

---

# Convolutional Code Based PAPR Reduction Scheme for Multicarrier Transmission with Higher Number of Subcarriers

SAJJAD ALI MEMON\*, IMRAN ALI QURESHI\*, AND ABDUL LATIF\*

RECEIVED ON 13.04.2017 ACCEPTED ON 29.05.2017

## ABSTRACT

Multicarrier transmission technique has become a prominent transmission technique in high-speed wireless communication systems. It is due to its frequency diversity, small inter-symbol interference in the multipath fading channel, simple equalizer structure, and high bandwidth efficiency. Nevertheless, in the time domain, multicarrier transmission signal has high PAPR (Peak-to-Average Power Ratio) that interprets to low power amplifier efficiencies. To decrease the PAPR, a CCSLM (Convolutional Code Selective Mapping) scheme for multicarrier transmission with a high number of subcarriers is proposed in this paper. Proposed scheme is based on SLM method and employs interleaver and convolutional coding. Related works on the PAPR reduction have considered either 128 or 256 number of subcarriers. However, PAPR of multicarrier transmission signal will increase as a number of subcarriers increases. The proposed method achieves significant PAPR reduction for a higher number of subcarriers as well as better power amplifier efficiency. Simulation outcomes validate the usefulness of projected scheme.

**Key Words:** Multicarrier Transmission, Peak-to-Average Power Ratio, Convolutional Codes, Selective Mapping, Number of Subcarriers.

## 1. INTRODUCTION

Multicarrier transmission technique has several advantages over the single-carrier scheme, including high rate transmission, frequency diversity, and small inter-symbol interference in the multipath fading channel. Therefore, it is widely used in several telecommunication standards e.g. ADSL (Asymmetric Digital Subscriber Line), DAB, and WLAN (Wireless Local Area Network) [1]. However, a major drawback of multicarrier transmission schemes is elevated PAPR, which consequences in in-band distortion that impairs BER (Bit Error Rate), and out-of-band radiation

that impedes with adjacent frequency bands [2]. To counter this high PAPR of the multicarrier transmission signal, the HPA (High Power Amplifier) needs to be operated in or near its linear region, however, this leads to small power efficiency and costly transmitter [3]. Therefore, it is obligatory to address high PAPR problem of multicarrier transmission technique in order to make multicarrier transmission cost effective in low-cost applications.

Until now, many different PAPR reductions schemes [4-15] have been proposed in the literature, based on clipping

---

Corresponding Author (E-Mail: sajjad.memon@faculty.muet.edu.pk)

\* Department of Telecommunication Engineering, Mehran University of Engineering & Technology, Jamshoro.

and filtering, SLM, partial transmit sequences, coding, tone injection and active constellation extension techniques. For a complete review of all the PAPR reduction techniques, [16-17]. However, schemes [4-15] and most of the schemes on PAPR reduction in literature have achieved significant PAPR reduction with either 128 subcarriers or 256 sub-carriers. Though PAPR is unswervingly proportional to a number of subcarriers, that is, it will increase as the number of subcarriers increase. Therefore, it is not certain that whether these schemes can achieve significant PAPR reduction with a higher number of subcarriers or not.

In this paper, CCSLM scheme for MC-CDMA systems is suggested to decrease the PAPR with 256,512,...,4096 a number of subcarriers. The proposed method is based on SLM method and employs interleaver and convolutional coding. The 2<sup>n</sup> different candidate data sequences of the original data sequence, all corresponding to the same information as the original data sequence, are first generated by adding *u*-tuple index bits to it, then processed by the interleaver and convolutional coding. Utilization of the interleaver and the convolutional coding causes every sequence further random and decreases the probability of in-phase summation of subcarriers, which consecutively, enhances the probability of PAPR diminution. Proposed method can achieve noteworthy PAPR diminution with better power efficiency, and also shun requirement for the side-information transmission.

The remaining of this paper is prepared as follows. In Section 2, system model for multicarrier transmission is discussed. Section 3 presents efficiency of the HPA in detail. In Section 4, conventional SLM method, CCSLM method and computational complexity are debated. The simulations and their outcomes are debated in Section 5. Section 6 presents power efficiency analysis of CCSLM method and to end with, some conclusions are made in Section 7.

