Peak to Average Power Ratio Reduction Using Modified SLM in MIMO-OFDM Systems

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Abstract: Multiple Inputs and Multiple Outputs - Orthogonal Frequency Division Multiplexing (MIMO-OFDM) is the most popular transmission technique in wireless communications as it is a multipath fading free, bandwidth efficient and capable of high data rate transmission. But the main drawback of OFDM is high peak to average power ratio (PAPR). Selective Level Mapping (SLM) is one of the promising schemes for reduction of PAPR but its computational complexity in terms of complex additions and multiplications is high due to requirement of more number of IFFTs. In addition to this, index of selected phase factor is required for proper recovery of the signal at the receiver. This paper presents a modified SLM (MSLM) scheme which considerably reduces the computational complexity with keeping the similar PAPR reduction performance compared with the conventional SLM scheme. The MATLAB simulation results indicate improvement in PAPR.

Keywords: MIMO (Multiple inputs and multiple outputs), OFDM (Orthogonal frequency division multiplexing), PAPR (Peak to average power ratio), SLM (Selected Level Mapping), MSLM (Modified-SLM).

I. INTRODUCTION

Key limitations of Wireless Technologies have been slow transmission rates that didn't come closer to the capabilities of wire line services and multipath fading environment. In a normal FDM system, many carriers are spaced apart in such way that the signals can be received using conventional filters and demodulators. In such receivers, guard bands have to be introduced between the different carriers. Introduction of these guard bands results in lowering of the spectrum efficiency [1]. It is possible, however, to arrange the carriers so that the sidebands of the individual carriers overlap and the signals can still be received without adjacent carrier interference. In order to do this the carriers must be mathematically orthogonal; each carrier has an integer number of cycles over a symbol period. Orthogonal carriers achieve spectral efficiency and multicarrier modulation combats over multipath fading effects [2]. Eventually OFDM is considered a promising technique to achieve high data rate transmission in multipath fading environment [3, 4].

MIMO is the theme of current research and it is a technology of next generation wireless networks. MIMO provides enormous data rates and channel capacity without increasing bandwidth and power. OFDM when combined with MIMO enhances the system performance on frequency selective fading environment and provides higher data rates. One of the applications of MIMO-OFDM is WIMAX (Worldwide Interoperability for Microwave Access) [7, 8].

One of the major drawbacks of OFDM is its high Peak to average power ratio (PAPR). When all the subcarriers are combined in phase results in high PAPR. Many PAPR reduction techniques were proposed in the literature. Some of the techniques are block coding, clipping with filtering, tone reservation and selected mapping. However, most of the techniques need coding overhead or side information at the transceiver. In this paper we have used modified Selective Level Mapping (SLM) technique [9].

The rest of this paper is organized as follows. In section II OFDM system model is given in section III PAPR Reduction in OFDM System is discussed in section IV MIMO System is explained in section in section V MIMO-OFDM System is discussed in section VI PAPR reduction by using SLM technique is explained in section VII Modified SLM Technique is proposed in section VIII Results and Analysis are described and finally concluded in Section IX.

II. OFDM SYSTEM MODEL

A Basic OFDM system is described in Figure1 Here an input data symbols are supplied into a channel encoder that data are mapped onto BPSK/QPSK/QAM constellation. The data symbols are converted from serial to parallel and using Inverse Fast Fourier Transform (IFFT) to achieve the time domain OFDM symbols. Time domain symbols can be represented as;

$$x_n = IFFT\{X_k\}$$
$$= \frac{1}{N}\sum_{k=0}^{N-1} X_k e^{\frac{j2\pi kn}{N}}., 0 \le n \le N-1 \;....(1)$$

Where, X_k is the transmitted symbol on the k^{th} subcarrier ; N is the number of subcarriers Time domain signal is cyclically extended to prevent Inter Symbol Interference (ISI) from the former OFDM symbol using cyclic prefix (CP). The Digital to Analog Converter (DAC) is performed to convert the baseband digital signal into analog signal. This operation is executed in DAC block of diagram. Then, the analog signal is preceded to the Radio Frequency (RF) frontend.

