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# Power Efficiency Enhancement using Hybrid Techniques for OFDM

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**ABSTRACT: With the increased number of internet traffic users there is a huge demand for high data rate and power efficient wireless communication system. The physical layer of any wireless communication systems plays a vital role in building the foundation for data rate enhancement. Using multicarrier modulation techniques multiple users can be accommodate having varies data rate requirements. The Orthogonal frequency division multiplexing system has been proved as best multicarrier modulation technique to fulfill the user requirement. Although the OFDM system is set to be the best example of multi carrier system it under goes sever problem of PAPR. As a consequence it induces nonlinear distortions in the system thus limiting the power amplifiers to work in linear regions only. In this article we propose a unique solution to the above mentioned problem that combats the nonlinearity in the communication systems. The proposed solution is a combination of OFDM and Superposition coded modulation. The comparative analysis is presented with the existing techniques used for PAPR reduction.**

**Keywords:** Clipping technique, Selective mapping, Partial Transmit sequence, Discrete Hartley Transform (DHT), Superposition Coded Modulation (SCM)-OFDM, Modified µ law Companding (MMC), Peak to Average Power Ratio (PAPR), Bit Error Rate (BER) , Complementary Cumulative Distribution Function(CCDF).

**Abbreviations:** OFDM, Orthogonal Frequency Division Multiplexing; SCM, Superposition Coded Modulation; PTS, Partial Transmit Sequence; TR, Tone Reservation; **DHT, D**iscrete Hartley Transform.

## I. INTRODUCTION

Orthogonal Frequency Division Multiplexing (OFDM) is an assured technique for systems that require a high data transmission rate, such as 4G LTE-Advanced and Wimax. Several researchers and academicians have studied the OFDM technique, which can cater to high data rate applications. OFDM offers several advantages over channels that experience frequency selectivity and time variations. Furthermore, the OFDM technique allows each subcarrier to independently select the constellation and coding scheme. OFDM offers robustness to the multipath fading channel and has a low- implementation complexity. Although OFDM exhibits several advantages, OFDM suffers from various technical challenges, such as high Peak to Average Power Ration (PAPR) and Carrier Frequency Offset (CFO).The complexity of Digital-to-Analog Converter (DAC) increases with PAPR, that leads to the degradation of power amplifier efficiency in OFDM system. The transmission of high-PAPR OFDM signals through nonlinear power amplifier causes spectral broadening, that will expand the dynamic range of the DAC. Superposition Coded Modulation (SCM) is emerging as non-bijective, bandwidth and power efficient coded modulation with Gaussian Quadrature components. The shaping gain in SCM is inherent without any additional complexity at the transmitter side. At the receiver side the complexity is low as O(K) for K-layer SCM when equal power is allocated to the symbols. Hybrid combination of multi layer SCM and OFDM can achieve greater data rates compared to single carrier OFDM system.

The main aim of this study is to decrease the PAPR in OFDM system to reduce the range of DAC and thereby decrease the cost of the system. We propose the use of a novel technique called hybrid precoding using DHT and µ companding for SCM- OFDM system. SCM-OFDM system increases the data rate of OFDM system complementing the advantages of OFDM. Implementing SCM coding scheme for MIMO system reaches Shannon channel capacity. But, using SCM in OFDM system further increases the PAPR problem in OFDM but increases the data rate and capacity of the OFDM system. Several techniques for PAPR reduction have been proposed in literature, and are categorized into three categories: multiplicative schemes, coding techniques and additive schemes. In multiplicative schemes, phase sequences are multiplied with OFDM sequences, the popular techniques using multiplicative schemes such as Selective Mapping (SM) and Partial Transmit Sequence (PTS) [1–5]. In [6], a low complexity PAPR reduction with modified linear SM scheme was suggested for the OFDM system. The performance for modified linear SM scheme for PAPR reduction in [6] was insignificant compared with conventional schemes. Additive schemes include Tone Reservation (TR) and clipping and filtering techniques. TR technique with low-complexity tones with null subcarriers was proposed in

[8] to decrease the PAPR in the filter bank multi carrier In [9], Decision directed method proposed for PAPR reduction for optical OFDM. In [10] a tone rejection technique for PAPR reduction was proposed. In [11], clipping and quantization noise cancellation is proposed for low-complexity PAPR reduction. Clipping PAPR reduction technique causes in- and out-band interferences that take out symmetry among subcarriers of OFDM that result in Inter Carrier Interference (ICI). A PAPR reduction system including coding technique anticipated in [12] implemented Reed Muller codes are implemented with PTS scheme. In [13] code scrambling method are used to reduce PAPR. All these schemes reduce PAPR at cost of computational complexity and with additional information need to be transmitted to receiver that increases bandwidth requirement. Motivated by the limitations of clipping and other techniques, we propose Modified µ law companding techniques with **D**iscrete Hartley Transform (DHT) as precoding technique for PAPR reduction in SCM-OFDM system. The proposed technique does not require any side information as compared to multiplicative methods, precoding techniques scrambles the signal phase to reduce the PAPR of the OFDM system. Precoding with DHT demonstrates higher PAPR reduction compare to Discrete Fourier Transform (DFT) technique.DHT distorts phase of the signal there by reducing PAPR. DHT is less complex compared to DFT as indicated in Table 2. DHT brings down the multiplication complexity by a factor of two contrasts with DFT, since DHT matrix has only real elements. DHT provides higher spectral efficiency, since it does not require side information compared to various different PAPR reduction systems like PTS and SLM techniques.

