Journal of Engineering and Sustainable Development
http://jeasd.uomustansiriyah.edu.iq/index.php
https://doi.org/10.31272/jeasd.25.4.8

Vol. 25, No. 04, July 2021
ISSN 2520-0917

PALM CLIPPING AND NONLINEAR COMPANDING TECHNIQUES BASED PAPR REDUCTION IN OFDM-DCSK SYSTEM

***Sajjad R. Abdulridha[1]** **Fadhil S. Hasan[1]**

1) Electrical Engineering Department, College of Engineering, Mustansiriyah University , Baghdad, Iraq

Received 28/11/2020 ***Accepted in revised form 13/2/2021*** ***Published 1/7/2021***

Abstract: The main drawback of the Orthogonal Frequency Division Multiplexing (OFDM) with Differential Chaos Shift Keying (DCSK) that is named (OFDM-DCSK) is the high Peak to Average Power Ratio (PAPR). In this paper, clipping and companding techniques are suggested to overcome the PAPR problem in the OFDM-DCSK system. For the clipping technique, the clipping function is applied before transmitting the signal without the need for an inverse function at the receiver side. While for companding techniques, the commanding function is applied at the end of the transmitter side and the corresponding decompanding function is applied at the receiver to recover the original signal. Different companding techniques are investigated including Hyperbolic, A-Law, and Mu-Law companding function that are compared with the Palm clipping technique. The MATLAB simulation result shows that the Mu-Law technique has the best PAPR reduction (7.22 dB) with a good bit error rate (BER) performance when the number of subcarriers is equal to 512.

Keywords: *Orthogonal Frequency Division Multiplexing, Differntial Chaos Shift Keying, Peak Power to Average Power Ratio, Palm Clipping, Companding techniques.*

1. Introduction

Chaotic system is widely used in the wireless communication systems due to the non-periodicity, the randomness property, and the high sensibility to the initial values [1], [2]. Among all types of chaotic based modulation systems, a non-coherent chaotic modulation scheme has highly interested by the researchers due to the simplicity in the design and removing the wanted chaotic synchronization circuit at the reception.

The famous practical circuit of non-coherent chaotic modulation shift keying is the differential chaos shift keying (DCSK) system [3], in which the system is designed with simple circuit with appropriate bit error rate (BER) under multipath fading channel without needing channel state information at the reception [4]. Nevertheless, as depicted in [5-7], in classical DCSK systems, only half of the bit period is consumed on carrying the data sequence, and the multicarrier based DCSK structure has been proposed in [5], such as the orthogonal frequency division multiplexing (OFDM), to reach higher information rate transmission and improve the energy efficiency of the DCSK system, which is also named Multicarrier-DCSK (MC-DCSK) or OFDM-DCSK system. In [8], the subcarriers are divided into multiple groups, only one chaotic reference is sent for each group.

OFDM-DCSK is a non-coherent chaos-based communication structure, improving data rate and saving the bit energy are the most important

**Corresponding Author*: sejjad_alqassab@yahoo.com

advantages of this system, it's also simple to design as it's not required RF delay, and adding to the mentioned advantages, there is no need to use chaotic sequence generator at the receiver end .The high Peak to Average Power Ratio (PAPR) of the transmitted signal is the major drawback of OFDM-DCSK. The RF power amplifier (RF-PA) is affected by the high PAPR which gives rise to the signal distortion. A high PAPR degrade the operation of the analog-to-digital and digital-to-analog converters and minimize the performance of the RF-PA, this distorts the transmitted OFDM signal which leads to poor BER performance of the whole system.

The PAPR is defined as the ratio of maximum power to the mean power of the transmitted OFDM signal during one symbol. it's also expressed in units of dB. PAPR occurs in a multicarrier system when the different subcarriers are out of phase with each other. In [8], [9] the problem of PAPR was investigated by authors and they have suggested PAPR reduction algorithms to improve the performance of the MC-DCSK systems. They insert dummy sequences in accordance to the Inverse Fast Fourier Transform (IFFT) [10] needs no receiver modifications. Also, several techniques were suggested to overcome the issue of PAPR for OFDM system like clipping including Classical Clipping (CC) [11], Smooth Clipping (SC) [12], Heavy-side Clipping (HC) [13], and Deep Clipping (DC) [14]. The Selective Mapping Technique (SLM) [15] and Partial Transmit Sequences (PTS) [16] are other methods that were suggested to reduce the PAPR. The channel coding can be used as a technique to reduce the PAPR and correct the errors, the basic concept is to find the best code word that gives the lower PAPR [17, 18]. Compressor/Expander is a good technique that is used to compress the OFDM signal at the transmitter end and expand it at the receiver which is called the companding technique. Lately, new techniques are proposed that are called Hybrid techniques, the basic idea is combining two or three techniques that give good results in terms of PAPR and Bit Error Rate (BER) [19–23].