## 2. SYSTEM MODEL

Fig. 1 demonstrates the signal generation of one complex data symbol  $m^{(e)}$  of MC-CDMA assigned to the user *e*. On the transmitter side, the complex-valued data symbol  $m^{(e)}$  is first multiplied with the user-distinct spread code,  $r^{(e)} = [r_0^{(e)}, r_1^{(e)}, \dots, r_{F-1}^{(e)}]^T$ , of spreading factor, *F*. The spread data sequence,  $p^{(e)}$ , acquired after spreading, can be specified in vector form as  $p^{(e)} = m^{(e)}r^{(e)} = [p_0^{(e)}, p_1^{(e)}, \dots, p_{F-1}^{(e)}]^T$ . Spread sequence  $p^{(e)}$  is then altered to the parallel  $p_f^{(e)}$  ( $f=0, 1, \dots, F-1$ ) and modulated onto  $M=1 \times F$  subcarriers pursued by the IDFT (Inverse Discrete Fourier Transform) of size  $M_{IDFT} = M$  to acquire the multicarrier spread spectrum signal. A TD (Time-Domain) baseband multicarrier transmission signal  $b^{(e)}(t)$ , following the IDFT, for a single MC-CDMA symbol,  $0 \leq t \leq T$ , is:

$$b^{(e)}(t) = \sum_{f=1}^F \sum_{e=1}^E m^{(e)} r_f^{(e)} e^{\frac{2\pi j f (f-1)}{T}} \quad (1)$$

where MC-CDMA symbol period and a total number of users are represented by *T* and *E*, respectively. The PAPR of a baseband multicarrier transmission signal in Equation (1) can be described as the ratio of largest instantaneous peak power to average power of multicarrier transmission signal [1-7] and it can be expressed as:

$$PAPR = \frac{\max |b(t)|^2}{P_{av}} \quad (2)$$

where average power is represented by  $P_{av}$  that can be given as:

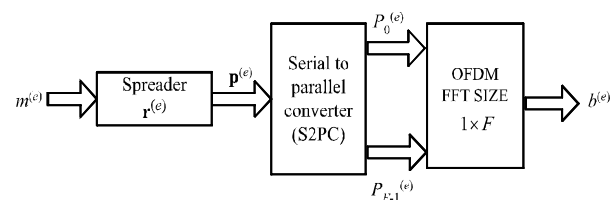


FIG. 1. SIGNAL FORMATION OF ONE COMPLEX DATA SYMBOL OF MC-CDMA

$$P_{av} = \frac{1}{T} \int_0^T |b(t)|^2 dt \quad (3)$$

where the number of subcarriers is represented by  $M$ . Likewise, discrete-time domain PAPR can be stated as:

$$PAPR = \frac{\max(|b(n)|^2)}{\frac{1}{M} \sum_{n=0}^M E(|b(n)|^2)} \quad (4)$$

Where  $E(|b(n)|^2)$  represents mathematical expectation operator.

It is indispensable to estimate statistical characteristics of PAPR because user data are non-deterministic in nature. CCDF (Complementary Cumulative Distribution Function) is the most traditional way for analyses of PAPR and it is explained as the probability of PAPR above a definite level  $w$  [17].

### 3. HIGH POWER AMPLIFIER EFFICIENCY

Consider the most linear HPA, that is Class A amplifier, which devours a steady quantity of power,  $P_{DC}$ , in spite of input power. Efficiency of HPA,  $\eta$ , is described as a ratio of the average output power  $P_{out,avg}$  to  $P_{DC}$ ; that is:

$$\eta = \frac{P_{out,avg}}{P_{DC}} \quad (5)$$

For a known multicarrier transmission signal, average input power must be fine-tuned so that peaks of the signal are barely clipped. That is, an input IBO must have to be applied to signal before amplification. The value of the IBO unswervingly connects to both PAPR and HPA efficiency. The high PAPR induce to an enlarged IBO and cheap HPA efficiency. Maximum efficiency of Class A HPA is 50%. Consider a perfect model for the HPA, where

linear amplification is accomplished toward saturation point, then HPA efficiency can be given as [3]:

$$\eta = \frac{0.5}{PAPR} \quad (6)$$

For a multicarrier transmission signal with 256 subcarriers, in order to warranty that no more than 1 in 10,000 frames are clipped, IBO that is corresponding to PAPR value at 0.0001 probability level must be applied. According to [17] the equivalent PAPR value is 14.02dB (25.235). Therefore, to amplify a 256 subcarrier multicarrier transmission signal with Class A HPA under a restraint that clipping probability must not surpass 0.0001, HPA efficiency befalls  $\eta = 0.5/25.235 = 1.98\%$ . Hence, such low power efficiency is a decisive stimulus for PAPR reduction in multicarrier transmission systems. Moreover, with a Class A HPA, each 3dB of PAPR diminution results into the doubling of power efficiency of the HPA.