This paper is organized as follows. In Section II, the SCM-OFDM system is discussed, and the PAPR and cumulative complementary distribution function (CCDF) are formulated. In Section III, the clipping technique for PAPR reduction for SCM-OFDM system, PTS and SM techniques were discussed. Section IV Simulation results were discussed, section V conclusion

## II. SCM-OFDM SYSTEM IS DISCUSSED ???????

*A. Characterization of the SCM-OFDM System*

OFDM system has high bandwidth efficiency compared to other multiple access system. However, there is continuous demand for high data rate and high capacity to meet the requirements of various evolving systems combined with OFDM system.

technologies and applications. Therefore there is strong motivation to come up with systems and methods that achieve even higher bandwidth efficiency compared to traditional OFDM system which inherits various advantages of traditional OFDM system. Superposition Coded Modulation is the multicarrier system, which has the advantage of adaptive modulation and coded techniques. Combining SCM with OFDM system further increases channel capacity and the data rate of the OFDM system, preserving the advantages of traditional OFDM system. However use of SCM system for OFDM further increases the PAPR problem in OFDM system. To reduce PAPR in SCM-OFDM system we propose DHT which provides spectral efficiency to SCM-OFDM system. In SCM –OFDM system, K-layer SCM is defined over a $2^K$ constellation, the binary data sequence **P** is partitioned into K sub-sequences {$\mathbf{P_k}$}. The k-th layer, resulting in a coded bit sequence $c_k$ = {$c_k(j)$} of length 2J. Where $c_k(j) \in \{0,1\}$ and J is the frame length. Coded sequence $c_k$ is then mapped to QPSK sequence $x_k(j)$.

$$x^K_k = x^K_{re,j} + i\, x^K_{im,j} \qquad (1)$$

The superscripts ‘Re’ and ‘Im’ denote the real and imaginary components, of complex numbers, respectively.

QPSK sequences are linearly superimposed to form $X_j$, which is given as follows:

$$x(j)=\sum_{k=0}^{K-1} \rho_k\, x_k(j), \qquad j= 0,1,\ldots J-1 \qquad (2)$$

Where $\{\rho_k\}$ are constant weighting actor $k$. In this study, $\{\rho_k\}$ was obtained using the simulation-based power allocation method projected in [12].

The superimposed symbols are fed to a customary OFDM modulator unit that consists of an $N$-point inverse discrete Fourier transform (IDFT) unit pursued by an $N_g$-point cyclic prefix (CP) converts linear convolution to circular convolution, applied as a guard band to avoid Inter Symbol Interference. The IDFT output is obtained as vector

$D_i = [D_i(0), D_i(1),\ldots D_i(N-1)]^T$. The CP is appended to $D_i$ such that

$$S_i(k) = \left\{\frac{1}{\sqrt{N}}\sum_{n=0}^{N-1} X_i(k)\, e^{j2\pi nk/N}\right\}, \qquad (3)$$

Where $X_i(k)=x(j)$ from Eqn. (2) is the superimposed modulated data symbol assigned to the sub carriers and $N_g$ represents the length of CP ($-Ng < n < N-1$).

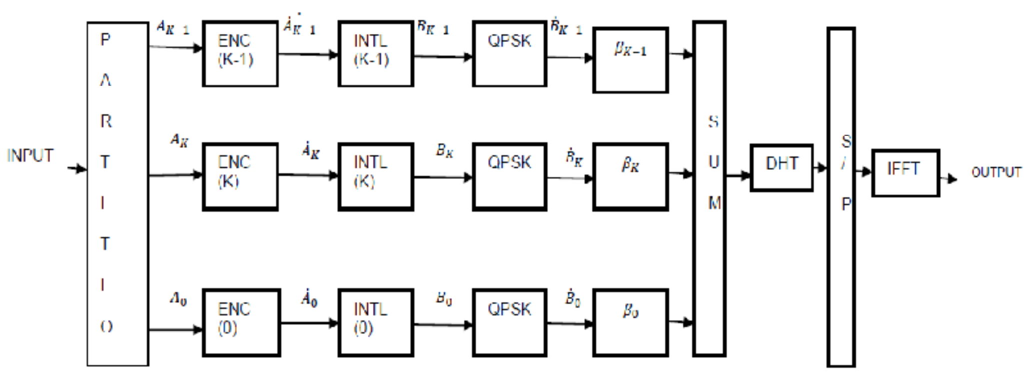


**Fig. 1.** The Proposed SCM-OFDM system for PAPR reduction.

*B. Peak-to-Average Power Ratio (PAPR)*

The PAPR is important for enabling the high-power amplifier to operate in the linear region. The SCM-OFDM signal is oversampled '*L*' times to better approximate the PAPR. The oversampled SCM-OFDM signal in time domain is given as follows:

$S_i(k) = \left\{\frac{1}{\sqrt{N}}\sum_{n=0}^{N-1} X_j(k) e^{j2\pi nk/LN}\right\}, 0 < n < LN$ (4)

The PAPR is termed as the ratio of the maximum instantaneous power to the average power and is formulated mathematically as follows:

$PAPR[S[n]] = \frac{max\,[|s[K]|^2]\; 0 \leq n \leq LN-1}{E[|s[K]|^2]}$, (5)

where E [.] specifies the expectation operator.

*C. Complementary Cumulative Distribution Function*

The CCDF refers to the probability that the distribution of the output power of the SCM-OFDM signal exceeds the predefined threshold value. It is done by determining the CCDF for the PAPR values. The CCDF is formulated and expressed as follows:

CCDF = Pr ($PAPR_{SCM-OFDM}$ > $PAPR_o$), (6)

Where $PAPR_{SCM-OFDM}$ and $PAPR_o$ are the output of the SCM-OFDM system and the threshold value respectively.

## III. RESULTS AND DISCUSSION

*A. Clipping technique for reducing the PAPR in the SCM-OFDM system*

In the SCM-OFDM system, the PAPR is maximum for a given $\{\rho_k\}$ when all $\theta_k$s are equal. To reduce the PAPR, clipping of $X_j$ to form $\overline{X}_j$ is followed based on the rule presented below:

$$\overline{X}_j = \begin{cases} s_j, |s_j| \leq A \\ \frac{As_j}{|s_j|}, |s_j| > A \end{cases} \quad (7)$$

where A > 0 is the clipping threshold.

From [13], we outline the clipping ratio as follows:

$\gamma = A^2 / E(|X_j^2|)$ (8)

The PAPR of the transmitted signal with clipping is given as follows

PAPR= $A^2 / E(|\overline{X}_j^2|)$.

The received signal can be written as follows:

$Y_j = \overline{X}_j + w_j$, (9)

where $w_j$ is the complex Gaussian noise with a zero mean and $\sigma^2$ variance.

*B. Selective Mapping*

Selective Mapping (SM) is a multiplicative PAPR reduction technique. The SCM-OFDM signal is copied and each copy is multiplied with different phase sequences, as a result different PAPR values are captured. The SM signal is a product of SCM-OFDM and phase sequences and represented by X(1), X(2), X(3),… X(k), where k is the number of SCM-OFDM signals. Inverse Discrete Fourier transform is performed on X(k). X(k) with lowest PAPR is selected and transmitted. With increase in number of k the performance of SM raises but as the k increases number of IDFTs also increases, increasing the complexity of the system. The block diagram of the SM is presented in Fig. 2. This technique also requires side information. The side information are extra bits that carries the phase sequences to receiver increasing the bandwidth. SM technique is not only spectral inefficient but also complex system.

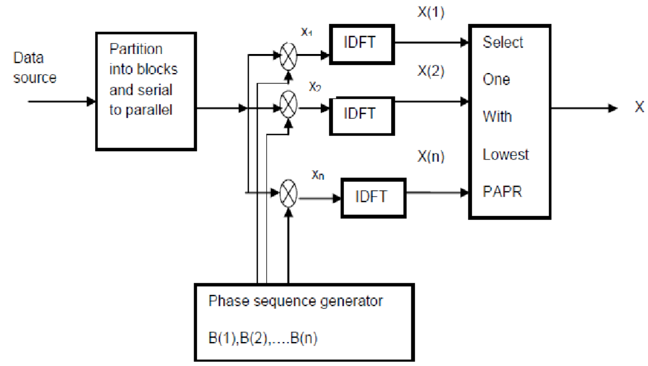


**Fig. 2.** Block diagram of Selective Mapping.

*C. Partial Transmit Sequence*

Partial transmit sequence is selection transmission technique with point-to-multipoint mapping, multiply single input data signals by a phase factor to map multiple candidate signals. Similar to SM technique, candidate signal with lowest PAPR is selected as the OFDM transmission signal. PTS also requires side information to be transmitted to receiver to retrieve which candidate signal was selected by the transmitter. Let X denote the random signal in frequency domain. Now X is partitioned into U disjoint subblocks represented by $\{X^{(u)}$, u = 1, 2,…U$\}$ where $X^{(u)}$ is given by

$X^{(u)}=[X_1^{(u)}, X_2^{(u)}, \ldots X_{M-1}^{(u)}]$ (10)

$X=\sum_{u=1}^{U} X^u$ (11)

The phase rotation factors are given by

$C_u = e^{j\theta u}$, u=1,2, U (12)

## IV. PROPOSED MMC-DHT PAPR REDUCTION TECHNIQUE FOR SCM-OFDM SYSTEM

The objective of this investigation is to realize PAPR reduction before OFDM modulation using Modified Companding and DHT precoding. Since the SCM symbols takes Gaussian distribution, it implies that there is no requirement of active shaping filters which is used to adapt the advanced modulation schemes such as QAM to Gaussian channel, thereby reducing the shaping filter burden on transmitter and receiver of the system. The Cumulative Distributed Function (CDF) of the un-companded signal is expressed as

$F_x(.)$ =1-exp($\frac{x_0^2}{\sigma_x^2}$), $x_o$>0 (13)

Where $x_o$ is that the discrete envelope of $x$(n) and $\sigma_x^2$ is the variance.

