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A Modified Selective Mapping Technique For OFDM Paper Reduction

Mr. Somnath Parmeshwar Tandale
Electronics and Telecommunication
Ramrao Adik Intitute of Technology
Navi Mumbai, India
mr.tandale_somnath@rediffmail.com

Mrs. Sujata Kadam
Electronics and Telecommunication
Ramrao Adik Intitute of Technology
Navi Mumbai, India
sujatamane@yahoo.com

Abstract — The orthogonal frequency division multiplexing is multicarrier transmission scheme .In orthogonal frequency division multiplexing (OFDM) systems, high peak-to-average power ratio (PAPR) is one of the major technical challenges, which brings serious impact on the hardware implementation. In literature, many schemes have been proposed for PAPR reduction, wherein the selective mapping (SLM) scheme is the most popular and widely discussed approach. However, SLM suffers from very high computational complexity because of the requirement of a large number of Inverse Fast Fourier Transformation (IFFT) operations.

A modified SLM approach based on time-domain sub-block conversion matrices to reduce the computational complexity due to multiple IFFTs. This scheme is modified from the conversion matrix scheme. By dividing the frequency-domain signals into multiple sub-blocks, the number of the valid conversion matrices can be increased, and thus more candidate signals are available for PAPR reduction. By applying our scheme, the number of candidate signals can be increased from 12 in the original conversion matrix scheme to 28 and 128 for the two sub-block and four sub-block cases, respectively.

Keywords-*OFDM, PAPR, SLM, MSLM, TSCM-SLM*

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I. Introduction

Orthogonal Frequency Division Multiplexing (OFDM) is the digital multicarrier modulation scheme for high speed communication systems. One of the major problems in OFDM is the occurrence of high Peak to Average Power Ratio (PAPR). Due to high PAPR the signal leads to out-of-band (OBO) distortion and increase in Bit Error Rate (BER). The reduction in PAPR is desirable in order to obtain the power efficiency of the amplifier at the transmitter. OFDM system is implemented in several broadband communication systems like Wireless Local Area Network (WLAN), worldwide interoperability for Microwave Access (WiMax), Digital Video Broadcasting (DVB) and Digital Audio Broadcasting (DAB).

Peak-to-Average Power Ratio (PAPR) is one of the main drawbacks in OFDM systems. The occurrence of PAPR will make the power amplifier to drive it to non-linearity which causes in-band & out-of-band (OBO) distortions and affects Bit Error Rate (BER) performance. Various methods for PAPR reduction in OFDM systems have been presented to avoid the occurrence of large PAPR. Partial Transmit Sequences (PTS) and Selective Mapping (SLM) are the most effective schemes to reduce large PAPR.

The selective mapping (SLM) scheme is the most popular and effective PAPR-reduction approach but its complexity is usually too high .In order to reduce the complexity of the conventional SLM, a modified SLM method is used in which the requirement of multiple inverse fast Fourier transformation (IFFT)operations. In MSLM only one IFFT operation is required, and the other candidate signals are obtained via multiplying the time-domain signal by the conversion matrices. To reduce the complexity, the real part and imaginary part of each element in the conversion matrices must be restricted to the three values {0, $\pm$1}. Therefore, the generation of a candidate signals involves no complex multiplications. Moreover, the phase rotation factor on each subcarrier is restricted to the four values {$\pm$1, $\pm$ j}. This restriction can benefit the phase compensation process at the receiver, since no complex multiplication is required.

In this work, we propose an improved scheme, named time domain sub-block conversion matrix (TSCM) SLM, in order to increase the number of available signal candidates, thereby improving the PAPR reduction performance. Note that since the number of signal candidates is increased, more side information is also required by the proposed scheme. In the proposed scheme, we divide the frequency-domain signals into multiple sub-blocks and generate the time-domain signal corresponding to each sub-block. Then, the partial time-domain signals are multiplied by the predetermined conversion matrices individually. Afterwards, a candidate signal is obtained by combining all the resultant signals corresponding to all sub-blocks. By this means, the number of valid conversion matrices is increased, and thus more candidate signals are available for PAPR reduction when compared to the MSLM scheme. Our scheme not only increases the number of candidate signals, but also reduce the average complexity of generating a candidate signal.