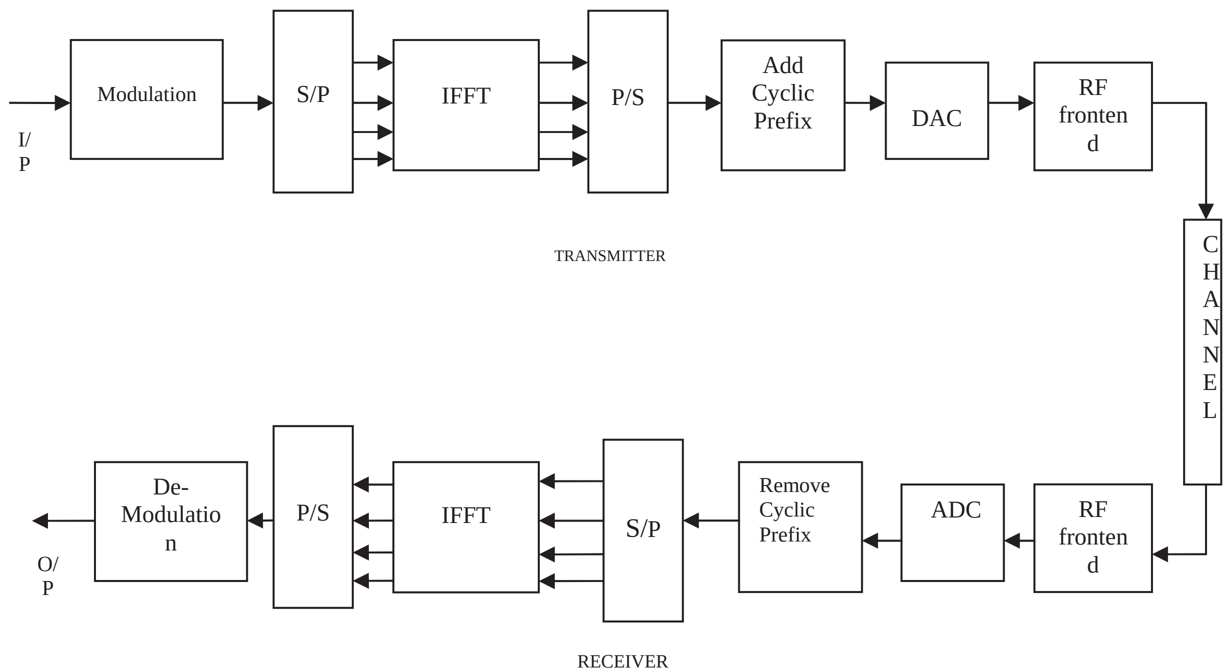

Figure 1: Block Diagram Representation of OFDM Transceiver

The RF frontend performs operations after receiving the analog signal. The signal is up converted to RF frequencies using mixer and amplified by using Power Amplifier (PAs) and then transmitted through antennas. At the receiver side, the received signal is down converted to base band signal by RF frontend. The analog signal is digitized and re-sampled by the Analog to Digital Converter (ADC). The ADC is used to digitize the analog signal and re-samples it. In the figure, frequency and time synchronization block are not shown because of simplicity. Cyclic prefix is removed from the signal in frequency domain. This step is done by the Fast Fourier Transform (FFT) block. The received symbols in the frequency domain can be represented as:

$$Y(k) = H(k)\, X_m(k) + W_k \;....(2)$$

Where, Y (k) is the received symbol on the k^{th} subcarrier, H (k) is the frequency response of the channel on the same subcarrier and W (k) is the additive noise added to k^{th} subcarrier which is generally assumed to be Gaussian random variable with zero mean and variance of σ_w^2 Thus, simple one tap frequency domain equalizers can be employed to get the transmitted symbols. After FFT signals are de-interleaved and decoded to recover the original signal.

III. PAPR REDUCTION IN OFDM SYSTEM

The OFDM technique divides the total bandwidth into many narrow sub-channels and sends data in parallel. It has various advantages, such as high spectral efficiency, immunity to impulse interference and, frequency selective fading without having powerful channel equalizer. But one of the major drawbacks of the OFDM system is high PAPR. OFDM signal consists of lot of independent modulated subcarriers, which are created the problem of PAPR. It is Impossible to send this high peak amplitude signals to the transmitter without reducing peaks. So we have to reduce high peak amplitude of the signals before transmitting.

A. Mathematical Definition of PAPR

In OFDM, Peak-to-Average Ratio (PAPR) is defined as "The ratio of the maximum instantaneous power to the average power". Reducing the PAPR is an important factor in OFDM, because it degrades the power amplifier performance. Above the threshold range they become non linear resulting in signal distortion.

$$PAPR = \frac{\max |x(t)|^2}{E\left[|x(t)|^2\right]} \quad \text{.... (3)}$$

Where, $\max|x(t)|^2$ =Peak Signal Power $E\left[|x(t)|^2\right]$ =Average Signal Power

IV. MIMO-OFDM

MIMO consists of multiple antennas at both the transmitter and receiver to improve communication performance. Multiple antennas offer diversity to the communication and improve transmission reliability over a fading channel. The main functions provided by MIMO are Spatial Diversity and Spatial Multiplexing. Spatial Diversity improved Bit Error Rate (BER) Performance and Spatial Multiplexing provides high data rate.

Space Diversity**:** It is a type of Diversity in which two (or) more number of signals sent over different paths by using multiple antennas at transmitting and receiving sides. The purpose of spatial diversity is to increase the diversity order of a MIMO link to mitigate fading by coding a signal across space and time so that a receiver could receive the replicas of the signal and combine those received signals constructively to achieve a diversity gain.