In this paper, Palm Clipping and Companding techniques using Hyperbolic, A-Law, and Mu-Law companding functions are suggested to reduce the PAPR in the OFDM-DCSK system. The rest of the paper is arranged as follows: the proposed OFDM-DCSK system model is presented in section 2. Section 3 presents the PAPR reduction techniques includes the Palm Clipping and the Companding techniques. Performance evaluation and descriptions of the tried techniques were presented in section 4. In the last, the conclusion is summarized in section 5.

2. OFDM-DCSK System Model

Fig.1 and Fig.2 describe the block diagram of the OFDM-DCSK system at transmitter and receiver, respectively. When the switch at position (1), Companding technique is used, and when the switch at position (2), the Palm Clipping technique is used to reduce the PAPR in the OFDM-DCSK system. In the first, the chaotic sequence is generated using second-order Chebychev Polynomial Function (CPF), which is given $x_{k+1} = 1 - 2x_k^2$ so that the k-th reference sequence is defined as X_k= $[X_{k,0}, X_{k,1}, \dots \dots \dots \dots, X_{k,\beta-1}]$ where β is the spreading factor. The mean value for the generated sequence is zero and mean square value is unity, E $[X_k]$ = 0 and E $[X_k^2]$ = 1. The k-th data sequence, b_k =$[b_{k,1}, b_{k,2}, \dots \dots \dots \dots, b_{k,M}]$ $\in \{-1,1\}$, is generated from the parallel mapped stream bits using parallel to serial converter, where M is the length of a data sequence. The parallel data sequence is multiplied by a chaotic reference sequence. Taking IFFT for each p-th vector, β number of IFFT transform is required to complete one symbol, the k-th transmitted OFDM-DCSK signal can be expressed as:

$$s_k(n,p) = \frac{1}{\sqrt{N}}\sum_{m=1}^{M} b_{k,m} X_{k,p} * e^{\left(\frac{j2\pi mn}{N}\right)} + \frac{1}{\sqrt{N}} X_{k,p} \ , \quad 0 \le n < N,\ p = 0,1,..,\beta-1 \qquad (1)$$

where N is the FFT size, N=M+1. The cyclic prefix is not considered as assumed in this work. Before the signal is transmitted over a multipath Rayleigh fading channel, it is processed by either the Palm Clipping function or the Companding function to reduce the PAPR. The k-th received signal is expressed as [5], [24]:

$$r_k(n,p) = \sum_{l=1}^{L} \gamma_l \tilde{s}_k(n-\tau_l, p) + w_k(n,p)\,, \quad 0 \le n < N, p = 0,1,..,\beta-1 \qquad (2)$$

where γ_l and τ_l are the Rayleigh channel coefficient and the corresponding time delay for the l-th path, respectively. L is the number of paths and w_k is the k-th AWGN with zero mean and variance of $N_0/2$. The Rayleigh pdf of γ_l is written as [5]:

$$f_\gamma(v) = \frac{v}{\sigma^2} e^{-\frac{v^2}{2\sigma^2}}\,,\ v > 0 \qquad (3)$$

where σ is the standard deviation of the distribution that is greater than zero. At the receiver, non-coherent detection is used, there is no channel estimation required as in OFDM system and no Radio Frequency (RF) delay required as in DCSK system. The received signal, r_k, either passing through the decompanding function and then converted to parallel sequence when the companding technique is used (the switch at position 1) or directly passing through the serial to parallel converter if the clipping technique is used (the switch at position 2). The k-th parallel sequence, $\tilde{r}_{j,k}$, j=0, 1,.., M, are passed through FFT transform to obtain the OFDM-DCSK demodulated signal at the k-th frame and p-th time as:

$$\tilde{R}_k(m,p) = \frac{1}{\sqrt{N}}\sum_{n=0}^{M} \tilde{r}_k(n,p) * e^{\left(\frac{-j2\pi mn}{N}\right)}$$

$$, m = 0,1,..,M, p = 0,1,..,\beta \qquad (4)$$

The first subcarrier (zero frequency) contains the received reference chaotic sequence, $\tilde{R}_k(0,p)$ and the remaining subcarrier contains the M received information chaotic sequenc-es, $\tilde{R}_k(m,p), m = 1,..,M$. M correlators are produced from these sequences by multiplying the reference chaotic sequence by the m-th information sequence and summing over β period. Then output of the m-th correlator is given by:

$$Q_{k,m} = \sum_{p=0}^{\beta-1} \tilde{R}_k(0,p) * \tilde{R}_k(m,p)\,, m = 1,..,M \quad (5)$$

For the k-th frame, the m-th recovered symbol is obtained by applying a decision threshold to the output correlator $Q_{k,m}$ and then the parallel symbol is converted to serial using parallel to serial converter. Finally, the recovered stream bits are obtained using Demapping function by mapping +1 to 1 and -1 to 0.