A. *Orthogonal Frequency Division Multiplexing*

OFDM is a modulation scheme that allows digital data to be efficiently and reliably transmitted over a radio channel and performs well even in multipath environments with reduced receiver complexity. Using ODFM, it is possible to exploit the time domain, the space domain, the frequency domain and even the code domain to optimize radio channel usage. OFDM transmits data by using a large number of narrow-band subcarriers. These subcarriers are regularly spaced in frequency, forming a block of spectrum. The frequency spacing and time synchronization of the subcarriers is chosen in such a way that the subcarriers are orthogonal, meaning that they do not cause interference to one another. This is despite the subcarriers overlapping each other in the frequency domain. The name 'OFDM' is derived from the fact that the digital data is sent using many subcarriers, each of a different frequency (Frequency Division Multiplexing), which are orthogonal to each other, hence Orthogonal Frequency Division Multiplexing. OFDM can be easily implemented using Fast Fourier Transforms (FFT), an efficient digital signal processing (DSP) realization of DFT.

B. Peak to Average Power in OFDM

Due to the nature of the IFFT, sums N sinusoids through superposition, some combinations of the sinusoids create large peaks. The drawback of a large dynamic range is that it places pressure on the design of components such as the word length of the IFFT/FFT pair, DAC and ADC, mixer stages, and most importantly the HPA which must be designed to handle irregularly occurring large peaks. Failure to design components with a sufficiently large linear range results in saturation of the HPA. Saturation creates both in band distortion, increasing the BER and out of band distortion, or spectral splatter, which causes ACI.

One obvious solution is to design the components to operate within large linear regions, however this is impractical as the components will be operating inefficiently and the cost becomes prohibitively high. This is especially apparent in the HPA where much of the cost and ~50% of the size of a transmitter lies.

C. What Is Peak to Average Power Ratio (PAPR)?

The PAPR is the relation between the maximum powers of a sample in a given OFDM transmit symbol divided by the average power of that OFDM symbol. It occurs when in a multi carrier system the different sub carriers are out of phase with each other, means at each instant they are different w.r.t each other at different phase values. When all the points reach the maximum value simultaneously, this will cause the output envelope to suddenly shoot up which causes a pick in the output envelop. Due to the presence of large number of independently modulated carriers in an OFDM system the pick value of the system will be very high as compared to the average of the whole system; hence the ratio of pick to average value is called PAPR.

Peak to average power ratio is a signal property that is calculated by dividing the peak power amplitude of the waveform by the RMS value of it, it is a dimensionless quantity which is expressed in decibels (dB). In digital transmission when the waveform is represented as signal samples, the PAPR is defined as

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

$$=10 \log10 [P_{peak}/P_{avg.}]$$

Where S[n] represents the signal samples, max(|S[n]|2) denotes the maximum instantaneous power and E{|S[n]|2} is the average power of the signal, and E{.} is the expected value operation.

D. The PAPR of a Multi-Carrier Signal

A multi-carrier signal is the sum of many independent signals modulated to sub-channels of equal bandwidth.OFDM is a special case of multi-carrier transmission, where a single data stream is transmitted over a number of lower rate subcarriers. The subcarrier frequencies are chosen to be orthogonal to each other. The main advantages of OFDM are its increased robustness against frequency selective channels and also efficient use of available bandwidth. Furthermore, the orthogonality allows for efficient modulator and demodulator implementation using the FFT (Fast Fourier Transform) algorithm on the receiver side, and inverse FFT on the sender side. In the transmitter, initially the binary input data are mapped into QAM (Quadrature Amplitude Modulation) symbols and then the IFFT block is used to modulate the symbol sequence, the N-point IFFT output is given by

$$x_k = \frac{1}{\sqrt{N}} \sum_{n=0}^{N-1} X_n e^{j\frac{2\pi nk}{N}}, \quad 0 \le k \le N-1, \qquad \ldots (1)$$

Where, Xn denotes the data symbols.

Since the OFDM symbol is the summation of N different QAM symbols, it can have high peaks when phases are accumulated constructively.