### 4. CONVOLUTIONAL CODE SLM METHOD

The CCSLM method is based on convolutional code and SLM method; therefore it is convenient to first briefly explain the convolutional code and conventional SLM method prior to explaining the CCSLM method, respectively.

#### 4.1 Convolutional Code

The convolutional codes integrate error detection and correction ability, which make it the enviable option to diminish the PAPR for multicarrier transmission systems [16]. A multicarrier transmission signal is the addition of several data symbols modulated onto sub-carriers. In phase summation of samples from all subcarriers results in an increase of peak power of a signal by  $M$  times to that of average power; therefore, this consequence in high PAPR. PAPR diminution can be accomplished by reducing

the probability of subcarriers being summed in phase and convolutional codes can be used to do it. In 1954 Peter Elias created binary convolutional codes [18]. They belong to a particular class of error control codes in which encoding can seem as filtering or convolution operation. Unlike block encoder, a convolutional encoder is a memory device [19]. Table 1 listed the parameters that are needed to explain a convolutional encoder. Fig. 2 illustrates nonsystematic feedforward convolutional encoder, which is used in this paper due to their great free distance and enhanced presentation with Viterbi decoding contrasted to systematic convolutional encoders [20].

### 4.2 SLM Technique

SLM technique is one of easiest techniques to condense PAPR. The principal idea of the SLM technique is to engender a set of multi-carrier data blocks, which should be independent based on their statistics. However, each data block equivalent to the similar information as of the original multi-carrier data block. Then, a data block having the least PAPR value is tabbed and transmitted. Set of multi-carrier data blocks can be formed by multiplying

TABLE 1. PARAMETERS OF CONVOLUTIONAL ENCODER

Parameters	Value
Output bits at a time	p
Input bits at a time	k
Constraint length	K
Code rate	R = k/p

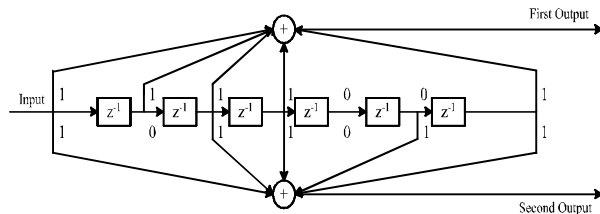


FIG. 2. ANONSYSTEMATIC FEEDFORWARD CONVOLUTIONAL ENCODER

original data block of length L,  $D = [D_1, D_2, \dots, D_L]$ , element-wise with N distinct phase sequences of length L,  $H^{(n)} = [h_{n,0}, h_{n,1}, \dots, h_{n,L-1}]^T$ ,  $0 < n < N-1$ , earlier to IDFT operation. An original data block can be included in these modified data blocks by setting  $H^{(1)}$  as all-one vector of length L. After that, multi-carrier transmission signal turns into IDFT of the element-by-element multiplication of D and h.

$$k^{(n)}(t) = \text{IDFT}[D_1 h_{n,0}, D_2 h_{n,1}, \dots, D_{L-1} h_{n,L-1}]^T, 0 \leq n < N-1 \quad (7)$$

After that, a data block having the least PAPR value in the modified set of data blocks  $\kappa^{(n)}$  is picked for transmission [15-17,21].

### 4.2 CCSLM Method

A CCSLM method uses  $u$ -tuple of  $u$  index bits trailed by an interleaver and convolutional code is proposed in this paper. This method has an identical concept for PAPR diminution as that of SLM scheme [8]; however, it also has the error-correction capability, as it employs convolutional code. In CCSLM scheme,  $u$ -tuple of  $u$  index bits are first inserted to spread data sequence  $p^{(e)}$  to engender  $2^u$  SDS (Spread Data Sequences), expressed as  $Q = [Q_0, Q_1, \dots, Q_{2^u-1}]$ , where

$$\begin{aligned} Q_0 &= [000000p^{(e)}] \\ Q_1 &= [000001p^{(e)}] \\ &\vdots \\ Q_{2^u-1} &= [111111p^{(e)}] \end{aligned} \quad (8)$$