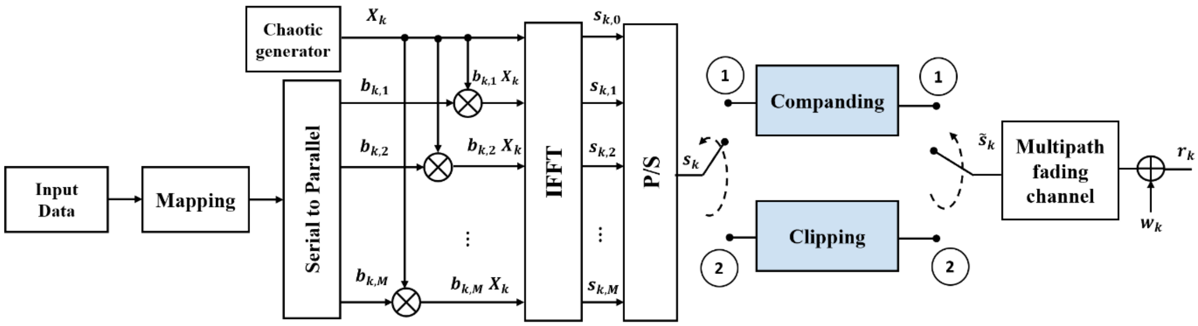

Figure1. OFDM-DCSK transmitter scheme.

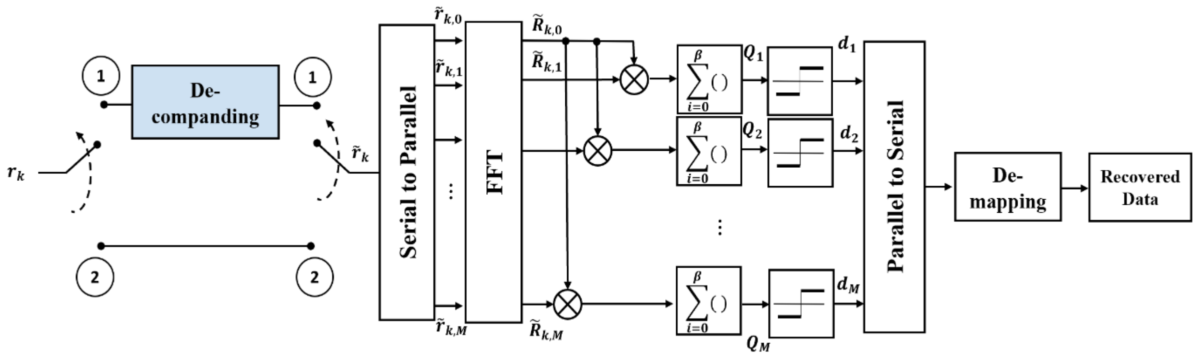

Figure 2. OFDM-DCSK receiver scheme.

1. Clipping and Companding Techniques

The Palm Clipping and nonlinear companding techniques are presented in this section.

3.1. Palm Clipping (PC) Technique

At the end of the transmitter, the PC block is added before transmitting the signal. The function of the Palm Clipping is described below [25]:

$$\tilde{s}(t) = \begin{cases} s(t) & , \ |s(t)| \le A \\ P_B^A\,(|s(t)|) * e^{j\phi(s(t))}, & |s(t)| > A \end{cases} \tag{6}$$

where A is the threshold value and defined to be ($\alpha * \sqrt{P_{mean}}$) and α is considered to be Clipping factor, ϕ is the phase of the input signal s(t), and the function $P_B^A(s(t))$ for a given absolute signal, |s(t)|, is expressed by:

$$P_B^A(|s(t)|) = \frac{A}{\cosh(\frac{|s(t)|-A}{B})} \tag{7}$$

where B is the smoothness factor of the PC function. In this paper, Clipping Ratio (CR) was used to find out the effect of the clipping method, there is a relation between CR, the clipping threshold A, and the average power of the OFDM-DCSK signal as described below:

$$CR = 20\,log_{10}(\frac{A}{\sqrt{P_{mean}}}) \quad [dB] \tag{8}$$

$$CR = 20\,log_{10}\,(\alpha) \quad [dB] \tag{9}$$

where $P_{mean} = E\,\{|x(n)|^2\}$ is the mean power of the chaotic sequence, *x*(n).