E. Why We Need to Reduce the PAPR?

Non-linear devices such as high power amplifiers (HPA) and digital to analog converters (DAC) exist in almost all communication links and demand for data transmission over longer ranges. At the same time higher power efficiency of the amplifiers, require the amplifier to operate in a more non-linear region, In general, there is a trade of between linearity and efficiency.

Due to high PAPR the transmitter require high power to transmit the signal. For example, PAPR 10 db means that for transmitting an average power of 0.2W, the transmitter should be able to handle peak power of 2W i.e.10 times higher, therefore the result is a very low efficiency and high battery power consumption.

In single-carrier modulation the signal amplitude is somehow deterministic, except for the pulse shaping filter effect, so the operating point in the amplifier can be determined accurately without destructive nonlinear impairments. But in the multi-carrier systems like OFDM, the envelope of the time domain signal will change with different data symbols. Accordingly, the input power amplitude will change with a noticeable variance in specified operating point and the non-linearity effect causes distortion. Distortion acts as noise for the receiver, and also the signal constellation rotates due to phase conversion. Moreover, the out-of-band distortion of subcarriers is the result of non-linearity impairments, which causes cross talk since the subcarriers are not orthogonal any more.

To estimate the distortion which is caused by non-linearity, it is desired to have a measure of the signal to show its sensitivity to non-linearity. A well known measure for the multi-carrier signals is peak to average power ratio (PAPR). The higher the PAPR, the more fluctuation in the signal amplitude, so the operating point in the amplifier needs to be set far enough from saturation point and this input back off reduces the efficiency.

II. EXISTING APPROACHES FOR PAPR REDUCTION

A. System Model

The considered OFDM system is assumed to comprise N subcarriers. Let X=[X0, X1…X (N-1)]^T denote the frequency-domain data vector transmitted in an OFDM symbol. The corresponding time-domain baseband signal is represented as

$$x(t) = \frac{1}{\sqrt{N}} \sum_{k=0}^{N-1} X_k \exp(j2\pi k\Delta f t), \quad 0 \le t \le T, \qquad \ldots\ldots (2)$$

Where Δf the subcarrier spacing and T is the OFDM symbol duration. The PAPR of $x(t)$ is defined as the ratio of the peak power to the average power of $x(t)$ and can be written as

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$$\text{PAPR}=\max_{0\le t\le T}\left|x(t)\right|^2 \Big/ E\left[\left|x(t)\right|^2\right].$$

For discrete-time analysis, we denote the discrete-time version of $x(t)$ as

$$x_k = x\left(kT/LN\right),\quad 0\le k< LN\ , \qquad \ldots (3)$$

Where L is the over-sampling factor and typically assumed to be 4. Accordingly, the PAPR can be rewritten as

$$\text{PAPR} = \max_{0\le k<LN}\left|x_k\right|^2 \Big/ E\left[\left|x_k\right|^2\right].$$

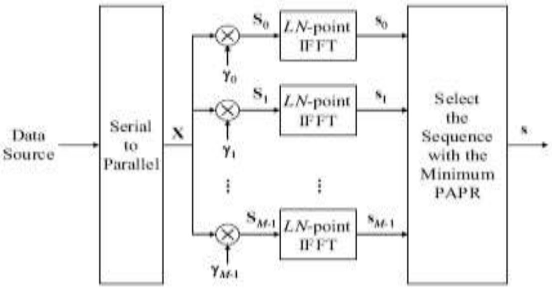

Figure 1: Block diagram of the conventional SLM scheme

B. Selective Mapping

In the conventional SLM scheme, M statistically independent phase sequences are generated, and then multiplied by the frequency-domain data sequence **X** to produce the M independent candidate signals. Through IFFT transformations, the candidate signal with the lowest PAPR is selected for transmission, as shown in Fig. 1. Let the frequency-domain candidate signal **S**0 = **X** be the original data vector and the corresponding time-domain signal be **s**0 = **F**-1**S**0 = **F**-1**X**, where **F**-1 represents the matrix of IFFT.