These  $2^u$  SDS are independent sequences based on their statistics. Afterward, QSDS are carried to interleaver. The interleaver is a device which works and permutes a block of  $c$  symbols that is a data block,  $Z = [Z_0, Z_1, \dots, Z_{C-1}]^T$  becomes  $Z' = [Z_{\pi(0)}, Z_{\pi(1)}, \dots, Z_{\pi(C-1)}]^T$  where  $\{c\} \leftrightarrow \{\pi(c)\}$  is a one-to-one mapping and

$\pi(c) \in \{0, 1, \dots, C-1\}$  for all  $c$ . To interleave  $Q$  SDS,  $Q$  interleaves are utilized to generate  $W$  permuted SDS symbolized as  $W = [W_0, W_1, \dots, W_{2u-1}]$ . Permutation directories  $\{\pi(c)\}$  are accumulated in the memory of both transmitter and receiver so that interleaving and deinterleaving can be performed easily.

Following interleaving, permuted SDS are carried to convolutional coding. The output from convolutional coding is represented as  $Y = [Y_0, Y_1, \dots, Y_{2u-1}]$ .

After convolutional coding, binary phase-shift keying is used to modulate YSDS followed by serial to parallel converter. Next, YSDS are carried to IDFT of size  $M_{IDFT}$ . The output from IDFT is symbolized as  $V = [V_0, V_1, \dots, V_{2u-1}]$ . Following the IDFT, VTD sequences are scanned to choose a TD signal with the least PAPR value for transmission.

At the receiver side when the selected TD signal with the least PAPR value is received, it is first processed through DFT of size  $M_{DFT}$ . After that, the output signal of DFT, which is a matrix of size  $M_{DFT} \times 1$ , is processed through parallel to serial converter that is pursued by BPSK demodulation. Following demodulation, received signal is sent to convolutional decoding and then to deinterleaving. To deinterleave a received signal, the receiver simply requires knowing which of interleavers utilized at transmitter has the least PAPR value. Following deinterleaving,  $u$ -tuple of  $u$  index bits is detached before sending the received signal to despreader. Finally, user data,  $m^{(e)}$ , is received.

### 4.3 Computational Complexity

One of the most important parameters to exhibit performance of PAPR diminution method is computational complexity. In general, PAPR diminution potential of more complicated schemes with fewer unwanted effects is superior to simple ones. The computational complexity of CCSLM scheme is definitely higher than SLM as it uses interleaver and convolutional code to diminish PAPR. Evaluation of computational complexities of CCSLM and the SLM schemes are illustrated in Table 2.

To execute  $N$  phase sequences each of length  $L$  in the SLM method,  $NL$  additions are needed to apply these phase sequences in hardware. Afterward,  $N$ -IDFT blocks are needed, adding  $2NL \log_2 L$  real multiplications and  $3NL \log_2 L$  real summations. PAPRs for  $N$  permutations of the multicarrier transmission signal are calculated by  $N(2L+1)$  real multiplications and  $N(3L-2)$  real summations. Lastly,  $(N-1)$  subtractions or summations are required to unearth least PAPR value. Overall complexity is  $2NL(1+\log_2 L)+N$  real multiplications and  $3NL(1+\log_2 L)+N(L-1)-1$  real summations [16].

For the computational complexity of CCSLM scheme, the computational complexity of interleaver is not considered. If  $N=2^n$  then to realize convolutional code,  $5NL$  modulo-2 summations are needed. Additionally, the convolutional code also entails  $2NL(1+\log_2 L)+N$  real multiplications and  $3NL(1+\log_2 L)+N(L-1)-1$  real additions.

TABLE 2. COMPUTATIONAL COMPLEXITY COMPARISON BETWEEN CCSLM AND SLM SCHEMES.

Method	Computational Complexity		
	Multiplications	Additions	Modulo-2 Additions
SLM	$2NL(1+\log_2 L)+N$	$3NL(1+\log_2 L) + N(L-1)-1$	Zero
CCSLM			$5NL$

## 5. RESULTS AND DISCUSSION

MATLAB software has been used to undertake the computer simulations to corroborate the effectiveness of the proposed scheme. The PAPR values against CCDF of the PAPR values are plotted to compare the performance of the proposed scheme with other schemes. A  $10^{-4}$  CCDF of the PAPR is used for comparison. Numbers of subcarriers used in the simulation are  $M=128, 256, \dots, 4096$ . The Walsh-Hadamard sequence with spreading factor of 8 is used as spreading sequence. Numbers of index bits used are  $u=2, 3, \dots, 7$ . A  $[177, 133]$  convolutional code generator polynomial with a constraint length of seven is used as convolutional code in simulations.