3.2. Nonlinear Companding Techniques

Nonlinear companding is a distinct case of clipping structure used to improve PAPR reduction with less degradation in the BER performance. The companding techniques magnify the slight signals while squeezing the great signals to rise the resistance of slight signals from noise and interference. The most PAPR reduction techniques used in OFDM system is the companding technique due to less difficulty and great BER performance. At the end of transmitter, the companding process is performed to attenuate the high amplitudes and magnify the low peaks. The decompanding process is performed at the receiver to detect the original signal. Furthermore, by taking suitable companding parameters, the mean sending power can be preserved unchanged after companding. Several nonlinear companding techniques were used in this paper to reduce the PAPR of OFDM-DCSK system, which are Hyperbolic tangent, Mu-Law and A-Law companding.

A. Hyperbolic Companding

At the end of the transmitter, the companding process is performed, it's given as [26]

$$F(s) = y_1 \tanh (y_2.s) \tag{10}$$

The quality of companding level was adjusted by using the parameters y1 and y2 which must be positive numbers. The decompanding process is performed for the received signal and it's given by

$$F^{-1}(r) = y_1 y_2 \, [\, 1 - \tanh^2(y_2.r)] \tag{11}$$

B. Mu-Law Companding

At the end of the transmitter, the companding function applied is given by [27]

$$F(s) = \mathrm{sgn}\,(s)\, \frac{\ln(1+Mu\,|s|)}{\ln(1+Mu)} \tag{12}$$

The companding level was adjusted by Mu ratio where Mu is the normalization constant. At the receiver, the decompanding function is given by

$$F^{-1}(r) = \mathrm{sgn}\,(r) \left(\frac{1}{Mu}\right) ((1 + \mathrm{Mu})^{|r|} - 1) \tag{13}$$

C. A-Law companding

Finally, the last companding function applied to the end of the transmitter is given by [28,29]

$$F(s) = \mathrm{sgn}(s) \begin{cases} \frac{A\,|s|}{1+ln(A)} & , |s| < \frac{1}{A} \\ \frac{1+ln(A|s|)}{1+ln(A)} & , \frac{1}{A} \le |s| \end{cases} \tag{14}$$

The A ratio is the control parameter of the companding function. The decompanding process performed at the receiver is given by

$$F^{-1}(r) = \mathrm{sgn}(r) \begin{cases} \frac{|r|(1+ln(A))}{A} & , |r| < \frac{1}{1+ln(A)} \\ \frac{exp(|r|(1+ln(A))-1)}{A} & , \frac{1}{1+ln(A)} \le |r| \le 1 \end{cases} \tag{15}$$

Equation (16) was used to calculate the PAPR before and after performing the clipping or companding techniques.

$$PAPR = \frac{Max\,(|s(n)|^2)}{E\{|s(n)|^2\}} \quad \text{when } 0 < n < N-1 \tag{16}$$

A Complementary Cumulative Distribution Function (CCDF) is described the PAPR, which is the probability that PAPR reaches the threshold value and it defines as below:

$$CCDF(PAPR_0) = Pr(PAPR \ge PAPR_0) \tag{17}$$

The threshold value is defined in the equation as $PAPR_0$.

The loss in SNR, SNR_{loss} and PAPR enhancement factor, $PAPAR_{EF}$ can be expressed respectively as:

$$SNR_{loss} = SNR_{new} - SNR_{original} \tag{18}$$

$$PAPR_{EF} = PAPR_{original} - PAPR_{new} \tag{19}$$

4. Performance Evaluation

To evaluate the performance of the Palm Clipping method that depicted in the Fig.3, we build the Matlab model of the system over multipath Rayleigh fading channel, the number of subcarriers N is set to 256, the number of generated symbols is 5000, the clipping ratios CR in dB are 1,2,34,5,6,7, the spreading factor β is 125, and the smoothing factor B is 200. Two paths Rayleigh fading channel, L=2, are used with delays, τ_l=0 and $\tau_2 = 2T_c$ and average power gain, $E[a_1^2] = \frac{2}{3}$ and $[a_2^2] = \frac{1}{3}$.

Firstly, the PAPR performances are studied by changing the CR values while setting the SNR value to 10 dB. In the second, the BER is evaluated with the same condition, but for variant SNR values. Fig.4 describes the gain in term of PAPR at CCDF = 10^{-3} & 10^{-2} for different clipping ratio values. It was noticed that when the CR value decreases, we got better PAPR gain.