We denote the random-generated phase vector as

$$\gamma_m = \left[b_0^{(m)}, b_1^{(m)}, \cdots, b_{N-1}^{(m)}\right]^T,\ \text{for } m = 0,\ \ldots,\ M-1 \qquad \ldots\ldots..(4)$$

and the frequency-domain candidate signals as

$$\mathbf{S}_m = \mathbf{R}_m\mathbf{X} = \left[b_0^{(m)}X_0, b_1^{(m)}X_1, \cdots, b_{N-1}^{(m)}X_{N-1}\right]^T, \qquad \ldots...(5)$$

for $m = 0, \ldots, M-1$, where

$$\mathbf{R}_m = \begin{bmatrix} b_0^{(m)} & & & \mathbf{0} \\ & b_1^{(m)} & & \\ & & \ddots & \\ \mathbf{0} & & & b_{N-1}^{(m)} \end{bmatrix} \qquad \ldots\ldots.(6)$$

is referred to as the phase rotation matrix corresponding to the phase rotation vector γ_m. Correspondingly, the time-domain candidate signals are **S**m= **F**-1**S**m, for m = 0, …,M – 1. In conventional SLM, the transmitter requires performing M IFFT operations in order to generate the M time-domain candidate signals, leading to a very high computational complexity.

III. Proposed System Model

In order to solve the high complexity problem in the conventional SLM scheme, the proposed MSLM scheme to generate candidate signals by multiplying the original time domain signal **x** with predetermined conversion matrices. The architecture of the scheme is shown in Fig. 2.

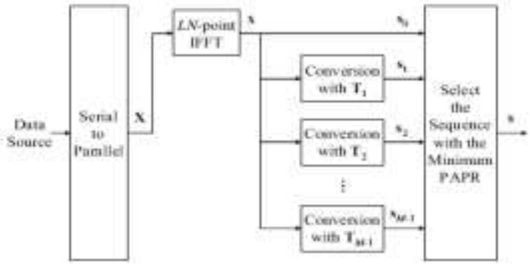

Figure 2: Block Diagram of the MSLM Scheme

The time-domain signal of the original data sequence is first generated by applying IFFT on **X**, i.e., **x** = **s0** = **F**-1***S**0. The conversion matrices are denoted as **T**m, for m = 0… M – 1, and the candidate signals are obtained by

$$\mathbf{s}_m = \mathbf{T}_m\mathbf{s}_0 = \mathbf{F}^{-1}\mathbf{R}_m\mathbf{X},\ \text{for } m = 0,\ \ldots,\ M-1, \qquad \ldots(7)$$

Where, **T0** is the identity matrix corresponding to the original time-domain signal, and thus no operation is required. Based on the fact that **s**0 = **F**-1**S**0, we can obtain the conversion matrix by **T**m = **F**-1**R**m**F**. accordingly, the conversion matrix **T**m can be expressed as

$$\mathbf{T}_m = \left[\mathbf{t}_m, \mathbf{t}_m^{<1>}, \cdots, \mathbf{t}_m^{<N-1>}\right], \qquad \ldots. (8)$$

Where, $\mathbf{t}_m^{<k>}$ is a circularly down-shifted version of the first column vector **t**m by k elements, and **t**m is obtained by

$$\mathbf{t}_m = \mathbf{F}^{-1}\gamma_m \qquad \ldots (9)$$

To reduce the computational complexity, it is suggested that some constraints must be satisfied:

The first column vector **t**m contains only i non-zero elements, where i = 2, 3, or 4.

The real and imaginary parts of each non-zero element in **t**m must be +1, -1, or 0 (ignoring the constant factor).

All the elements of the corresponding phase rotation vector must be non-zero and have the same magnitude, in order to prevent any distortion on the frequency-domain signals [6].

For the case that **t**m contains four non-zero elements, it requires three complex vector additions in the generation of a candidate signal. By computer searching based on the constraints proposed in [6], only 12 candidate signals, i.e., M = 12, are available for PAPR reduction. If the constraint of the same magnitude in a phase rotation vector is relaxed, more candidate signals can be obtained; however, the bit error rate (BER) performance will be significantly degraded.

Following table shows the phase sequences generated for the MSLM. In order to find all possible partial phase rotation vectors efficiently, we introduce the following proposition.