The PAPR performance of the CCSLM method for multicarrier transmission systems has been compared with reduced PAPR allocation (RPA) method [12] and conventional SLM method in Fig. 3. Seven index bits ( $2^u = 2^7 = 128$ ) are used for the CCSLM method whereas the corresponding number of random phase sequences that are  $N = 128$  used for SLM method. Y-axis signifies CCDF of PAPR and x-axis signifies the PAPR. It is evident from Fig. 3 that the proposed CCSLM method achieves significant PAPR reduction of 10 dB compared to conventional SLM method. It is also evident from Fig. 3 that the proposed CCSLM method also performed better than the RPA method as it achieves a significant PAPR reduction of 4.5 dB compared to RPA scheme. Therefore, it can be deduced from Fig. 3 that the CCSLM scheme achieves significant PAPR reductions compared to RPA and conventional SLM methods. Moreover, unlike to SLM, CCSLM scheme does not require any side information to retrieve original data.

The above simulation result is achieved using  $M=128$  a number of subcarriers as most of the related works considered either 128 or 256 number of subcarriers [3-17]. However, the PAPR of a multicarrier transmission signal

will increase as the number of subcarriers increases. Therefore, the projected CCSLM scheme is contrasted with conventional SLM for  $M=256, 512, \dots, 4096$  number of subcarriers. The PAPR performance of the CCSLM method for multicarrier transmission systems has been compared with conventional SLM method in Fig. 4 for  $M=256, 512, \dots, 4096$  number of subcarriers. Two index bits ( $2^u = 2^2 = 4$ ) are used for the CCSLM method whereas the corresponding number of random phase sequences that is  $N=4$  used for conventional SLM method. Fig. 4 shows that the PAPR values of the conventional SLM method increase from 19-29 dB as the number of subcarriers increases from 256-4096. Whereas, the PAPR values of the CCSLM method increases from 9.4-11.5 dB as the number of subcarriers increases from 256-4096. Hence, it is quite clear that the proposed CCSLM method can reduce the PAPR effectively even for a large number of subcarriers. Similarly, Figs. 5-8 compares the PAPR performance of proposed CCSLM method with conventional SLM method for  $M=256, 512, \dots, 4096$  subcarriers with  $u=3, 4, 5, 6$  index bits and their corresponding  $N=8, 16, 32, 64$  random phase sequences. It can be seen that as more number of index bits are inserted more reduction in PAPR can be achieved and this PAPR reduction is significant compared to conventional SLM.

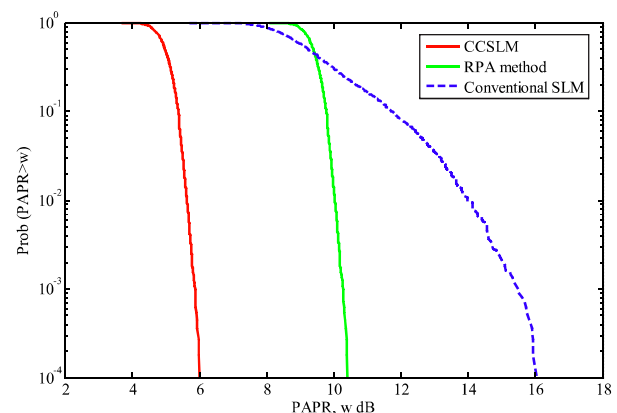


FIG. 3. CCDF OF PAPR OF THE MULTICARRIER TRANSMISSION SIGNAL, CONTRASTING CCSLM, RPA AND SLM METHODS WITH  $2^u = N = 128$

However, this PAPR reduction with increasing number of index bits if compared with each other then this PAPR reduction is not significant as seen from Figs. 5-8. Therefore, it can be concluded that significant PAPR reduction for  $M=256,512,\dots,4096$  subcarriers can be achieved even with a small number of index bits in the CCSLM method. Table 3 summarizes the PAPR comparison of the proposed scheme with conventional SLM schemes for higher number of subcarriers.