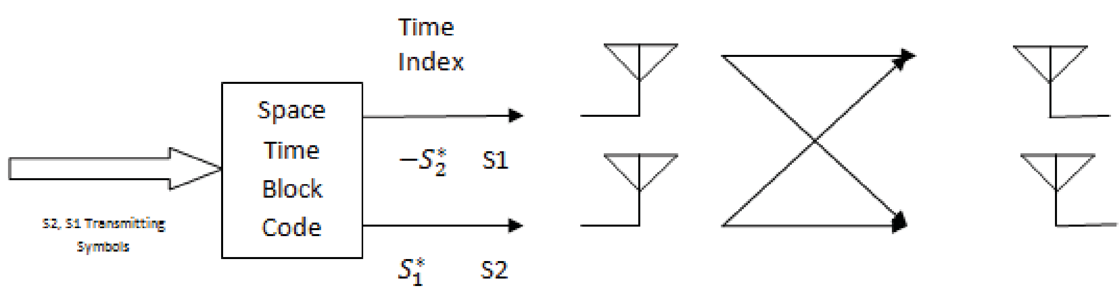

Figure 2. Block Diagram of Spatial Diversity

Spatial Multiplexing: In MIMO Multiple antennas are used to send and receive the data. Spatial multiplexing has been generally used to increase the capacity of a MIMO link by transmitting independent data streams in the same time slot and frequency band simultaneously from each transmit antenna, and differentiating multiple data streams at the receiver using channel information about each propagation path

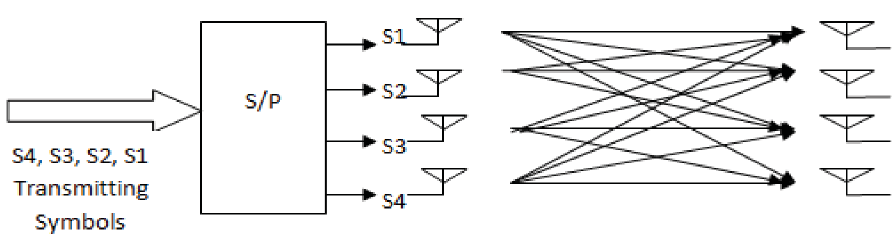

Figure 3. Block Diagram of Spatial Multiplexing

A. N×M MIMO System

The basic structure of MIMO which consists of N×M antennas is shown in Figure 4 where T_N stands for the n^{th} transmitter antenna and R_M resembles the m^{th} receiver antenna. In a MIMO system, data (x_1, x_2… x_N) are transmitted with N transmitting antenna arrays. The receiver is constructed of M (M>=N) antenna arrays. Let r_j(j= 1, 2,…, M) represents the signal received by the j^{th} antenna, then the signals received at the receiver can be represented as shown in fig 4.

In a MIMO system, data (x_1, x_2… x_N) are transmitted with N transmitting antenna arrays. The receiver is constructed of M (M>=N) antenna arrays.

The signals received at the receiver can be represented as:

$$
\begin{aligned}
r_1 &= h_{11} x_1 + h_{12} x_2 + \cdots + h_{1N} x_N \\
r_2 &= h_{21} x_1 + h_{22} x_2 + \cdots + h_{2N} x_N \\
&\;\;. \\
&\;\;. \\
r_2 &= h_{21} x_1 + h_{22} x_2 + \cdots + h_{2N} x_N \qquad \ldots (4)
\end{aligned}
$$

The MIMO channel communication takes advantage of multipath propagation. The MIMO channel can be described by the following matrix

$$Y = Hx + n....(5)$$

Where Y is the received signal vector, x is the transmitted signal vector, H is the channel matrices and n is the noise. For a system with M_T transmitters and M_R receivers, the MIMO channel at a given time may be represented by $M_R \times M_T$ matrix as demonstrated below, Where $H_{M,N}$ is the channel gain between M^{th} receive and N^{th} transmit antenna. The N^{th} column of H is called as the spatial signature of the N^{th} transmit antenna. Therefore, in MIMO system, the transmitted signals $\{x_j\}$ can be recovered by estimating the channel matrix H and the receiving signal vector R.

$$H = \begin{bmatrix} H11 & H12 & \cdot\cdot & H1,MT \\ H21 & H22 & \cdot & H2,MT \\ . & . & \cdot\cdot & . \\ HMR,1 & HMR,2 & \cdot\cdot & HMR,MT \end{bmatrix} ....(6)$$