The $\mu$ companding was introduced based on [15]

$F_{EC}(x(n)) = sgn(x).\sqrt{3\sigma_x^2}.\,\mathrm{erf}(\frac{|x|}{\sqrt{2\sigma_x^2}})$ ,0≤ $x \leq 1$ (14)

The above equation is the fundamental error function due to companding transform.

$\mu$ law companding with constant value for $\mu$ applied to SCM-OFDM signal is given by

$y_c(n)$=F($x_j(n)$) (15)

$=sgn(x_j(n))\; \frac{A_s \times \log(1+\mu\left|\frac{x_j(n)}{A_s}\right|)}{\log(1+\mu)}$

where $sgn(x(n))=\frac{x(n)}{|x(n)|}$ is the phase and $A_s$=max($|x_j(n)|$.

The multi $\mu$ is simulated for SCM-OFDM system for better PAPR reduction .The fundamental problem in $\mu$ companding is, it enlarges the amplitudes of the lower amplitude signal keeping higher amplitude signals unchanged at the output of the compander. Thus increasing the average power and reduces the PAPR. However, this technique leads to unfair improvement of BER when compared to uncompanded signal. The companding profile known as peak ratio is presented in [15], it is articulated as the ratio of amplitude A of the signal specified in $\mu$ compander to the peak amplitude of the actual signal to be companded i.e.

$$K=\frac{\text{Peak amplitude of compressor}}{\text{Peak of actual signal}} = \frac{A}{x_{j\,\text{peak}}} \quad (16)$$

The transfer characteristics of the modified $\mu$ compander including new parameter peak ratio 'K' is expressed by substituting the above equation in (15).

$$y=K\times x_{jpeak}\times\frac{\log\left(1+\mu\frac{|x_{j\text{peak}}|}{K\times x_{j\text{peak}}}\right)}{\log(1+\mu)}sgn(x) \quad (17)$$

The above comapanding profile permits the $\mu-$Law companding profiles to be modified such that all amplitudes as well as the peaks of the input signal can be amplified by changing the value of K. Higher the values of K, greater is the gain for the peaks and much higher the gain for the lower amplitude signals.

OFDM signal is precoded using DHT precoder before IFFT block. The Hartley Transform of $S_i(n)$ is expressed as

$$H_s(\omega)=\int_{-\infty}^{\infty}f(t)Cas(\omega t)dt. \quad (18)$$

$$Cas(\omega t)=\cos(\omega t)+\sin(\omega t) \quad (19)$$

$$f(t)=\int_{-\infty}^{\infty}H_s(\omega)Cas(\omega t)d\omega \quad (20)$$

To reduce the number of functional computation $Cas(\omega t)$ can be expressed as:

$$\sqrt{2}\cos\left(\omega t-\frac{\pi}{4}\right)=\sqrt{2}\sin\left(\omega t+\frac{\pi}{4}\right) \quad (21)$$

For discrete signal Hartley Transform is expressed as:

$$H_s(k)=\frac{1}{\sqrt{2}}\sum_{n=0}^{NL-1}y_i(n)Cas\left(\frac{2\pi nk}{N}\right) \quad (22)$$

$$H_s(k)=\frac{\sqrt{2}}{\sqrt{N}}\sum_{n=0}^{NL-1}y_i(n)\cos\left(\frac{2\pi nk}{N}\frac{\pi}{4}\right) \quad (23)$$

k=0, 1,...... N-1.

The discrete Hartley Transform rotates the phase of input SCM symbols. While precoding, the signal is re-established to the single carrier. SCM-OFDM is analysed in AWGN channel. The received signal is as follows:

$$Y_j(n)=\left\{\frac{1}{\sqrt{N}}\sum_{n=0}^{N-1}H_s(k)e^{\frac{j2\pi nk}{LN}},\right\}+\text{w(n)} \quad (24)$$

$$0 < n < LN-1$$

## V. SIMULATION RESULTS

In this study, computer simulations were performed to evaluate the performance of the SCM-OFDM system. Cyclic prefix is added to the time domain signal to avoid the Inter Symbol Interference (ISI). Besides PAPR drawback in OFDM system, OFDM is additionally sensitive to spectral null problem over a frequency selective fading channel. By using Discrete Hartley Transform over the entire bandwidth the nulls are spread to increase the probability of correctly receiving the transmitted symbols.