### 6. POWER EFFICIENCY OF NESLM METHOD

As stated in Section 3 that Class A HPAs have maximum power efficiency and that is 50%. Therefore, an ideal model

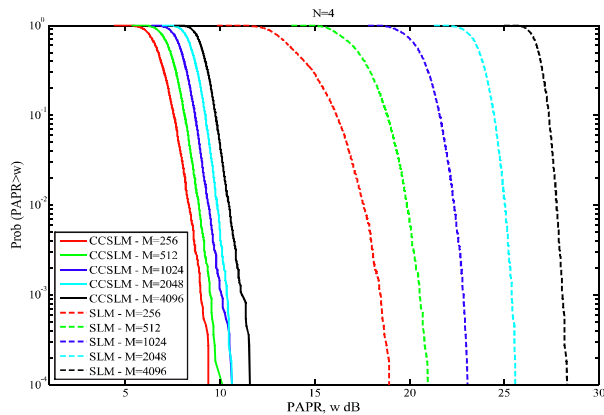


FIG. 4. PAPR COMPARISON OF CCSLM SCHEME WITH CONVENTIONAL SLM METHOD FOR  $M=256,512,\dots,4096$  WITH  $2^u=N=4$

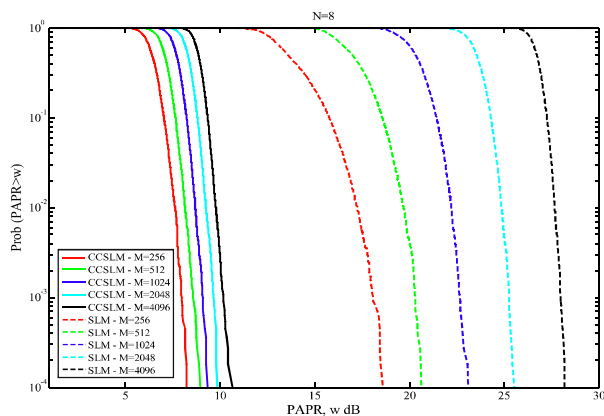


FIG. 5. PAPR COMPARISON OF CCSLM SCHEME WITH CONVENTIONAL SLM METHOD FOR  $M=256,512,\dots,4096$  WITH  $2^u=N=8$

for Class A HPA to analyze the power efficiency of CCSLM method is considered. The PAPR performance comparison of CCSLM method with RPA method [12] and conventional SLM method has been plotted for the multicarrier transmission systems in Fig. 3. Noteworthy PAPR diminution accomplished by CCSLM scheme, compared to conventional SLM method (16 dB), is obvious from Fig. 3 that is 10dB at 0.0001. The PAPR diminution accomplished by ascheme of [12] is 5.6 dB at the level of 0.0001. The corresponding power efficiencies of conventional SLM, [12] and CCSLM method are listed in Table 4. It is clear from Table 4 that CCSLM scheme has the highest power efficiency among all the methods. This shows that CCSLM method has better power efficiency than those of the SLM and RPA methods.

