Improved Clipping Technique for Reducing the Peak to Average Power Ratio in OFDM Systems

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Abstract— Peak to Average Power Ratio (PAPR) is one of the disadvantages of OFDM system, which had been studied in several papers and reduced in several techniques. Clipping and filtering are an effective technique for reducing the PAPR in OFDM systems. It requires an accurate filtering to reduce the resulting in-band and out-of-band noise. In this paper, an improved clipping technique is proposed. The technique calculates the error signal between the original and clipped signals and then feeds it back to the data symbols input. The technique uses a weighting process to the error signal to minimize the effect of in-band distortion. Our technique aims to clip the OFDM symbol to some threshold that is calculated by assuming a clipping ratio of 1 and measuring the Root Mean Square value (RMS) of the signal. The result from the difference between the original and the clipped signal can be added to the frequency domain OFDM (input to the IFFT) with zero padding the high frequency subcarriers to reduce the side loops power (out-of-band radiation). This results in decreasing Adjacent Channel Interference (ACI) that may affect the neighboring systems. In addition, some weight is added to the inserted in-band signal to the desired data subcarriers to reduce the amount of interference and decrease the resulted BER. The PAPR is calculated for the time domain OFDM symbol using MATLAB/SIMULINK simulation which compares the proposed technique to the clipping and filtering technique. By using a weighting factor of 0.8, the proposed technique reduces the PAPR by more than 4dB with maintaining a good BER performance of 3.6x10-5 at SNR=9dB.

Keywords— Clipping, Filtering, In-band distortion, OFDM, PAPR, Out-of-band radiation.

I. INTRODUCTION

Orthogonal Frequency Division Multiplexing (OFDM) is a multicarrier modulation technique that divides the available band width (BW) into a number of equally spaced frequency bands called sub-carriers. Its basic principle is to split the high data rate stream into lower data rate streams, which are used to modulate the available orthogonal frequency sub-carriers, hence the name "OFDM" [1], [2]. The division of the available BW into orthogonal sub-carriers by OFDM technique transforms the wideband channel with frequency selective fading characteristics into narrowband channels with flat fading characteristics. Using orthogonal flat fading sub-carriers OFDM obtains high spectral efficiency [3].

The OFDM scheme is based on the theory of Fourier Transform where sub-carriers in the frequency domain are modulated using an IFFT process producing the OFDM signal in the time domain [3]-[5]. The "OFDM symbol" represents the output of the IFFT process, which represents the time domain version of the OFDM signal with time duration of (T_u) and given by the following:

$$s(t)=\frac{1}{N}\sum_{k=-N/2}^{N/2-1} S_k e^{j2\pi k f_{sc} t} p(t) \qquad (1)$$

where $p(t)=rect\left(\frac{t-T_u/2}{T_u}\right)$

The output of the IFFT is an N samples of the time domain OFDM symbol, which is given by:

$$s[n]=\frac{1}{N}\sum_{k=-N/2}^{N/2-1} S_k e^{j2\pi kn/N} p[n] \qquad n=0:N-1$$
$$\text{where} \quad p[n]=rect\left(\frac{n-N/2}{N}\right) \tag{2}$$

Multicarrier networks, such as FDM, were used by military systems in the late 1950's [6], [7]. In December 1966, Robert W. Chang [8] presented a way to transmit messages simultaneously through a linear band limited channel without an inter symbol interference (ISI). Around the same time, Saltzberg performed an analysis of OFDM system [9].

In 1971, Weinstein and Ebert proposed a modified OFDM system [10] which used the Discrete Fourier Transform (DFT) to perform baseband modulation and demodulation. In 1980, Peled and Ruiz [11] introduced the cyclic prefix to overcome the multipath effect and conserve the orthogonality between sub-carriers. Late and at the same year, the work began on the development of OFDM for commercial use with the introduction of the Digital Audio Broadcasting (DAB) system [12]. In 1985, Cimini [13] presented analytical and simulation results on the performance of OFDM modems in mobile communication channels.

OFDM was adopted as the physical layer for several wireless local area network (WLAN) standard, such as HiperLAN/2 in Europe and the (IEEE 802.11a, g) standards in the United States [14]. OFDM has been identified as the leading contender for the physical layer of the fourth generation (4G) wireless services [15].