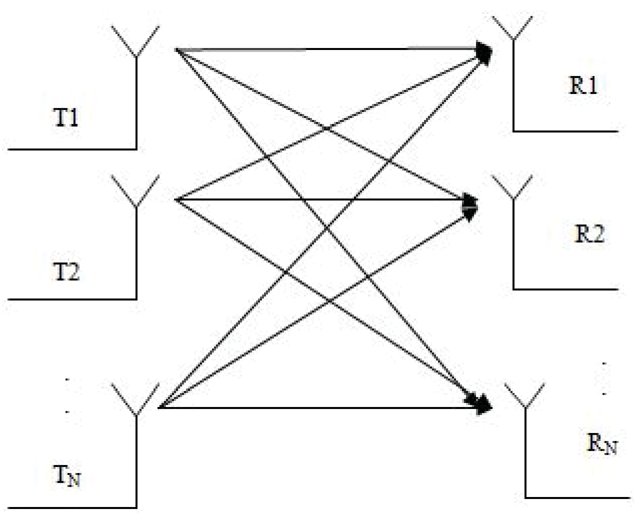

Figure 4: M×N MIMO System

The following figure 4 shows the basic block diagram of the MIMO-OFDM. In that information source generate the random data this generated random data is modulated by some modulation techniques such as BPSK, QPSK, and QAM etc. This Modulated data is again coded using Space Time Block coding. The main functions provided by Space time Block code is Space Diversity and Time Synchronization. Space Diversity improved Bit Error Rate performance and time synchronization provided time synchronization between Multiple Transmitting and Receiving Antennas. STBC coded data is passed through IFFT and finally it send to the receiving antennas by using transmitting antennas. At the receiver side first FFT operation is performed this processed data is coded with time space block code for the purpose of Time Synchronization and space diversity, after that demodulation operation is performed finally original information is received by destination.

In MIMO-OFDM system, the frequency response of k^{th} subcarrier can be expressed as follows:

$$H_K^{(q,p)}(n) = \sum_{l=1}^{L-1} h_l^{(q,p)}(n) W_K^{Kl} \quad ....(7)$$

Where, $K = 0, ... K-1$, $h_l^{(q,p)}(n)$ is the impulse response, that is from p^{th} transmitter antenna to l^{st} channel of q^{th} receiver antenna, n is sequence number of the symbol and K is the total number of subcarriers. Assuming that $W_K = \exp{-2j\pi/K}$, while M and N is the total number of transmitter and receiver antennas. The output response for the q^{th} receiver antenna can be written as:

$$y_k^q(n) = \sum_{p-1}^{M} h_k^{(q,p)}(n) X_k^p(n) + \xi_k(n) ....(8)$$

$q = 1 \dots, N$; $k = 0 \dots, K-1$ and $\xi_k(n)$ is Gaussian noise with variance δ^2.

V. PAPR REDUCTION BY USING CONVENTIONAL SLM

In selected mapping method, firstly M statistically independent sequences which represent the same information are generated, and next, the resulting M statistically independent data blocks $s_m = [s_{m,1}\, s_{m,2} \cdots s_{m,n}]^T$ m=1,2,3,…..M are then forwarded into IFFT operation simultaneously. Finally, at the receiving end, OFDM symbols $x_m = [x_1, x_2, \cdots x_N]^T$ in discrete time-domain are acquired, and then the PAPR of these M vectors are calculated separately. Eventually, the one sequence with the smallest PAPR will be selected for transmission. Fig.5 illustrates the basic structure of selected mapping method for suppressing the high PAPR.