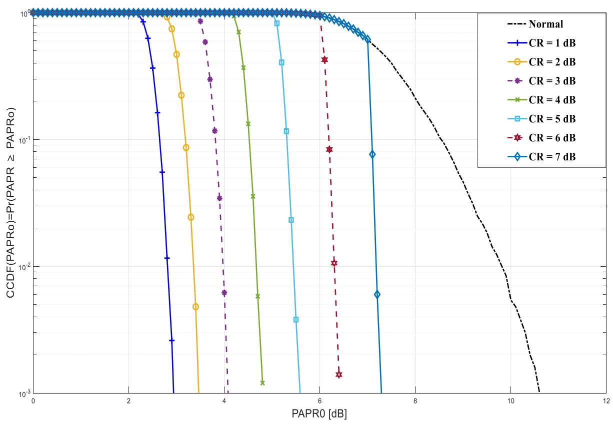

Figure 3. The CCDF of PC OFDM-DCSK for various Clipping Ratio Values, N=256 and β=125.

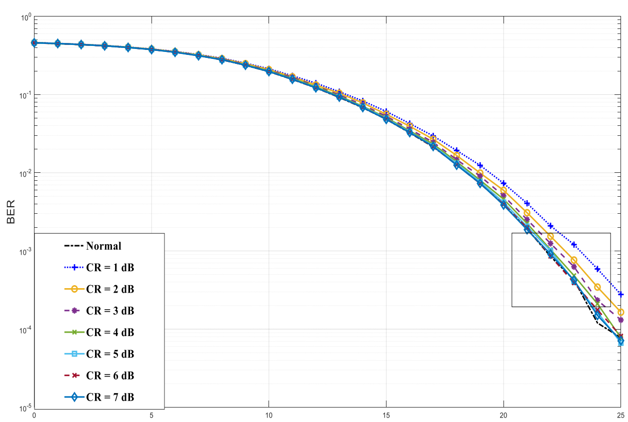

Figure 4. (a) BER performance Comparison of PC OFDM-DCSK for different Clipping Ratio values, N=256 and β=125.

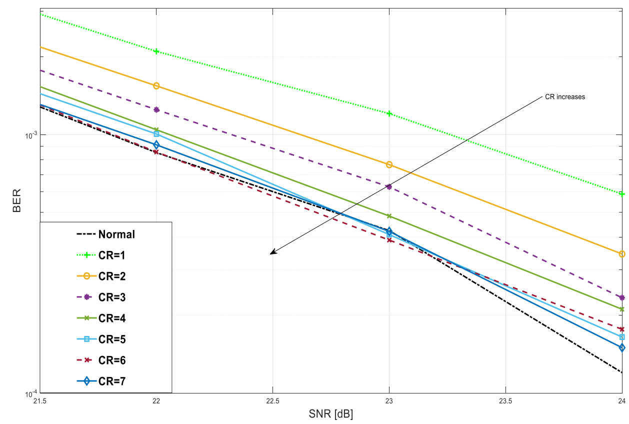

Figure 4. (b) BER performance Comparison of PC OFDM-DCSK for different Clipping Ratio values, N=256.

The main parameter affecting the PAPR reduction of the OFDM-DCSK system is the number of subcarriers, its noticeable that increasing the number of subcarriers leads to increase the PAPR. In our work, the effect of companding techniques on the PAPR of OFDM-DCSK system is studied. Fig.5 shows the CCDF as a function of the PAPR of OFDM-DCSK system for Mu-Law companding, A-Law companding, Hyperbolic, and Palm Clipping (CR=5dB) techniques with number of subcarriers is equal to 256, it can be observed that at CCDF=10^{-3} & 10^{-2}, we got better PAPR reduction which is approximately 6.92 dB and 6.1 dB respectively by using Mu-Law companding technique.

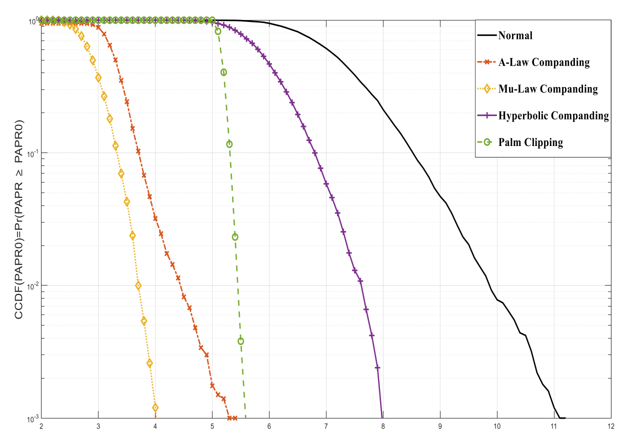

Figure 5. The CCDF PAPR performance Comparison for all the tried techniques, N=256 and β=125.

Fig.6 illustrates the CCDF performance versus $PAPR_0$ of OFDM-DCSK system for Mu-Law companding, A-Law companding, Hyperbolic companding, and Palm Clipping (CR=5dB) techniques with number of subcarriers is equal to approximately 7.22 dB and 6.32 dB respectively512, it can be observed that at CCDF=10^{-3}&10^{-2}, we got better PAPR reduction which is by using Mu-Law companding technique.