One of the major drawbacks of OFDM technique is the occasionally occurring large PAPR in the time domain signal due to a large number of subcarriers with varying amplitude. The high PAPR means producing large peaks of the OFDM signal that leads to intermodulation products among the subcarriers and disturbing out-of-band energy [16]-[18]. Therefore, it is desirable to reduce the PAPR of an OFDM symbol, which is given by the following:

$$PAPR(s)=\frac{\max|s(t)|^2}{\mathrm{E}\left\{|s(t)|^2\right\}}$$
$$PAPR_{dB}=\max_{dB}-\mathrm{mean}_{dB} \tag{3}$$
$$PAPR_{dB}=10\log_{10}\left(\max|s(t)|^2\right)-10\log_{10}\left(\mathrm{E}\left\{|s(t)|^2\right\}\right)$$

Where $\mathrm{E}\{\cdot\}$ refers to Expectation operator that results in the mean or average value. Several PAPR reduction techniques have been proposed such as Signal Scrambling Techniques and Signal Distortion Techniques, which will be discussed in the following sections.

A. Signal Scrambling Techniques

They are based on scrambling each symbol in OFDM signal with diverse scrambling distributions and selecting the sequence which gives the smallest PAPR [19]. These techniques are implemented before generating OFDM signals (before the IFFT stage at transmitter side) like the Coding Technique [18], Selective Mapping (SLM) [20] and Partial Transmit Sequence (PTS) [21].

B. Signal Distortion Techniques

These techniques reduce the PAPR by distorting the non-linear transmitted OFDM signal before it passes through the PA (after the IFFT stage). The well-known distortion techniques shown in [18] include Peak Windowing [22], Companding Techniques [23] and Clipping and Filtering [24].

II. AN OVERVIEW OF CLIPPING AND FILTERING TECHNIQUES

The simplest method among the PAPR reduction methods mentioned above is clipping and filtering where a threshold value of fixed amplitude is considered for determining the maximum value of envelope. This is done with the aid of a clipper that limits the signal envelop to the threshold level if the signal goes beyond this level; otherwise, a clipper signal remains without change and passes through it [15], [24]. Clipping technique is presented as follows:

$$s_C[n] = \begin{cases} s[n] & |s[n]| \le A \\ Ae^{j\phi_n} & |s[n]| > A \end{cases} \tag{4}$$

where $s_c[n]$ is the clipped OFDM signal; (A) is the maximum permissible amplitude (threshold level) over which the signal is clipped; and (ϕ_n) is the angle of the clipped sample. In research analysis, a clipping Ratio (CR) is defined instead of (A), which is given as follows:

$$CR = \frac{A}{\sigma}, \quad \sigma = \sqrt{\frac{1}{N}\sum_{n=1}^{N} s^2[n]} \tag{5}$$

where (σ) is the root mean squared value (RMS) of the OFDM signal $s[n]$ [25], [26].

When OFDM signals are clipped, in-band distortion and out-of-band radiation will be introduced into the communication [25].

The out-of-band radiation, which is generated by clipping, causes spectral spreading, which is eliminated by subsequent filtering operation. Furthermore, in–band distortion degrades the BER performance which is suppressed by employing a coding technique and/or clipping noise cancellation methods [27].

Reference [28] suggested recursive clipping with a filtering scheme that achieves significant PAPR reduction while carrying the distortion of the data on the subcarriers passing through HPA under control. This method used four recursion times under an Additive White Gaussian Noise (AWGN) channel.

In [24] and [29], authors proposed another scheme based on their previous consideration for clipping and filtering methods. A composed filter (FIR based HPF) is used to filter the clipped signal before passing a LPF to reduce out-of-band radiation. This causes improvement in the BER performance with medium amount of PAPR reduction.

The filtering operation contributes to peak regrowth problems, which can be suppressed using iterative clipping and filtering (ICF) techniques. However, each iteration requires two FFT/IFFT operations; furthermore, one additional IFFT operation is needed to convert the clipped OFDM symbol to time domain. Therefore, an ICF technique with K iterations demands ($2K$+1) IFFT operations. An increase in the number of iterations increases computational complexity [30].

Reference [31] proposed a new clipping and filtering approach which is based on cancellation of clipping noise to overcome the drawback of PAPR in OFDM. Our proposed technique maintains the BER performance by using a weighting factor (δ) to the in-band distortion signal and eliminating the out-of-band radiation by zero padding.