Use of Precoding, further improves the PAPR performance of an OFDM multicarrier system. SCM-OFDM system is simulated in MATLAB 2017 environment. Each layer in multicarrier is coded using convolution encoder with rate ½. The coded code word is interleaved to remove any burst error present in the data stream. Each layer is modulated using different modulation schemes. We adopted QPSK and 16 QAM for the layer 1 and layer 2 respectively.

The simulation result of SCM scheme with two layers, where layer 1 adopted QPSK and for layer 2 16QAM and resultant superimposed signal is shown in Fig. 3. In SCM symbols are arranged such that the PAPR is reduced with different power factor $'\beta'$ .For the higher modulation scheme when SCM is simulated with 64QAM PAPR obtained is 6.4089dB, OFDM with 64QAM is 9.31dB. Compared to OFDM PAPR in SCM improved by 31.2%. However, PAPR in the hybrid system SCM-OFDM system is 13.53dB. PAPR in hybrid system increases due to nonlinearity in SCM; Since Gaussian like transmitted signal has a relatively high PAPR. SCM-OFDM with clipping resulted in reduction of PAPR by 2.87dB. Although PAPR reduction using clipping and filtering technique is reduced to 2.87dB, but BER performance of the same reduction scheme is poor as shown in Fig. 4 compared to BER performance of the proposed method. The BER performance is enhanced using proposed hybrid technique for SCM-OFDM system using DHT. PAPR for SCM-OFDM signal is 5.8971dB, thereby reducing PAPR by 4.7565dB compared to clipping and without reduction technique by 7.6329dB respectively, thereby improving performance of PAPR by 56.41%.

**Table 1: Simulation Parameters**

| Bandwidth | 20MHz |
|---|---|
| Carrier frequency | 2.5GHz |
| Number of subcarriers | 256 |
| Subcarrier spacing | 15KHz |
| Number of Cyclic prefix | 64 |
| Convolution encoder rate | ½ |
| Interleaver | Random Interleaver |
| Modulation for layer 1 | 256 QAM |
| Modulation for layer 2 | 256 QAM |

With proposed hybrid technique the PAPR is further reduced to 1.7949 dB and PAPR performance improvement by 86.7%. The proposed system is also simulated with 256 QAM, PAPR in OFDM with 256 QAM is as high as 30dB due to nonlinearity in the 256 QAM. PAPR will increase up to a greater extent in OFDM system. Computer simulation is done and results are shown in figure 9. With the proposed hybrid scheme the PAPR is reduced significantly to 12.5dB. Fig. 3 shows the simulation of SCM symbols, considering K=2 layers the number of symbols in SCM is 2. Fig. 4 show that the PAPR reduction in SCM-OFDM system with DHT precoder and clipping as a PAPR reduction technique. DHT precoder outperforms clipping technique by 7.01dB. BER performance is better compared to clipping technique for SCM-OFDM system.