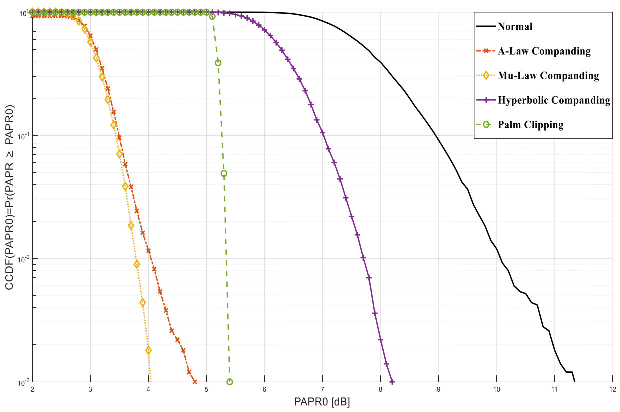

Figure 6. CCDF PAPR performance Comparison for all the tried technique, N=512 and β=125.

Fig.7 and Fig.8 show the simulated BER performance for OFDM-DCSK system with the all techniques mentioned previously for number of subcarriers are equal to 256 and 512 respectively, it's obvious from this figure that A-Law technique presents the best performance when the A parameter is set to 13, At a BER=10^{-3} which is suitable BER for the quality of service, the loss of the signal to noise ratio is 0.095 dB when the number of subcarriers is equal to 256 and 0.14 when the number of subcarriers is 512.

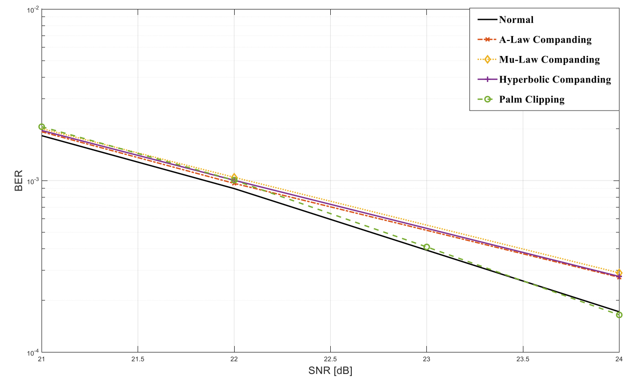

Figure 7. (b) BER Performance Comparisons for the tried techniques, N=256 and β=125.

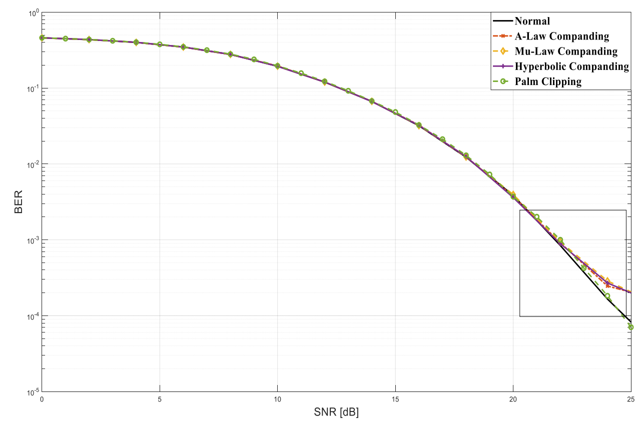

Fig.8 (a) BER Performance Comparisons for the tried techniques, N=512 and β=125.

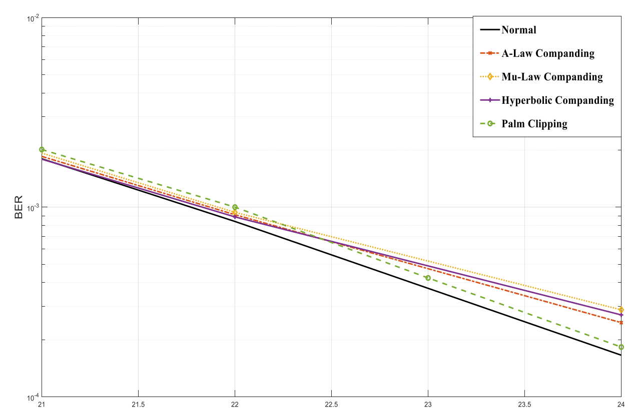

Figure 8. (b) BER Performance Comparisons for the tried techniques, N=512 and β=125.

Finally, the results of the performance evaluation are listed for all the techniques that were used in our work in Tables 1 and 2 for N=256 and 512, respectively. The included results are obtained for different number of N with changing the spreading factor (β).