III. AN IMPROVED CLIPPING TECHNIQUE

Our proposed technique is based on calculating the clipping noise and converting it to the frequency domain. The portion of the resulted error function is added to the desired OFDM data sub-carriers with some weighting to enhance the BER performance of the system neglecting the zero padded sub-carriers. This reduces the number of IFFT operations used in other clipping techniques and even less than the number of IFFT operations in PTS technique. This technique is illustrated in Fig. 1 and stated as follows:

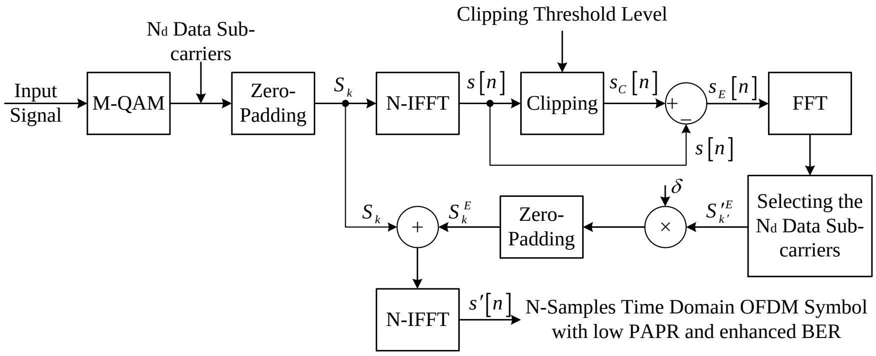

Fig. 1. Improved clipping technique for PAPR reduction

1. The input binary data signal is mapped to (N_d) data sub-carriers by means of an M-QAM mapper (modulator) and zero padded to the closest N=2^m greater than (N_d), making sure that an oversampling process is performed for more resolution of the OFDM symbol in the time domain and more guard band around the OFDM spectrum.
2. The (S_k) symbols modulate the OFDM sub-carriers using the IFFT process; the output of the IFFT is the OFDM discrete signal $s[n]$.
3. OFDM discrete signal $s[n]$ is clipped using the process shown in Fig. 2; the output of this process is the clipped signal $s_c[n]$.
4. The clipping process shown in Fig. 2 starts by measuring the Root Mean Square (RMS) value of the desired signal multiplied by the Clipping Ratio (CR) to determine the clipping threshold level (A).
5. A comparison between the magnitude of the desired signal and (A) results in true (represented by 1) and false (represented by 0) signals denoted by b_{Keep} and b_{Clip}.

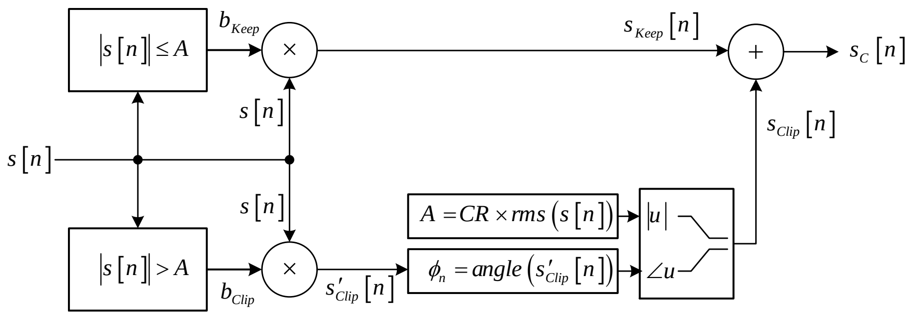

Fig. 2. Clipping of the OFDM symbols for a threshold of the RMS value of the OFDM signal

6. The desired signal is multiplied by the b_{Keep} signal to produce $s_{Keep}[n]$ that represents the samples of the desired signal whose magnitudes are less than or equal to the clipping threshold level. The other samples in this stream are multiplied by zero and clipped in the other stream. The $s_{Keep}[n]$ signal is illustrated in Fig. 3a as follows:

$$s_{Keep}[n]=\begin{cases} s[n] & |s[n]|\le A \\ 0 & \text{elsewhere} \end{cases} \tag{6}$$