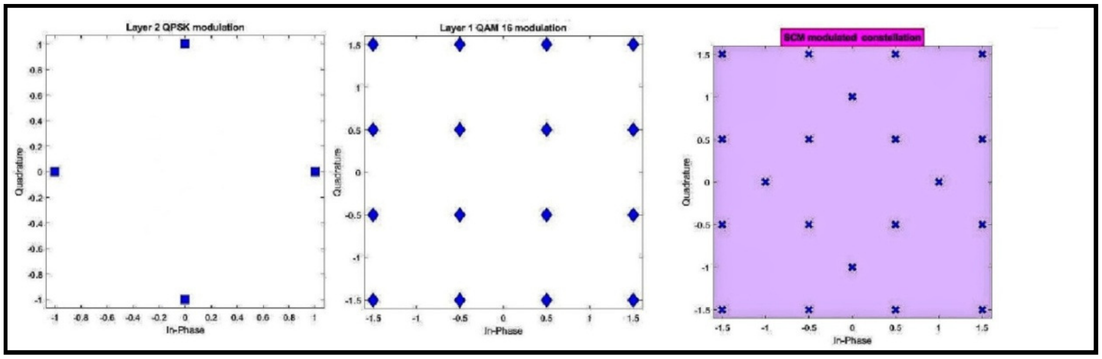


**Fig. 3.** Simulation result of Superposition Coded Modulation of two signals QPSK and 16 QAM modulated signal.

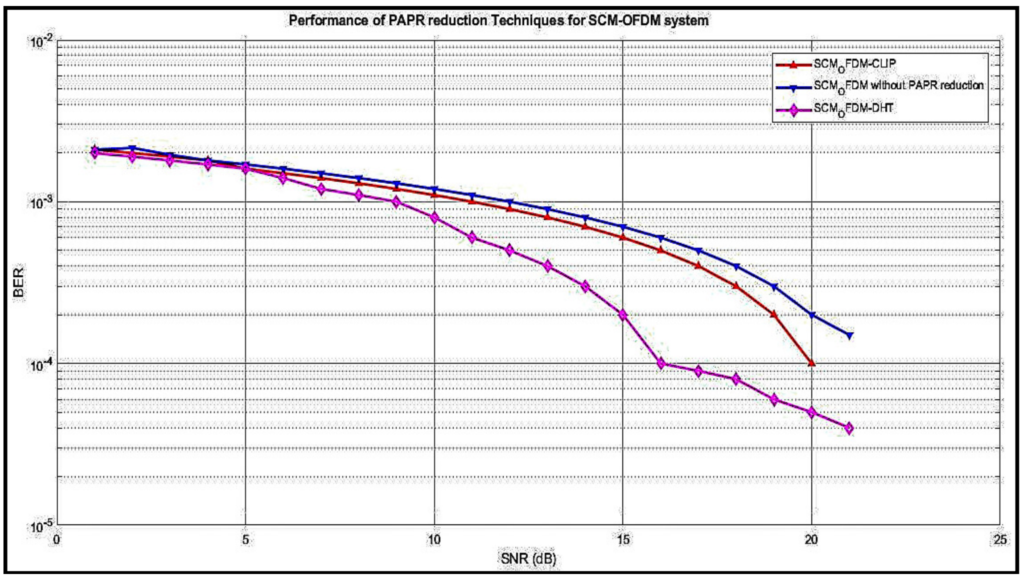


**Fig. 4.** BER performance of Clipping and DHT PAPR reduction techniques in SCM-OFDM system.

Fig. 5 present that when Modified µ law Compander with different value of µ, with µ=30 and above, the PAPR of SCM-OFDM system reduces to 3.8 dB. Increment in PR ratio to 2, increases the BER performance, compared to other µ-law companding technique as shown in Fig. 6. The BER performance in DHT precoder is better than the BER of µ-law companding techniques. The simulation uses different µ-law companding levels and is denoted as $U_1$ and $U_2$ in the result. However, the PAPR is more in DHT precoding technique compared to µ-law companding. The proposed system considers the advantages of both the techniques. Fig. 7 show different PAPR reduction technique for SCM-OFDM system, the proposed system outperforms the other reduction technique with PAPR of 1.79 dB. The BER performance of proposed system and its outperformance with the other PAPR reduction techniques is shown in Fig. 7. The Table 2 shows the comparison of computational complexity in DHT and DFT scheme for PAPR reduction. Since DHT requires less multiplications compared to DFT, proposed system is low computationally complex system. Table 3 compares the spectral efficiency of the DHT with other alternative techniques. PTS and SLM techniques use side information which increases bandwidth requirement. The proposed method is bandwidth efficient, since no side information is required. Fig. 8 provides BER comparative study of SCM –OFDM system with different PAPR reduction techniques. PAPR reduction for SCM-OFDM system with proposed reduction technique is 12.5dB for 256 QAM modulations. Table 4 provides the PAPR results and comparisons with SCM only, OFDM only and Hybrid combination of SCM-OFDM system with Clipping, SLM, PTS and MMC- DHT precoder for 64 QAM and 256 QAM. It is evident that from Table 4 with MMC-DHT precoder improves PAPR Performance of SCM-OFDM system.

**Table 2: Comparison of DHT and DFT for computational complexity.**

| Schemes | Real multiplications | Complex additions |
|---|---|---|
| DHT | $2L^2$ | L(L-1) |
| DFT | $4L^2$ | L(L-1) |

where L is order of DHT matrix and DFT matrix.

From the Table 3 it is observed that the computational complexity is reduced to 50% in case of DHT compared to DFT precoding. With use of DHT precoding for PAPR reduction it not only reduces PAPR but also reduces computational complexity in the system.

Where S is the number of subblocks and $\phi$ : is the number of phase factors.

The PAPR reduction techniques such as PTS and SLM requires side information which reduces the spectral efficiency of the system, on the contrary, DHT precoding requires no information for PAPR reduction in SCM-OFDM system improving spectral efficiency in the system as compared to existing reduction techniques.

The number od side information required for the above mention techniques are mentioned in Table 3.

**Table 3: Comparison of DHT for spectral efficiency.**

| Scheme | Sideband information (bits/OFDM symbol) |
|---|---|
| DHT | None |
| PTS | $S \log_2 \phi$ |
| SLM | $\log_2 \phi$ |

From the Table 4 it is evident that the proposed technique is efficient, 61% PAPR reduction compared to DHT alone for the SCM-OFDM system.