Methods	SNR_{loss} (dB) at BER=10^{-3}		$PAPR_{EF}$ (dB) at CCDF=10^{-2}		$PAPR_{EF}$ (dB) at CCDF=10^{-3}	
	β=75	β=125	β=75	β=125	β=75	β=125
Mu-Law	0.2	0.14	6.45	6.32	7.07	7.22
A-Law	0.25	0.14	4.85	6.03	4.8	6.55
Hyperbolic	0.24	0.15	2.37	2.4	2.66	3.1
Palm Clipping	0.12	0.25	6.48	4.7	7.07	5.5

Methods	SNR_{loss} (dB) at BER=10^{-3}		$PAPR_{EF}$ (dB) at CCDF=10^{-2}		$PAPR_{EF}$ (dB) at CCDF=10^{-3}	
	β=75	β=125	β=75	β=125	β=75	β=125
Mu-Law	0.2	0.16	6.3	6.1	7	`6.92
A-Law	0.27	0.095	5.27	6.08	5.4	6.5
Hyperbolic	0.27	0.16	2.3	2.22	3.05	2.68
Palm Clipping	0.19	0.2	4.46	4.35	5.35	5.02

Methods	$PAPR_{EF}$ (dB) at CCDF=10^{-2}	$PAPR_{EF}$ (dB) at CCDF=10^{-3}
	β=64	β=64
Mu-Law	**6.35**	**6.95**
Merit factor, C=2	**1.05**	**2**
Merit factor, C=8	**3**	**4.45**

According to the results presented in the tables, we got better PAPR reduction values when the number of subcarriers is increased, it's obvious that Mu-Law technique gives 7.22 dB $PAPR_{EF}$ when number of subcarriers is equal to 512, the spreading factor is equal to 125 at CCDF=10^{-3} while the SNR_{loss} value is 0.14 dB. Table 3 presented the comparison with Merit factor technique [30] in terms of PAPR reduction where c represents the number of candidates.

5. Conclusion

In this paper, the comapanding and clipping techniques were performed to overcome the issue of high PAPR which affects the efficiency of Power Amplifier. PARR reduction was done by involving clipping or companding blocks to the OFDM-DCSK system before transmitting the signal over multipath Rayleigh fading channel, the inverse function was used at the receiver in case of companding techniques. The simulation results were obtained by performing Matlab program depict that the PAPR reduction value is gotten better on the account of BER. Mu-Law techniques gives the best results from the other tried techniques in terms of PAPR reduction and BER performance.

Conflict of interest

The publication of this article cause no conflict of interest.

6. References

1. F. C. M. Lau and C. K. Tse (2003). “Chaos-Based Digital Communication Systems”. New York, NY, USA: Springer.

2. H. Dedieu, M. P. Kennedy, and M. Hasler (1993). Chaos shift keying: Modulation and demodulation of a chaotic carrier using self-synchronizing Chua’s circuits. IEEE Trans. Circuits Syst. II, Analog Digit. Signal Process., Vol. 40, No. 10, pp. 634–642.

3. G. Kolumbän, B. Vizväri, W. Schwarz, and A. Abel (1996). Differential chaos shift keying: A robust coding for chaos communication. In Proc.NDES96, pp. 87–92.

4. Y. Fang, G. Han, P. Chen, F. C. M. Lau, G. Chen, and L. Wang (2016). A survey on DCSK-based communication systems and their application to UWB scenarios. Commun. Surveys Tuts., Vol. 18, No. 3, pp. 1804–1837.

5. G. Kaddoum, F. D. Richardson, and F. Gagnon (2013). Design and analysis of a multi-carrier differential chaos shift keying communication system. IEEE Trans. Commun., Vol. 61, No. 8, pp. 3281–3291.

6. T. Huang, L. Wang, W. Xu, and F. G. Chen (2017). A multi-carrier M-ary differential chaos shift keying system with low PAPR. IEEE Access, Vol. 5, pp. 18 793–18 803.

7. G. Kaddoum (2016). Design and performance analysis of a multiuser OFDM based differential chaos shift keying communication system. IEEE Trans. Commun., Vol. 64, No. 1, pp. 249–260.

8. S. Li, Y. Zhao, and Z. Wu (2015). Design and analysis of an OFDM based differential chaos shift keying communication system. Journal of Communications, Vol. 10, No. 3, pp. 199–205.

9. G. Cai, Y. Fan, G. Han, F. C. M. Lau, and L. Wang (2016). A square constellation-based M-Ary DCSK communication system. IEEE Access, Vol. 4, pp. 6295–6303.

10. H. Ryu, J. Lee, and J. Park (2004). Dummy sequence insertion (DSI) for PAPR reduction in the OFDM communication system. Vol. 50, pp. 89-94.

11. Li, X.; Cimini, L.J. (1998). Effects of clipping and filtering on the performance of OFDM. IEEE Commun. Lett., Vol. 2, pp. 131–133.