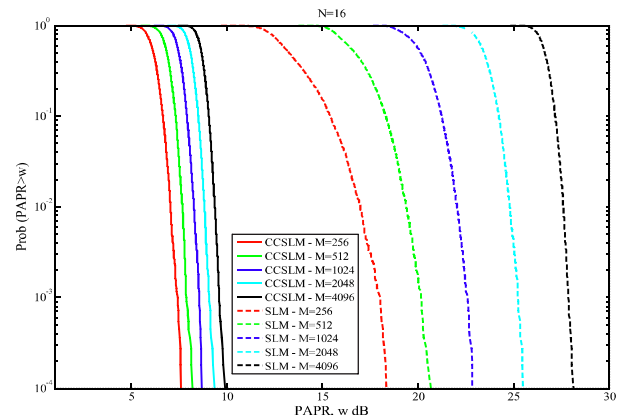


FIG. 6. PAPR COMPARISON OF CCSLM SCHEME WITH CONVENTIONAL SLM METHOD FOR  $M=256,512,\dots,4096$  WITH  $2^u=N=16$

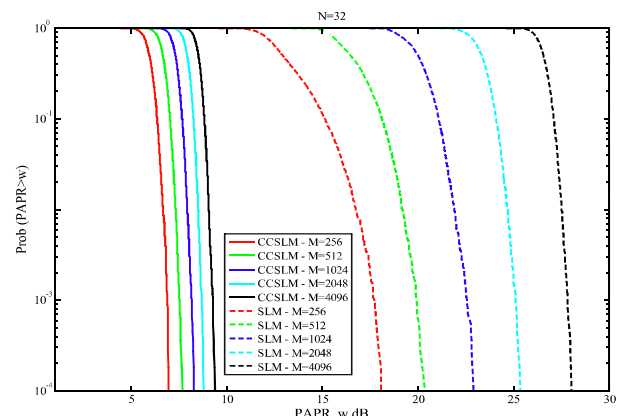


FIG. 7. PAPR COMPARISON OF CCSLM SCHEME WITH CONVENTIONAL SLM METHOD FOR  $M=256,512,\dots,4096$  WITH  $2^u=N=32$

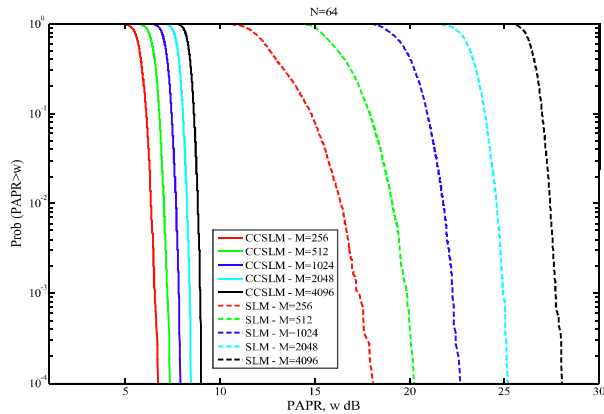


FIG. 8. PAPR COMPARISON OF CCSLM SCHEME WITH CONVENTIONAL SLM METHOD FOR  $M=256,512,\dots,4096$  WITH  $2^u=N=64$

TABLE 3. SIMULATION RESULTS COMPARISON

	CCSLM (dB)	Conventional SLM (dB)
M=256	8.9	18.77
M=512	10.1	22.75
M=1024	10.9	23
M=2048	11	25.5
M=4096	12.15	27

TABLE 4. COMPARISON OF POWER EFFICIENCIES

Method	Power Efficiency = $05/PAPR$
SLM	1.2%
RPA [12]	4.5%
CCSLM	12.5%

## 7. CONCLUSION

Multicarrier transmission technique has several advantages over the single-carrier scheme, including high rate transmission, frequency diversity, and small inter-symbol interference in the multipath fading channel. However, a major drawback of multicarrier transmission schemes is elevated PAPR which consequences in in-band distortion that impairs bit error rate, and out-of-

band radiation that impedes with adjacent frequency bands. To counter this high PAPR of the multicarrier transmission signal, the HPA needs to be operated in or near its linear region, however, this leads to small power efficiency and costly transmitter. Therefore, it is obligatory to address high PAPR problem of multicarrier transmission technique in order to make multicarrier transmission cost effective in low-cost applications.

Therefore, in this paper a CCSLM scheme for the PAPR reduction in the multicarrier transmission system is proposed. The CCSLM scheme employs  $u$ -tuple index bits to engender  $2^u$  sequences of an original data sequence. Simulation outcomes confirm usefulness and flexibility of CCSLM scheme and disclose that CCSLM scheme achieves significant PAPR reductions compared to RPA and SLM. The CCSLM method also has the better power efficiency for the multicarrier transmission system compared to RPA and SLM methods. Furthermore, the CCSLM scheme is also effective in reducing PAPR for a large number of subcarriers as it achieves note worthy PAPR reductions compared to SLM method for  $M=256,512,\dots,4096$  with  $2^u=N=4,\dots,64$ . A trade-off can also be observed among number of  $u$  index bits and PAPR diminution in the simulation results. That is larger the number of index bits higher will be the PAPR reduction but system will be more complex than the system with alower number of index bits. Therefore, a moderate number of index bit should be chosen that can give better PAPR reduction performance with theless complex system.

## ACKNOWLEDGEMENT

The authors thank the anonymous reviewers and the editors for their many helpful suggestions.