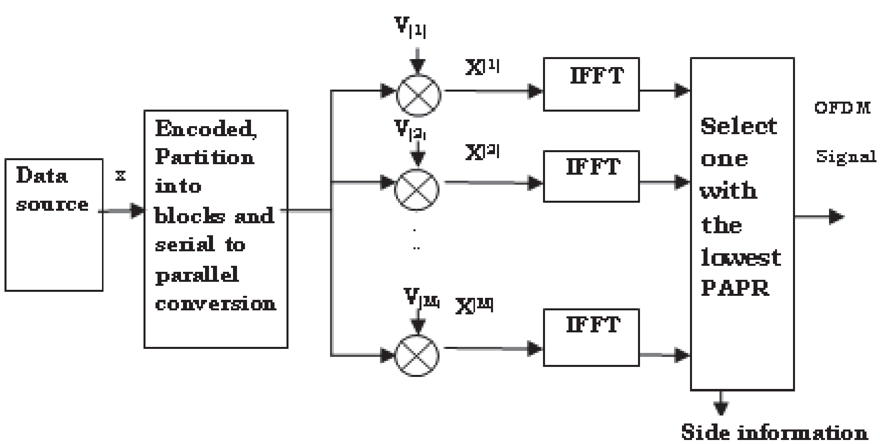

Figure 5.Block Diagram Selective Level Mapping

This method can significantly improve the PAPR performance of OFDM system. The reasons behind that are: Data blocks $s_m = [s_{m,1}\, s_{m,2} \cdots s_{m,n}]^T$ m=1,2,3,…..M are statistical independent, assuming that for a single OFDM symbol, the CCDF probability of PAPR larger than a threshold is equals to '***p***'. The general probability of PAPR larger than a threshold for k OFDM symbols can be expressed as p^k. It can be verified that the new probability obtained by SLM algorithm is much smaller compared to the former. Data blocks S_m are obtained by multiplying the original sequence with M uncorrelated sequence V_m. The key point of selected mapping method lies in how to generate multiple OFDM signals when the information is the same. First, defined different pseudo-random sequences $V_m = [V_{m,1} V_{m,2} \cdots V_{m,n}]^T$, m=1,2,3,…..M, where $V_{m.n} = e^{j\varphi_{m,n}}$ stands for the rotation factor. $V_{m,n}$ is also known as the weighting factor. $\phi_{m,n}$ is uniformly distributed in [0 2π]. The N different sub-carriers are modulated with these vectors respectively so as to generate candidate OFDM signals. This process can also be seen as performing dot product operation on a data block X_m with rotation factor V_m. In the reality, all the elements of phase sequence $P1$ are set to 1 so as to make this branch sequence the original signal. The symbols in branch m are expressed as and then transfer these M OFDM frames from frequency domain to time domain by performing IFFT calculation. The entire process is given by

$$s_m = [x_1 v_{m,1}, x_2 v_{m,2}, \ldots, x_N v_{m,n}]^T \quad \text{....(9)}$$

$$x_m(t) = \frac{1}{\sqrt{N}} \sum_{n=0}^{N-1} x_n v_{m,n} e^{j2\pi n \Delta f t} \quad 0 \le t \le NT,\ m=1,2,3,\ldots..M \quad \text{…..(10)}$$

Finally, the one which possess the smallest PAPR value is selected for transmission. Its mathematical expression is given as

$$x_d = \arg \min_{t \le m \le M} (PAPR(x_m)) \text{...(11)}$$

VI. Proposed Method (Modified SLM)

To get the large PAPR reduction in the conventional SLM scheme we have to generate large number of candidate blocks of OFDM signal sequences, that causes the high computational complexity because IFFT should be performed to generate each alternative OFDM signal sequence Therefore, it is desirable if we can reduce the number of IFFTs without compromising the PAPR reduction performance. Let x_i and x_k be the alternative OFDM signal sequences, which are generated by the conventional SLM scheme as in equation 12 using the linear property of Fourier transform, the linear combination of these two sequences can be given as

$$X_{i,k} = C_i X_i \pm j C_k X_k \text{....(12)}$$

$$\begin{aligned} X_{i,k} &= C_i \,\mathrm{IFFT}(X \otimes V_i) \pm j C_k \,\mathrm{IFFT}(X \otimes V_k) \\ &= \mathrm{IFFT}\left[A \otimes \left(C_i V_i \pm j C_k V_k\right)\right] \text{...(13)} \end{aligned}$$

Where C_i and C_k are some complex numbers. If each element of the $(c_i v_i \pm c_k v_k)$ sequence in equation (13) has unit magnitude $(C_i V_i \pm C_k V_k)$ can also be a phase sequence for the SLM scheme $X_{i,k}$ and can be considered as the corresponding OFDM signal sequence. Therefore, with the help of OFDM signal sequences x_i and x_k, another alternative OFDM signal $X_{i,k}$ sequence can be obtained without doing IFFT. Note that the phase sequence $(c_i v_i \pm j c_k v_k)$ is not statistically independent to v_i and v_k. Now, it has to investigate how to make each element of $(c_i v_i \pm j c_k v_k)$ to have unit magnitude under the condition that each element of the phase sequences v_i and v_k has unit magnitude. Clearly, the elements of the sequence $(c_i v_i \pm j c_k v_k)$ have the unit magnitude if the following conditions are satisfied: i) each element of v_i and v_k takes the value in {+1,-1}, ii). is $Ci = \pm\left(\frac{1}{\sqrt{2}}\right)$ and $C_k = \pm\left(\frac{1}{\sqrt{2}}\right)$. Since two alternative OFDM signal sequences generated from the phase sequence $\pm(c_i v_i \pm j c_k v_k)$ have the same PAPR, here the considered case is $Ci = \pm\left(\frac{1}{\sqrt{2}}\right)$ and $C_k = \pm\left(\frac{1}{\sqrt{2}}\right)$.

Since $\left|c_i\right|^2 = \left|c_k\right|^2 = \frac{1}{2}$ the average power of $x_{i,k}$ is equal to one half of the sum of average powers of x_i and x_k .

From binary phase sequences, it can be obtain $2\binom{M}{2}$ additional phase sequences with $\binom{M}{2}$ $= M\ (M^2 - 1)$ and, thus, total M^2 phase sequences.