Proposition 1: Under the constraint that the time-domain column vector in a conversion matrix contains no more than two non-zero elements, the elements of the

	First Column Vectors	Phase Vectors
$\mathbf{T}_m$	$t_1 = [1\,0\,0\,0\,1{+}j\,0\,0\,0\,{-}j\,0\,0\,0\,0\,0\,0\,0]^T$	$\gamma_1 = [1\ \ 1\ \ {-j}\ \ j\ \ 1\ \ 1\ \ {-j}\ \ j]^T$
	$t_2 = [j\,0\,0\,0\,1{-}j\,0\,0\,0\,1\,0\,0\,0\,0\,0\,0\,0]^T$	$\gamma_2 = [1\ \ {-1}\ \ j\ \ j\ \ 1\ \ {-1}\ \ j\ \ j]^T$
	$t_3 = [1\,0\,0\,0\,1{+}j\,0\,0\,0\,{-}j\,0\,0\,0\,0\,0\,0\,0]^T$	$\gamma_3 = [1\ \ {-j}\ \ j\ \ 1\ \ 1\ \ {-j}\ \ j\ \ 1]^T$
	$t_4 = [-j\,0\,0\,0\,1{+}j\,0\,0\,0\,1\,0\,0\,0\,0\,0\,0\,0]^T$	$\gamma_4 = [1\ \ {-j}\ \ {-j}\ \ {-1}\ \ 1\ \ {-j}\ \ {-j}\ \ {-1}]^T$

corresponding partial phase vector have the following relation

TABLE I: Phase sequences generated for the MSLM

TABLE II. The first column vectors of sub-block conversion matrices and the corresponding phase vectors for two sub-block

	First Column Vectors	Phase Vectors
Ag	a1 = $[1\,0\,0\,0\,0\,0\,0\,0]^T$	$\gamma_{A,1}=[1 \times 1 \times 1 \times 1 \times]^T$
	a2 = $[0\,1\,0\,0\,0\,0\,0\,0]^T$	$\gamma_{A,2}=[1 \times -j \times -1 \times j \times]^T$
	a3 = $[0\,0\,1\,0\,0\,0\,0\,0]^T$	$\gamma_{A,3}=[1 \times -1 \times 1 \times -1 \times]^T$
	a4 = $[0\,0\,0\,1\,0\,0\,0\,0]^T$	$\gamma_{A,4}=[1 \times j \times -1 \times -j \times]^T$
B_h	b1=$[1\ 0\ 0\ 0\ 0\ 0\ 0\ 0]^T$	$\gamma_{B,1}=[\times 1 \times 1 \times 1 \times 1]^T$
	b2=$[0\ 0\ j\ 0\ 0\ 0\ 0\ 0]^T$	$\gamma_{B,2}=[\times 1 \times -1 \times 1 \times -1]^T$
	b3=$[0\ j\ 0\ j\ 0\ 0\ 0\ 0]^T$	$\gamma_{B,3}=[\times 1 \times 1 \times -1 \times -1]^T$
	b4=$[0\ 1\ 0\ -1\ 0\ 0\ 0\ 0]^T$	$\gamma_{B,4}=[\times 1 \times -1 \times -1 \times 1]^T$
	b5=$[0\ j\ 0\ 0\ 0\ -1\ 0\ 0]^T$	$\gamma_{B,5}=[\times 1 \times -j \times -1 \times j]^T$
	b6=$[0\ 0\ 0\ -1\ 0\ 0\ 0\ -j]^T$	$\gamma_{B,6}=[\times 1 \times j \times -1 \times -j]^T$

TABLE III: The first column vectors of sub-block conversion matrices and the corresponding phase vectors for four sub-block

	First column vectors	Phase vectors
A_k	a1=[1000000000000000]	$\gamma_{A,1}=[1\times\times\times1\times\times\times1\times\times\times1\times\times\times]^T$
	a2=[0100000000000000]	$\gamma_{A,2}=[1\times\times\times-j\times\times\times-1\times\times\times j\times\times\times]^T$
	a3=[0010000000000000]	$\gamma_{A,3}=[1\times\times\times-1\times\times\times1\times\times\times-1\times\times\times]^T$
	a4=[0001000000000000]	$\gamma_{A,4}=[1\times\times\times j\times\times\times-1\times\times\times-j\times\times\times]^T$
B_l	b1=[1000000000000000]	$\gamma_{B,1}=[\times1\times\times\times1\times\times\times1\times\times\times1\times\times]^T$
C_p	c1=[1000000000000000]	$\gamma_{C,1}=[\times\times1\times\times\times1\times\times\times1\times\times\times1\times]^T$
	c2=[00j0000000000000]	$\gamma_{C,2}=[\times\times1\times\times\times-1\times\times\times1\times\times\times-1\times]^T$
D_q	d1=[100000000000000]	$\gamma_{D,1}=[\times\times\times1\times\times\times1\times\times\times1\times\times\times1]^T$