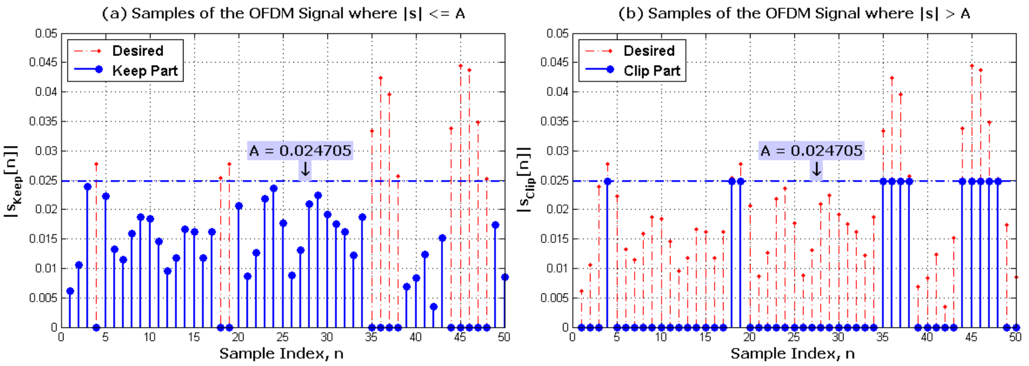

Fig. 3. OFDM symbol parts where the clipping process takes place

7. In the other stream, the desired signal is multiplied by the b_{Clip} signal to produce $s_{Clip}[n]$ that represents the samples of the desired signal whose magnitudes are higher than the clipping threshold level and replaced by complex numbers. The threshold level (A) and phases (ϕ_n) are equal to the desired signal phases of these samples at the same sampling time. The rest of the samples in this stream are multiplied by zero, where the unclipped samples are presented. The $s_{Clip}[n]$ signal is illustrated in Fig. 3b and given as follows:

$$s_{Clip}[n]=\begin{cases} 0 & \text{elsewhere} \\ Ae^{j\phi_n} & |s[n]|>A \end{cases} \tag{7}$$

8. The $s_{Keep}[n]$ and $s_{Clip}[n]$ samples are added together, where the Keep samples are added to the zeros of the Clip samples and vice versa. The $s_C[n]$ signal is illustrated in Fig. 4a and given as follows:

$$\begin{aligned} s_C[n]&=s_{Keep}[n]+s_{Clip}[n] \\ s_C[n]&=\begin{cases} s[n] & |s[n]|\le A \\ 0 & \text{elsewhere} \end{cases}+\begin{cases} 0 & \text{elsewhere} \\ Ae^{j\phi_n} & |s[n]|>A \end{cases} \\ s_C[n]&=\begin{cases} s[n] & |s[n]|\le A \\ Ae^{j\phi_n} & |s[n]|>A \end{cases} \end{aligned} \tag{8}$$

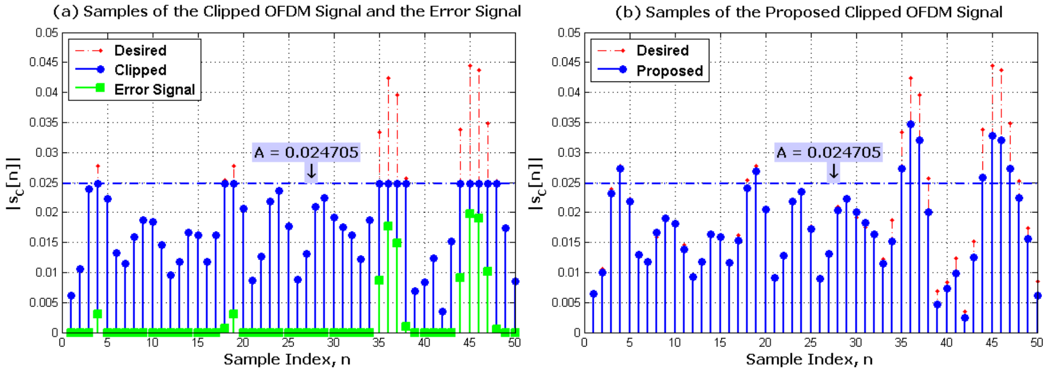

Fig. 4. OFDM symbol parts for clipped and proposed techniques

9. An error signal is calculated from the difference between the original signal and the clipped one. The clipping error signal $s_E[n]=s_C[n]-s[n]$ is illustrated in Fig. 4a and given as follows:

$$s_E[n]=s_C[n]-s[n]=\begin{cases} s[n] & |s[n]|\le A \\ Ae^{j\phi_n} & |s[n]|>A \end{cases}-s[n]$$
$$s_E[n]=\begin{cases} 0 & |s[n]|\le A \\ Ae^{j\phi_n}-s[n] & |s[n]|>A \end{cases} \tag{9}$$

10. The error signal $s_E[n]$ is transformed to the frequency domain by the FFT process. After FFT transformation, the (N_d) desired sub-carriers are selected. The out-of-band radiation is neglected in the error signal producing $(S_{k'}^{\prime E})$, which is given as follows:

$$S_{k'}^{\prime E}=FFT\{s_E[n]\} \qquad k'=-\frac{N_d}{2}:\frac{N_d}{2}-1 \tag{10}$$