12. Boonsrimuang, P., Puttawong, E., Kobayashi, H., Paungma, T. (2003).

Reduction Using Smooth Clipping in OFDM System. In Proceedings of the 3rd Information and Computer Engineering PostgraduateWorkshop (ICEP 2003), Songkhla, Thailand, pp. 158–161.

13. [13] Qian, H., Raich, R., Zhou, G.T. (2004). “On the benefits of deliberately introduced baseband nonlinearities in communication systems”. In Proceedings of the ICASSP IEEE International Conference on Acoustics, Speech and Signal Processing, Montreal, QC, Canada, Vol. 2, pp. 905-908.

14. Kimura, S., Nakamura, T. (2008). “Saito, M.; Okada, M. PAPR reduction for OFDM signals based on deep clipping”. In Proceedings of the 3rd International Symposium on Communications, Control and Signal Processing,St. Julian’s, Malta, pp. 911–916.

15. Prasad, S., Jayabalan, R. (2020). PAPR Reduction in OFDM Systems Using Modified SLM with Different Phase Sequences. Wirel. Pers. Commun. 110, pp. 913–929.

16. Bäuml, R.W., Fischer, R.F.H., Huber, J.B. (1996). Reducing the peak-to-average power ratio of multicarrier modulation by selected mapping. Electron. Lett., Vol. 32, No. 22, pp. 2056–2057.

17. Shakeel, I., Grant, A. (2006). Joint Error Correction and PAPR Reduction of OFDM Signals. In Proceedings of the 2006 IEEE Information TheoryWorkshop—ITW’06, Punta del Este, Uruguay, pp. 611–615.

18. Sharma, A., Salim, M. Polar Code (2017). “The Channel Code contender for 5G scenarios”. In Proceedings of the 2017 International Conference on Computer, Communications and Electronics (Comptelix), pp. 676–682.

19. Bakkas, B., Chana, I., Ben-Azza, H. (2019). “PAPR reduction in MIMO-OFDM based on polar codes and companding technique”. In Proceedings of the 2019 International Conference on Advanced Communication Technologies and Networking, CommNet 2019, Rabat, Morocco.

20. Jangalwa, M., Tokekar, V. (2019). Performance analysis of Selective Mapping and clipping based multicarrier-CDMA system with and without MIMO technique. AEU Int. J. Electron. Commun., Vol. 101, pp. 62–68.

21. Tang, B., Qin, K., Chen, C., Cao, Y. (2020). A Novel Clipping-Based Method to Reduce Peak-to-Average Power Ratio of OFDM Signals. Information, Vol. 11, No. 2, pp. 113.

22. Lain, J.-K., Wu, S.-Y., Yang, P.-H. (2011). PAPR reduction of OFDM signals using PTS: A real-valued genetic approach. EURASIP J. Wirel. Commun. Netw. 2011, pp. 126.

23. Kim, M., Lee, W., Cho, D.H. (2018). A novel PAPR reduction scheme for OFDM system based on deep learning.IEEE Commun. Lett., Vol. 22, pp. 510–513.

24. Fadel S.H., Alejandro A.V. (2018). Design and Analysis of an OFDM-based Orthogonal Chaotic Vector Shift Keying Communication System. IEEE Access, Vol. 6, pp. 46322–46333.

25. B. Bakkas, R. Benkhouya, I. Chana, and H. Ben-Azza (2020). Palm date leaf clipping: A new method to reduce PAPR in OFDM systems. Inf., Vol. 11, No. 4.

26. D. Lowe, X. Huang (2007). “Optimal adaptive hyperbolic companding for OFDM”. in: Proc. 2nd International Conference on Wireless Broadband and Ultra-Wideband Communications, pp. 24–24.

27. N. Varghese, J. Chunkath, V.S. Sheeba, (2014). “Peak-to-average power ratio reduction in FBMC-OQAM system”. in: 2014 Fourth International Conference on Advances in Computing and Communications, pp. 286–290.

28. N. Raju, S.S. Pillai (2015). “Companding and pulse shaping technique for papr reduction in FBMC systems”. in: 2015 International Conference on Control,Instrumentation, Communication and Computational Technologies,ICCICCT, Kumaracoil, pp. 89–93.

29. Imad A. Shaheen, Abdelhalim Zekry, Fatma Newagy, Reem Ibrahim (2017). Proposed new schemes to reduce PAPR for STBC MIMO FBMC systems. Commun. Appl. Electron. Vol. 6, No. 9, pp. 27–33.

30. M. Mobini, M.R. Zahabi (2019). A Low Complexity PAPR Reduction Architecture for OFDM-DSCK Communication System. Wireless Pers. Commun. Vol. 107, No. 4, pp. 1759–1776.