A modified SLM scheme can be explained as follows. By combining each pair among M alternative OFDM signal sequences x_m obtained by using M binary phase sequences as the above, a set **S** of M^2 alternative OFDM signal sequences is generated as

$$S = \{x_m, 1 \le m \le M\} U \left\{ \frac{1}{\sqrt{2}} (x_i \pm j x_k) 1, k \le M \right\} \quad ....(14)$$

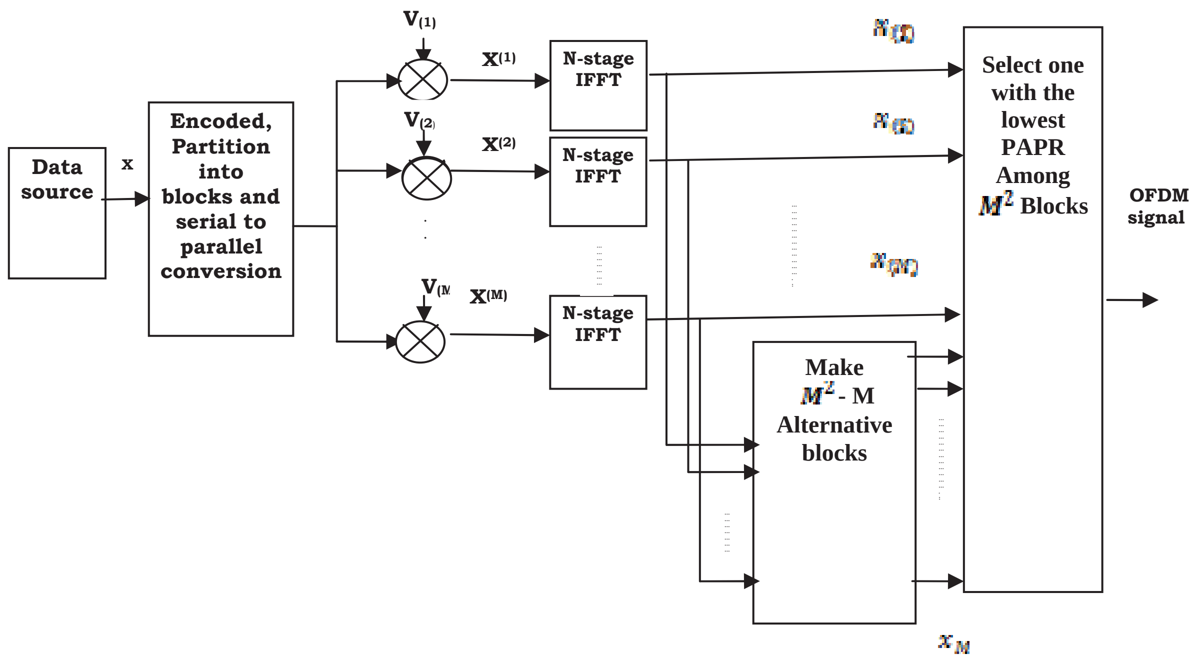

Figure 6.Block Diagram of Modified SLM Technique

Where M is number of IFFTs and additional summations of M^2-M pairs of OFDM signal sequences are needed. The modified SLM scheme is described in Fig.6. However, the computational complexity for the summations of OFDM signal sequences is negligible compared with that of IFFT. In the next subsection, the computational complexity of the proposed scheme is analysed in detail. Next, the alternative OFDM signal sequences X_d with the minimum PAPR among the alternative OFDM signal sequence in S have to select for transmission.

VII. RESULTS AND ANALYSIS

The PAPR reduction of the proposed scheme is examined by MATLAB simulation. In this work first the improvement in PAPR for conventional SLM scheme determined, later the improvement of PAPR for modified SLM is investigated and compared with conventional SLM. Here the comparison has done for different number of IFFTs (U=3, 4, 8, and 16 etc...). To evaluate the performance, the complementary cumulative distribution (CCDF) of PAPR for OFDM signal x is,

$$\text{ccdf}\ (\text{papr}(x)) = p_T\ (\text{papr}(x) > \text{papr}_0 \quad ...(15)$$

CCDF can be interpreted as the probability that the PAPR of an OFDM signal exceeds some threshold level PAPR0. PAPR0 is referred to as the symbol chip probability and determined by the amplifiers in the system. The computational complexity reduction ratio (CCRR) of the proposed scheme over the conventional SLM scheme is defined as

$$\mathrm{CCRR} = \left(1 - \frac{\mathrm{ComplexityofproposedSLM}}{\mathrm{ComplexityofConvontionalSLM}}\right) \times 100 \,...(16)$$

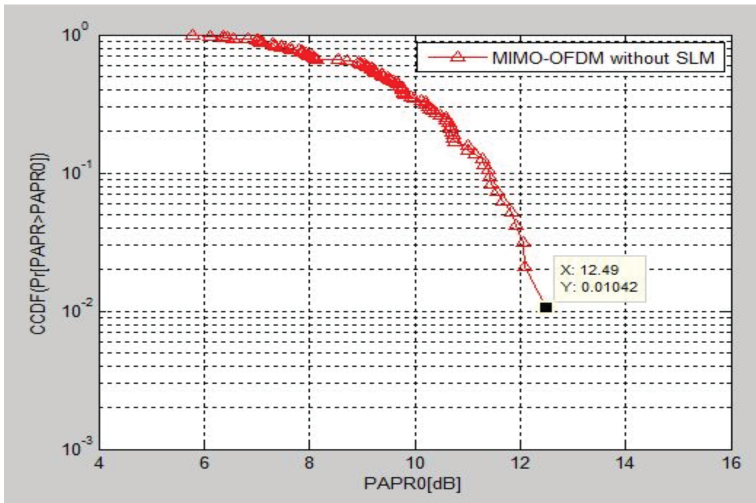

Figure 7.Complementary Cumulative Distribution Function of MIMO-OFDM without SLM technique.