IV. TSCM-SLM Scheme with Two Sub-Block and Four Sub-Block Scheme

We propose the TSCM-SLM scheme in order to obtain a sufficient number of candidate signals while maintaining a very low computational complexity without causing any degradation in the BER performance. The basic concept of the TSCM-SLM scheme is to divide the frequency-domain data sequence into multiple sub-blocks by using interleaved partition. In other words, each sub-block contains the data symbols upon subcarriers with equally-spaced indices. By this means, the number of valid conversion matrices is greatly increased. For convenience of analysis and explanation, the cases with two sub-blocks and four sub-blocks are utilized in the following discussion.

A. Two Sub-Block TSCM-SLM

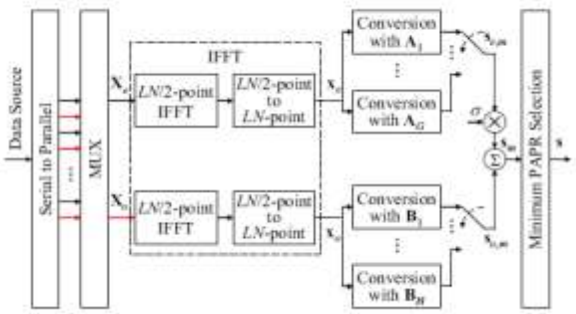

Figure 3: Block diagram of the Proposed Two-Sub-block TCSM-SLM Scheme.

Shown in Fig. 3 is the architecture of the proposed two sub-block TSCM-SLM scheme. The input data sequence is divided into two sub-blocks with length $N/2$. In other words, the $N/2$ even-indexed subcarriers are grouped in one sub-block $\mathbf{X}e$ and the $N/2$ odd-indexed subcarriers are grouped in the other one $\mathbf{X}o$. After over-sampling and passing through the $LN/2$ -point IFFT operation, we obtain the time-domain signals with the length equal to $LN/2$. Note that the length of the partial candidate signals is equal to $LN/2$ and can be extended to length LN easily by applying the basic concepts of FFT [7].The resultant time-domain signals are represented as $\mathbf{x}e$ and $\mathbf{x}o$, respectively. Then, $\mathbf{x}e$ and $\mathbf{x}o$ are respectively multiplied by the conversion matrices $\mathbf{A}g$ and $\mathbf{B}h$ to obtain the partial candidate signals. Finally, a candidate signal $\mathbf{s}m$ is obtained by summing up the two extended partial candidate signals $\mathbf{s}e,m$ and $\mathbf{s}o,m$. To guarantee that the complexity of the proposed TSCM SLM scheme is not higher than that of the MSLM scheme, we restrict the total number of involved complex vector additions, including the operation of sub-block conversions and the summation of partial candidate signals, to be less than three. As a result, we have the modified constraint .In order to ensure that no more than three complex vector additions are required for the generation of a candidate signal.

The first column vector $\mathbf{t}m$ contains no more than two nonzero elements. Therefore, the generation of a candidate signal involves no complex multiplications, and there is no degradation in the BER performance.

B. Four Sub-Block TSCM-SLM

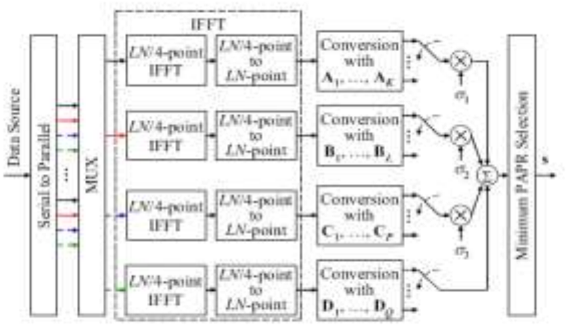

Figure4. Block Diagram of the Proposed four Sub-block TSCM-SLM Scheme.