**Table 4: Comparison of PAPR Reduction techniques for SCM-OFDM system.**

| PAPR reduction technique | SCM | OFDM | SCM-OFDM without PAPR reduction | SCM-OFDM with clipping | SCM-OFDM with DHT | SCM-OFDM with $\mu$ companding | SCM-OFDM with Proposed PAPR reduction for 64 QAM | SCM-OFDM with Proposed PAPR reduction for 256 QAM |
|---|---|---|---|---|---|---|---|---|
| PAPR (in dB) | 6.4089 | 9.31 | 13.53 | 10.6536 | 5.8971 | 3.64 | 1.7949 | 12.5 |

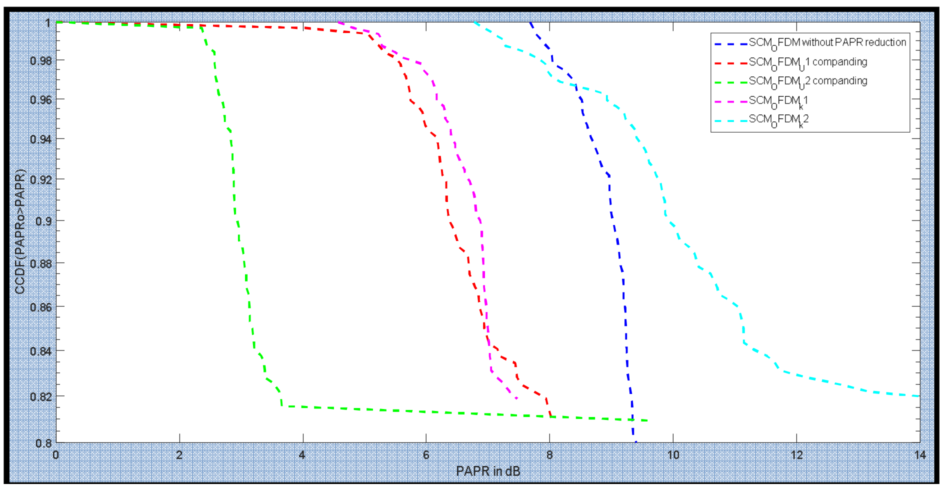


**Fig. 5.** CCDF Vs PAPR for different $\mu$ companding profiles ($u_1$,$u_2$) and modified $\mu$ companding techniques.

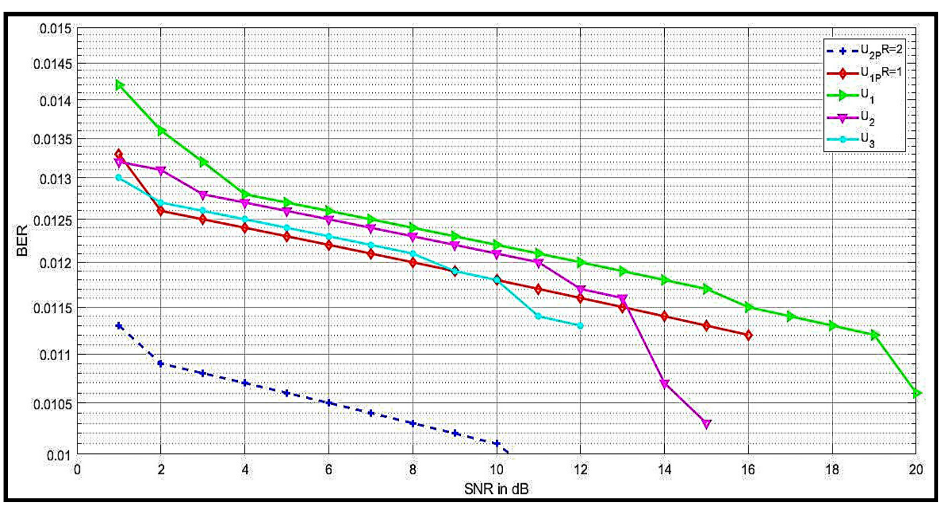


**Fig. 6.** BER performance of Modified µ law companding technique on SCM-OFDM system with different companding levels $U_1$,$U_2$ and $U_3$.Table IV: Comparison of PAPR Reduction techniques for SCM-OFDM system.