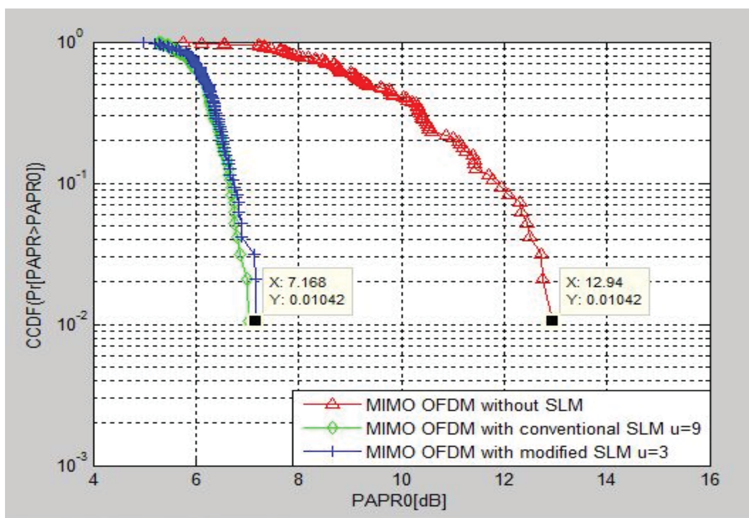

Figure 8.Complementary Cumulative Distribution Function of MIMO-OFDM System using conventional SLM Techniques with U=9 and modified SLM Techniques with U=3.

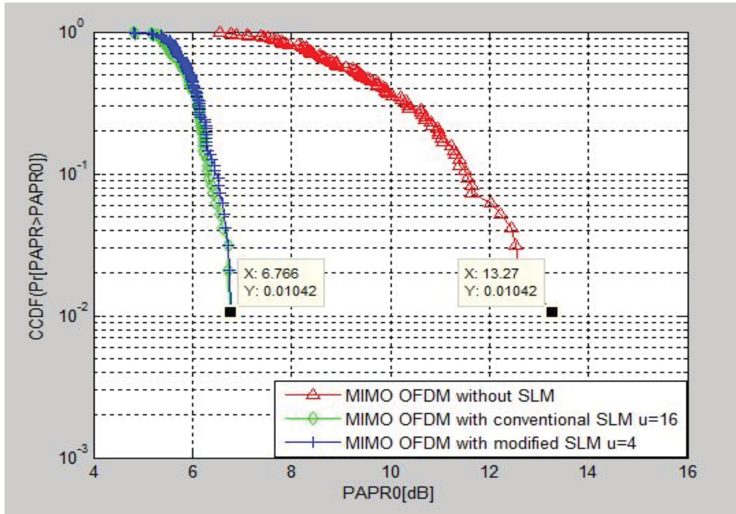

Figure 9.Complementary Cumulative Distribution Function of MIMO-OFDM System using conventional SLM Techniques with U=16 and modified SLM Techniques with U=4.

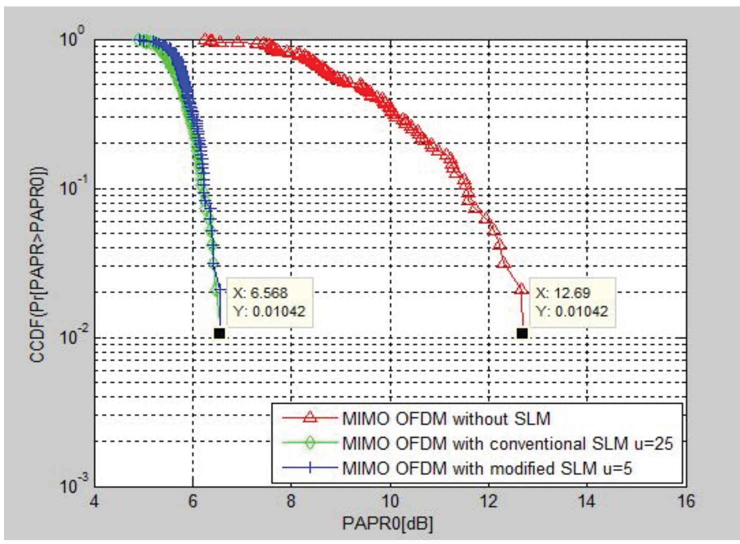

Figure 10.Complementary Cumulative Distribution Function of MIMO-OFDM System using conventional SLM Techniques with U=25 and modified SLM Techniques with U=5.