In order to obtain more available candidates, we can divide the frequency-domain OFDM signal into more sub-blocks, e.g. four sub-blocks. Figure 4 shows the architecture of the four sub-block TSCM-SLM scheme. In this approach, the modified constraint to restrain the computational complexity is:

1) The first column vector **t**m contains only one non-zero element.

Therefore, we need only three complex vector additions for the generation of a candidate signal.

V. ALGORITHMS

A. *Algorithm for Conventional and Modified SLM*

1] Generating random input data
2] Convert data from serial to parallel
3] Generating random phase vectors
4] Multiplication of random data and phase vectors
5] By using LN –point IFFT, generating time domain signal
6] Calculating minimum PAPR
7] Calculating computation time
8] Plot graphs
9] Calculating average no of multiplications and additions per candidate signal to compare computational complexity

B. *Algorithm for Proposed System*

1] Project Operation follows DFT.
2] Phase sequences are governed by twiddle factor analysis [computer search method].
3] Even phase vector/sequence follows cyclically the twiddle factor and same with odd phase.
4] First starting element of block is always identity matrix.
5] Even phase sequences go sequentially and odd phase sequences go opposite to even.
6] Odd phase last sequence is placed in reverse order.
7] Odd phase second sequence is equal to the result of division of last sequence & second sequence twiddles value.
8] Two block analysis will be same to four blocks and also to six blocks.
9] In odd sequence phase vector operators, first two & last two phase vectors follow in different option.

VI. SIMULATION RESULTS

For the simulation, 9600 input symbol sequences are randomly generated and 16-QAM is used. For the conventional SLM scheme, each element of the phase rotation vectors is randomly selected from {$\pm$1, $\pm$ j}. Similarly, to determine the shift values for the MSLM scheme, random generation method is used.

Fig. 5,6,7 and 8 shows the PAPR reduction performance of the conventional SLM,MSLM, two sub-block TSCM-SLM and four sub-block TSCM-SLM scheme with N = 256,512,and 1024 respectively, L=4 and 16-QAM is used. Fig.6 shows that the PAPR reduction performance of the MSLM scheme becomes better as compared to conventional SLM. It is also observed from Fig.7 and 8 that the PAPR reduction performance of the two sub-block and four sub-block TSCM-SLM scheme is better to that of the conventional SLM and MSLM scheme as M increases. It is also observed from the simulation, the computational complexity of the conventional SLM is more than that of the modified SLM. Following table shows the comparison performance of the conventional SLM and MSLM.

TABLE IV: Comparison performance of the conventional SLM and MSLM

Parameters	**Conventional SLM**	**Modified SLM**	**TSCM-TWO SUB BLOCK**	**TSCM-FOUR SUB-BLOCK**
PAPR	7.2 (dB)	6.4(dB)	5.7(dB)	3.9(dB)
No. of additions	2048	875	521	779
No. of Multiplications	1024	85	37	8
No of subcarriers	256	512	1024	1024