## REFERENCES

- [1] Fazal, K., and Kaiser, S., "Multi-Carrier and Spread Spectrum Systems: From OFDM and MC CDMA to LTE and WiMAX", John Wiley & Sons, Chapter-2, UK, 2008.
- [2] Litsyn, S., "Peak Power Control in Multicarrier Communications", Chapter-5, Cambridge University Press, USA, 2007.
- [3] Baxley, R.J., and Zhou, G.T., "Power Savings Analysis of Peak-to-Average Power Ratio in OFDM", IEEE Transactions on Consumer Electronics, Volume 50, No. 3, pp. 792-798, USA, 2004.
- [4] Sohn, I., "A Low Complexity PAPR Reduction Scheme for OFDM Systems via Neural Networks", IEEE Communications Letters, Volume 18, No. 2, pp. 225-228, USA, 2014.
- [5] Zhou, Y., Jiang, T., Huang, C.A., and Cui, S.G., "Peak-to-Average Power Ratio Reduction for OFDM/OQAM Signals via Alternative-Signal Method", IEEE Transactions on Vehicular Technology, Volume 63, No. 1, pp. 494-499, USA, 2014.
- [6] Damavandi, M.G., Abbasfar, A., and Michelson, D.G., "Peak Power Reduction of OFDM Systems Through Tone Injection via Parametric Minimum Cross-Entropy Method", IEEE Transactions on Vehicular Technology, Volume 62, No. 4, pp. 1838-1843, USA, 2013.
- [7] Ji, J.W., and Ren, G.L., "A New Modified SLM Scheme for Wireless OFDM Systems Without Side Information", IEEE Signal Processing Letters, Volume 20, No. 11, pp. 1090-1093, USA, 2013.
- [8] Khademi, S., and van der Veen, A.J., "Constant Modulus Algorithm for Peak-to-Average Power Ratio Reduction in MIMO OFDM/A", IEEE Signal Processing Letters, Volume 20, No. 5, pp. 531-534, USA, 2013.
- [9] Li, L., and Qu, D., "Joint Decoding of LDPC Code and Phase Factors for OFDM Systems With PTS PAPR Reduction", IEEE Transactions on Vehicular Technology, Volume 62, No. 1, pp. 444-449, USA, 2013.
- [10] Jiang, T., Ni, C., and Guan, L., "A Novel Phase Offset SLM Scheme for PAPR Reduction in Alamouti MIMO-OFDM Systems Without Side Information", IEEE Signal Processing Letters, Volume 20, No. 4, pp. 383-386, USA, 2013.
- [11] Ye, C., Li, Z., Jiang, T., Ni, C., and Qi, Q., "PAPR Reduction of OQAM-OFDM Signals Using Segmental PTS Scheme With Low Complexity", IEEE Transactions on Broadcasting, Volume 60, No. 1, pp. 141-147, USA, 2014.
- [12] Giannetti, F., Lottici, V., and Stupia, I., "PAPR Analytical Characterization and Reduced-PAPR Code Allocation Strategy for MC-CDMA Transmissions", IEEE Transactions on Wireless Communications, Volume 10, No. 1, pp. 219-227, USA, 2011.
- [13] Taspinar, N., Karaboga, D., and Yildirim, M., "Partial Transmit Sequences Based on Artificial Bee Colony Algorithm for Peak-to-Average Power Ratio Reduction in Multicarrier Code Division Multiple Access Systems", IET Communications, Volume 5, No. 8, pp. 1155-1162, UK, 2011.
- [14] Hao, M.J., and Lai, C.H., "Precoding for PAPR Reduction of OFDM Signals with Minimum Error Probability", IEEE Transactions on Broadcasting, Volume 56, No. 1, pp. 120-128, USA, 2010.
- [15] Han, S.H., and Lee, J.H., "An Overview of Peak-to-Average Power Ratio Reduction Techniques for Multicarrier Transmission", IEEE Wireless Communications, Volume 12, No. 2, pp. 56-65, April, 2005.
- [16] Rahmatallah, Y., and Mohan, S., "Peak-to-Average Power Ratio Reduction in OFDM Systems: A Survey and Taxonomy", IEEE Communications Surveys and Tutorials, Volume 15, No. 4, pp. 1567-1592, USA, 2013.
- [17] Jiang, T., and Wu, Y., "An Overview: Peak-to-Average Power Ratio Reduction Techniques for OFDM Signals", IEEE Transactions on Broadcasting, Volume 54, No. 2, pp. 257-268, USA, 2008.

- |   |   |
|---|---|
| [18] Elias, P., "Error-Free Coding", Transactions of the IRE Professional Group on Information Theory, Volume 4, No. 4, pp. 29-37, USA, 1954. | [20] Sweeney, P., "Error Control Coding: from Theory to Practice", John Wiley & Sons, Chapters-3-4, UK, 2002.   |
| [19] Bernard, S., "Digital Communications Fundamentals and Applications", Prentice-Hall, Chapters-6-7, USA, 2001.                             | [21] Bäuml, R.W., Fischer, R.F., and Huber, J.B., "Reducing the Peak-to-Average Power Ratio of Multicarrier Modulation by Selected Mapping", Electronics Letters, Volume 32, No. 22, pp. 2056-2057, UK, 1996. |