From the figure 7 the minimum power (Threshold) required in MIMO OFDM system without SLM is 12.86dB.at CCDF = 10^{-2}. From the figure 8The minimum power (threshold) required to generate 128 carriers without SLM is 12.21 dB at CCDF =0.01042. The minimum power (threshold) required to generate 128 carriers with conventional SLM (U=9) and modified SLM (U=3) is 7.168 dB at CCDF =0.01042. From the figure 9 the minimum power (threshold) required to generate 128 carriers without SLM is 13.27 dB at CCDF =0.01042. The minimum power (threshold) required to generate 128 carriers with conventional SLM (U=16) and modified SLM (U=9) is 6.766 dB at CCDF =0.01042. From the figure 10 the minimum power (threshold) required to generate 128 carriers without SLM is 12.69 dB at CCDF =0.01042. The minimum power (threshold) required to generate 128 carriers with conventional SLM (U=25) and modified SLM (U=5) is 6.568 dB at CCDF =0.01042.

From the figure11 the minimum power (threshold) required to generate 128 carriers with conventional SLM (U=3) and modified SLM (U=9) is give same PAPR at CCDF =0.01042.The minimum power (threshold) required to generate 128 carriers with conventional SLM (U=4) and modified SLM (U=16) is give same PAPR at CCDF =0.01042. From this entire analysis we can say that the value of U increases the PAPR decreases.

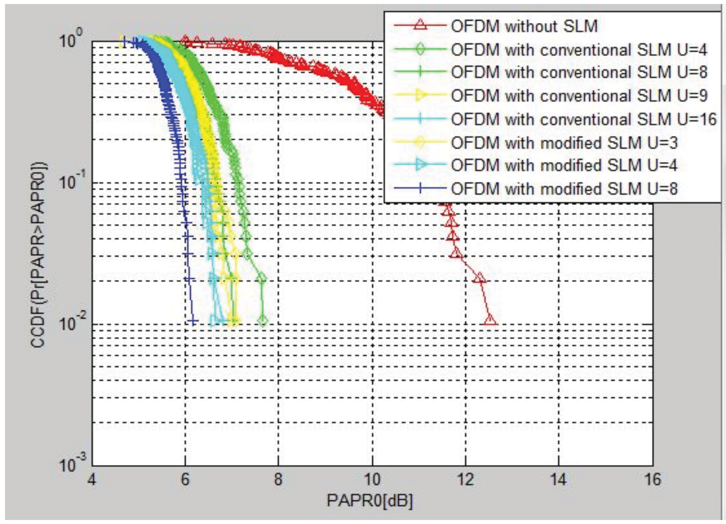

Figure 11.Complementary Cumulative Distribution Function of MIMO OFDM System using conventional SLM Techniques with U=4, 8, 9, 16. And modified SLM with U=3, 4, 8.

Parameter	Conventional SLM U=9	Modified SLM U=3	CCRR (%)
#Complex Multiplications	4032	2496	38.09
Complex Additions	8064	3456	57.1
PAPR(dB)	7.168	7.177	

Table 1.Comparison of computational complexity and PAPR between conventional and modified SLM at CCDF is 10^{-2} for N=128

Parameter	Conventional SLM SLM U=16	Modified SLM U=4	CCRR (%)
Complex Multiplications	7168	3776	50.43
Complex Additions	14336	5120	64.3
PAPR(dB)	6.766	6.767	

Table 2.Comparison of computational complexity and PAPR between conventional and modified SLM at CCDF is 10^{-2} for N=128

Parameter	Conventional SLM	Modified SLM	CCRR (%)
Complex Multiplications	4032	2496	38.09
Complex Additions	8064	3456	57.1

Table 3.Comparison of computational complexity between conventional and modified SLM at CCDF is 10^{-2} for N=128 U=9 and 3 respectively.

Parameter	ConventionalSLM	Modified SLM	CCRR (%)
Complex Multiplications	7168	3776	50.43
Complex Additions	14336	5120	64.3

Table 4.Comparison b/w conventional and modified SLM at CCDF is 10^{-2} for N=128, U=16 and 4 respectively.

Parameter	Conventional SLM with U=9	Modified SLM with U=3	Conventional SLM with U=16	Modified SLM with U=4
PAPR(dB)	7.168	7.169	6.766	6.767

Table 5 Comparison of PAPR0 (dB) at CCDF 10^{-2} for N=128 in MIMO OFDM between SLM & MSLM

VIII. CONCLUSION

From the results it is concluded that modified SLM scheme for the PAPR reduction of MIMO-OFDM system, which considerably reduces the computational complexity while it maintains the similar PAPR reduction performance compared with the conventional SLM scheme. MIMO-OFDM system with 128 subcarriers, the proposed scheme with 4 binary phase sequences can reduce the complex multiplications by 64.3% with the similar PAPR reduction compared with the SLM scheme with 16 binary phase sequences.

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