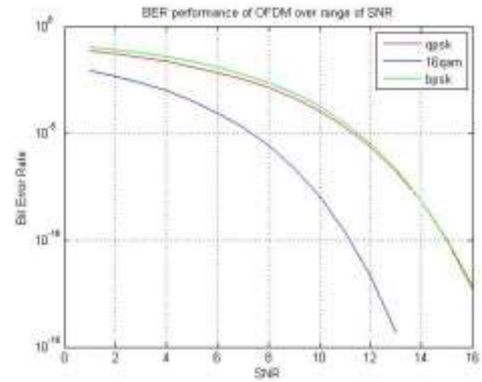

Fig 9: BER performance of OFDM for different modulation schemes

It is shown from simulation that BER performance of 16-QAM is better than the QPSK & BPSK for more number of transmitted symbols >16, hence 16-QAM modulation will be used for further implementations.

5.2 POWER SPECTRUM OF ORIGINAL OFDM

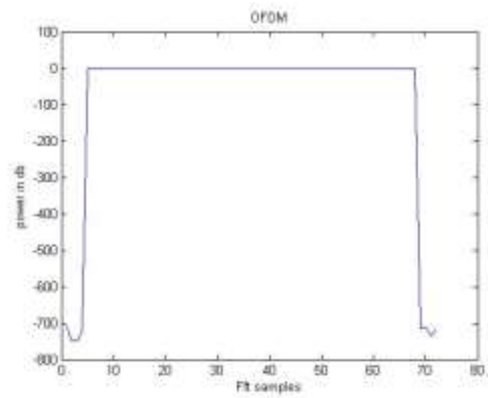

Fig 10: Power Spectrum of Original OFDM

5.3 FREQUENCY SPECTRUM

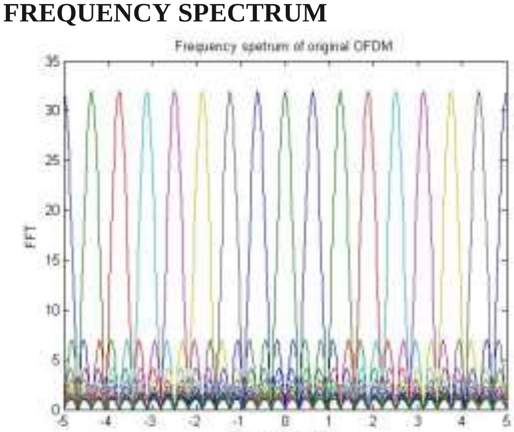

Fig 11: Frequency Spectrum of original OFDM centered at 2.4 GHz

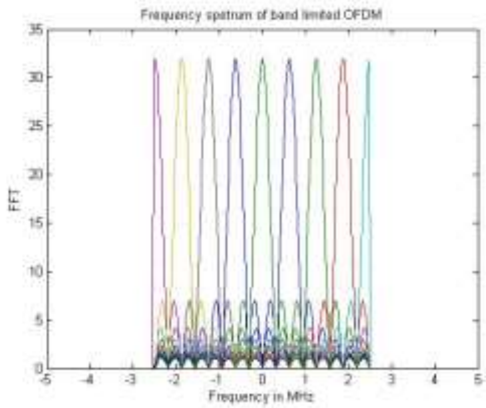

Fig 12: Frequency Spectrum of Band Limited OFDM

5.4 PAPR REDUCTION USING PROPOSED SLM TECHNIQUE

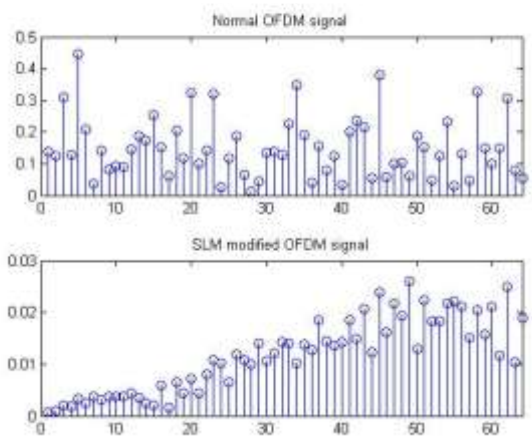

Fig 13: PAPR comparison of Proposed SLM with original OFDM

5.5 PAPR REDUCTION USING PROPOSED CMA TECHNIQUE

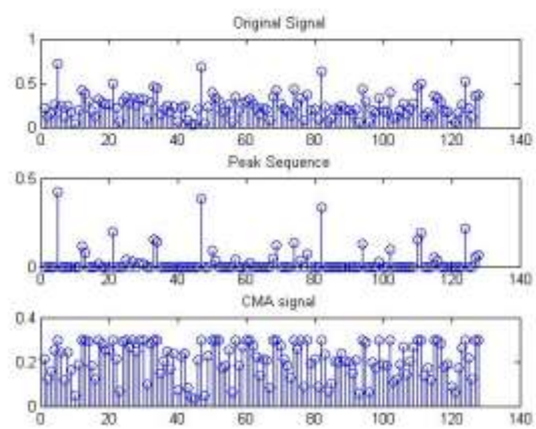

Fig 14: PAPR comparison of Proposed CMA with Original OFDM

5.6 COMPARISON OF PROPOSED M-2M SLM AND CMA ALGORITHM

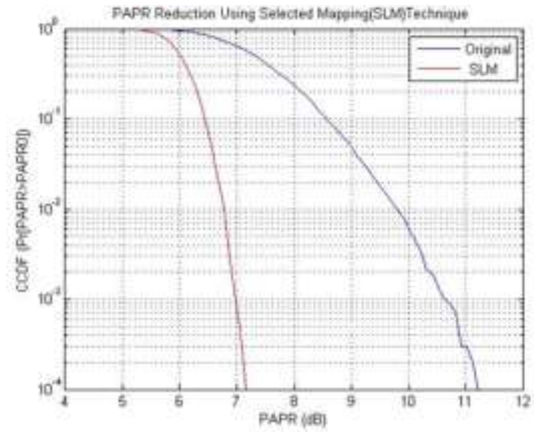

Fig 15: PAPR vs CCDF using Proposed SLM technique

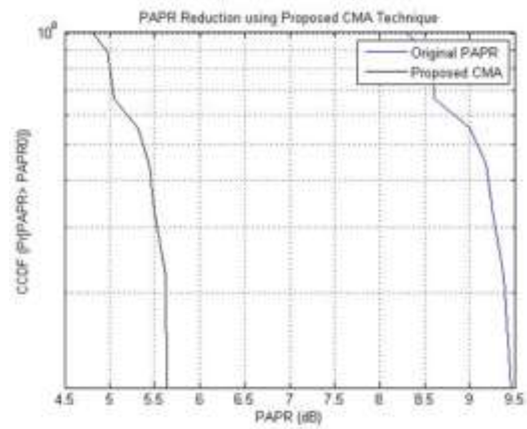

Fig 16: PAPR vs CCDF using Proposed CMA technique

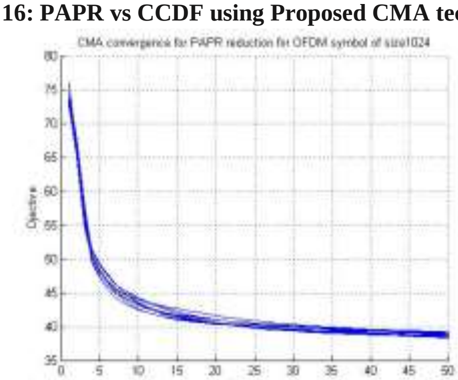

Fig 17: CMA convergence for PAPR reduction for OFDM symbol of size 1024

5.7 SIMULATION RESULTS SUMMARY

PAPR of normal OFDM= 18.2370 dB

PAPR of SLM modified OFDM= 7.208

PAPR Reduction using CMA = 5.2381 dB

MMSE= 0.0050 (Original vs CMA)

Efficiency of Proposed SLM technique with original OFDM in percentage = 60.50 %

Efficiency of Proposed CMA technique with original OFDM in percentage = 71.24 %

Efficiency of Proposed CMA technique with Proposed SLM in percentage = 27.77 %

Hence, CMA technique provides more reduction in PAPR than SLM.

VI. CONCLUSION