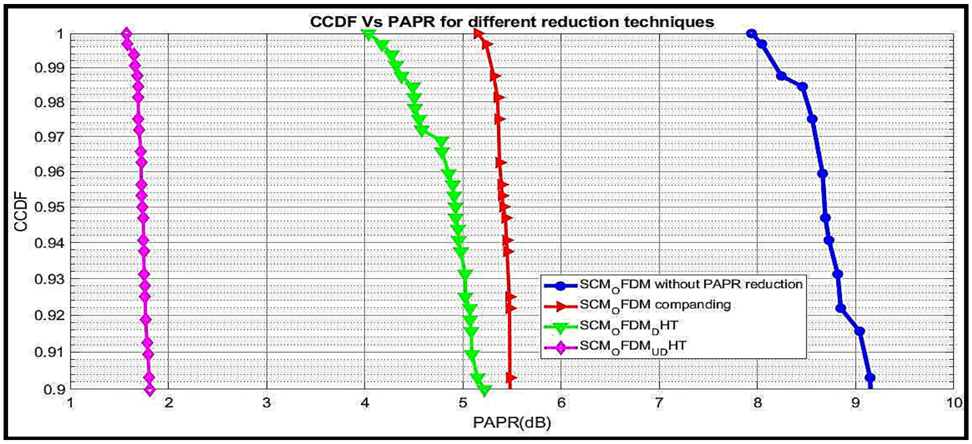


**Fig. 7.** CCDF Vs PAPR for different PAPR reduction techniques on SCM-OFDM system.

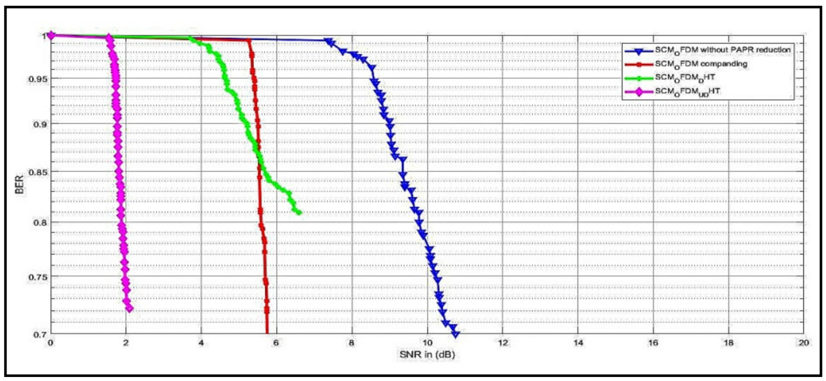


**Fig. 8.** BER performance of different PAPR reduction technique on SCM-OFDM system.

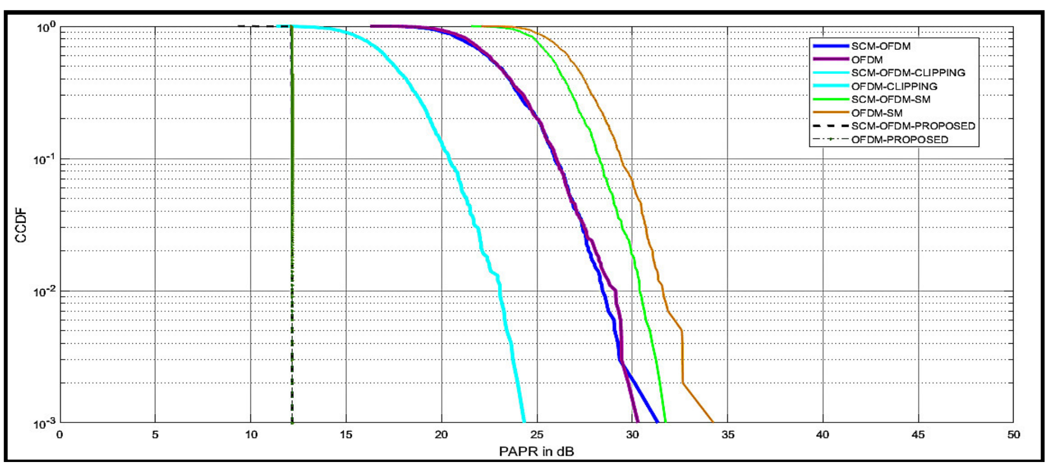


**Fig. 9.** Comparative study of PAPR on SCM-OFDM systems for 256 QAM modulation with different reduction techniques.

The SCM OFDM system is simulated for 64 QAM and 256 QAM respectively, PAPR for SCM signal and OFDM signal PAPR are 6.4089dB and 9.31dB respectively. With the combination of SCM-OFDM system PAPR increased to 13.53dB due to Gaussian like signal of SCM-OFDM signal and with equal power allotted for two layers of SCM. Clipping technique reduces PAPR by 2.87dB, where as DHT achieves PAPR reduction by 7.63dB. PAPR is further reduced by 9.89dB by $\mu$ companding technique. As observed from the simulation results DHT technique provides better BER performanc, µ companding technique provides better PAPR performance. Combining the advantages of both the technique we achieved reduction in PAPR by 11.73dB and improvement in PAPR by 86.7%. SCM-OFDM system is simulated with 256QAM to demonstrate the proposed method works better compared to well known PAPR technique such as PTS and Selective Mapping (SM). The Fig. 9 shows that PAPR in SCM-OFDM without PAPR reduction is 33dB, with SM technique PAPR is reduced to 32 dB. Some improvement is observed when PTS is applied to SCM-OFDM system. Significant result is obtained with the proposed technique, PAPR is reduced to 12.5dB, PAPR performance is improved by 62.1%.

## VI. CONCLUSIONS

A novel PAPR reduction technique for the OFDM system with SCM is presented and elaborated in this paper. An investigation on performance of different reduction techniques on SCM-OFDM system is achieved through computer simulation. The results indicated that the proposed technique outperformed the clipping technique by 83.1%, PTS by 58.3% , SM by 62% and achieved PAPR of 1.7949 dB with 64QAM SCM-OFDM system, 12.5dB with 256QAM SCM-OFDM system. The proposed method is beneficial for high data rate systems, where many constellations are required to achieve a high data rate.

Future scope: For future research, time-varying channels can be studied; furthermore, different modulations and layers can be experimented with SCM-OFDM system.

**Conflict of Interest:** No conflict of interest.

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