A. *Plots of different PAPR reduction schemes.*

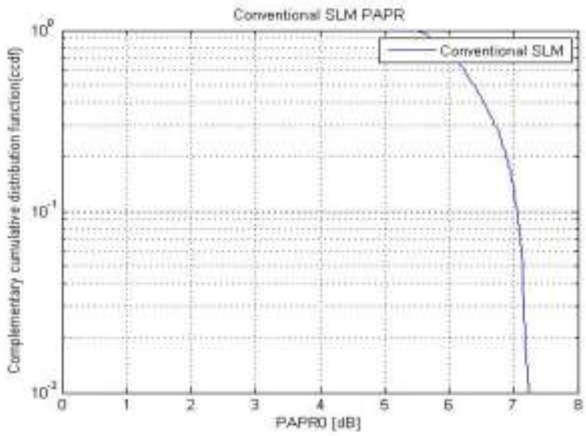

Figure5: PAPR of Conventional SLM

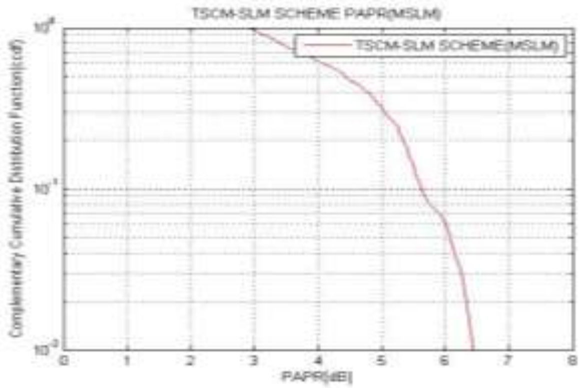

Figure6: PAPR for Modified SLM

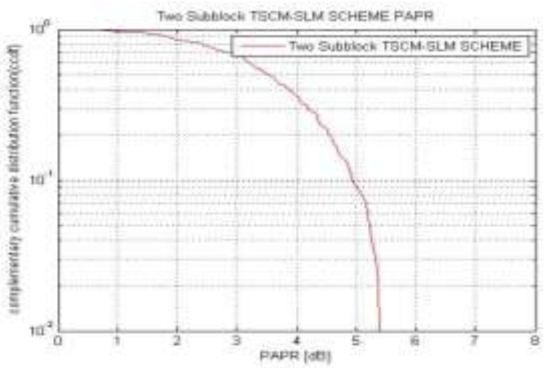

Figure7: PAPR of Two Sub-block TSCM-SLM

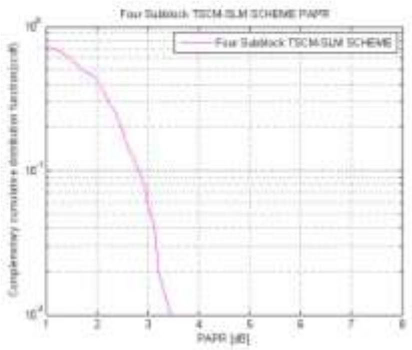

Figure 8: PAPR of Four Sub-Block TSCM-SLM

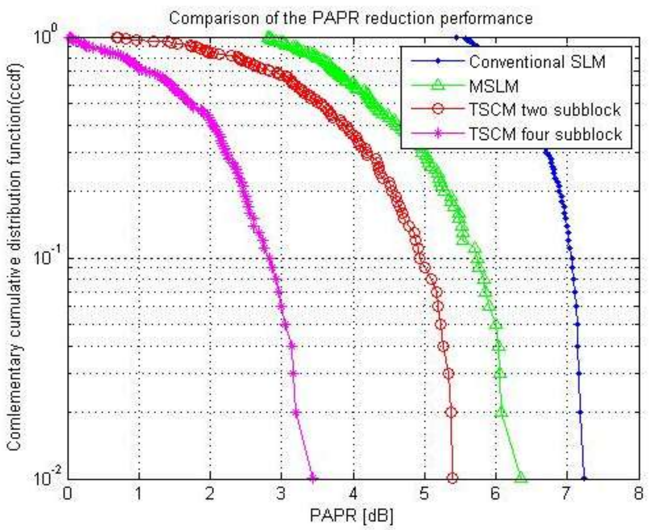

Figure 9: Comparison Performance of conventional SLM, MSLM and two and four TSCM-SLM

VII. CONCLUSION

The PAPR reduction problem for OFDM signals has received a great deal of attention recently, both in academia and industry. This issue attracted more attention after development of smart grid systems and the need for reliable multiuser communication. In this work, we propose an efficient low-complexity SLM scheme, TSCM-SLM, for PAPR reduction. Under the constraint that all phase elements in a phase vector belong to {(1,-1), (*j*,-*j*)}, we can find 28 and 128 valid candidate signals for the cases with two sub-blocks and four sub-blocks respectively .Compared to MSLM [6], applying the proposed scheme can result is not only more valid candidate signals, but also less computational complexity per candidate signal.

Computer simulation shows that the algorithm offers improved performance in terms of complementary cumulative density function (CCDF) while reducing PAPR effectively. Compared to the existing PAPR reduction methods, MSLM algorithms can get better PAPR reduction due to its lower complexity. Performance study of the proposed method demonstrates its feasibility and performance.

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