OFDM is the efficient modulation technique for multi-carrier transmission and high data rate transmission and it is also spectrally efficient. Major limitation of this scheme is PAPR. In this paper, new algorithms are proposed by mapping of phase rotation factor, by the mapping of M-ary data points to the 2M constellation points of 2M-ary modulation scheme using two phase rotation factors (1, j), and hence it is known as "M-2M Mapping" scheme. With this property, the proposed algorithms can reduce half of the computational complexity compared with the conventional algorithms. Simulation results demonstrate that the proposed algorithm can provide significant computational complexity reduction with good performance. An improvement of 60.50 % reduction in PAPR for SLM compared to original OFDM & 71.24% for CMA techniques using proposed scheme. Efficiency of Proposed CMA technique with Proposed SLM is 27.77 %.

Figures show the simulation result of using SLM and CMA method to an OFDM system, separately. In CMA method, we set the number of sub-carrier's N = 64 and applying pseudo-random partition scheme, for each carrier, adopting QPSK/QAM constellation mapping,

Weighting factor $bv \in (\pm1, \pm j)$; In SLM method, rotation factor $Pm, n \in (\pm1, \pm j)$. Based on the theory, we know that the IFFT calculation amount of these two methods is same when V = M, but for CMA method, it can provide more signal manifestations, thus, CMA method should provide a superior performance on PAPR reduction. In fact, this deduction is confirmed by simulation result. From the above figures we observed that with the same CCDF probability 1%, the PAPR value equals to 6.965dB when CMA is employed, while the PAPR rise up to 8.313dB when SLM is employed under the same circumstance. Figures show the PAPR vs CCDF of both the techniques, which shows that CMA performs better than SLM techniques.

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