11. These sub-carriers are weighted by some levels (δ) to control the BER performance of the signal. They are also zero padded to obtain the (N) number of sub-carriers producing the error signal(S_k^E). This zero padding is used to eliminate the influence of sub-carriers at the guard band protecting the other systems from an ACI.

$$S_k^E=\delta\times S_{k'}^{\prime E}+Zero\ Padding \tag{11}$$

12. The resulted zero padded (S_k^E) symbols are added to the desired (original) (S_k) symbols and then transformed to the time domain OFDM signal by an IFFT process. The generated OFDM signal,$(s'[n])$, is the improved signal for enhancing low PAPR and better BER performance. The resulted signal is illustrated in Fig. 4b and given as follows:

$$s'[n]=IFFT\{S_k+S_k^E\} \tag{12}$$

IV. Simulation and Numerical Results

The proposed PAPR reduction technique that is discussed in the previous section is assessed using a MATLAB/SIMULINK simulation. The OFDM system parameters and their values that are used for the performance assessment under the effect of AWGN channel are presented in Table 1.

TABLE 1
OFDM SYSTEM PARAMETERS

Description	Value
Modulation Type	$M = 4\ (QPSK)$
Cyclic Prefix	$T_g \geq \tau_{\max} = 4\ \mu s$
Bandwidth	$BW = 20\ MHz$
OFDM Symbol Useful Time Duration	$T = 4 \times T_g = 16\ \mu s$
Sub-Carrier Frequency	$f_{sc} = \frac{1}{T} = 62.5\ kHz$
Number of Data Sub-Carriers	$N_d = \frac{BW}{f_{sc}} = 320$
FFT Size	$N = 1024$

MATLAB/SIMULINK simulation results are presented in Bit Error Rate (*BER*) as a function of Signal to Noise Ratio (*SNR*) and different values of weighting factors (δ), which are the most common plot to measure the performance of the communication system [32]. BER is the ratio of the number of bits received in error to the total number of bits, which is given by:

$$BER = \frac{Bits\ in\ Error}{Total\ Number\ of\ Bits} \tag{13}$$

Multipath propagation channel as a transmission media for digital transmission is one of the major sources of errors that increase the BER in addition to the AWGN channel. Attenuation due to path loss, multipath effect (Delay Spread) and Doppler Spread (Frequency Shift) are the major effects of the propagation channel on the transmitted signal [33], [34]. In this paper, the assessment of BER is performed under the conditions of AWGN channel.

Clipping the OFDM signal introduces an in-band and out-of-band distortion that leads to BER performance degradation [25], [29]. In addition to the reduction of the PAPR, the BER performance of the system is maintained by a weighting factor (δ) applied to the in-band portion of the signal added to the desired OFDM signal, which is introduced to manage a balance between reducing the PAPR and obtaining good BER performance.

The BER performance evaluation of the OFDM system without optimizing the in-band distortion added to the desired signal is illustrated in **Error! Reference source not found.**a. This is by using unity weighting factor $(\delta = 1)$, and assuming a unity clipping ratio (*CR*=1) where the clipping threshold level equals to the RMS value of the OFDM signal.

For a signal to noise ratio of (*SNR*=9dB), the desired signal obtained a bit error rate of $(BER = 1.5 \times 10^{-7})$, where the other signals have approximately $(BER = 2 \times 10^{-4})$ due to the in-band distortion added to the desired signal.

Table 2 shows the values of the BER and PAPR before using the proposed technique.

TABLE 2
PAPR REDUCTION AND BER PERFORMANCE

	PARP	*PARP* Reduction	*BER* @ *SNR*=9dB	*SNR* @ *BER*=$2\text{x}10^{-4}$
Desired	12.31dB	0 dB	$1.6\text{x}10^{-7}$	6dB
Clipped	2.31dB	10dB	$2.3\text{x}10^{-4}$	9dB
Clipped and Filtered	4.1dB	8.21dB	$2\text{x}10^{-4}$	9dB
Proposed @ δ= 1	6dB	6.31dB	$2.1\text{x}10^{-4}$	9dB

This is clearly shown in Fig. 5b that illustrates the BER as a function of the weighting factor (δ), where the BER performance decreases with decreasing (δ). For low (δ) values, $(\delta \leq 0.2)$, the BER performance of the proposed technique approaches that of the BER performance of the desired signal. This is a result of decreasing the in-band distortion. The system recovers the data with errors similar to that of those desired signal.

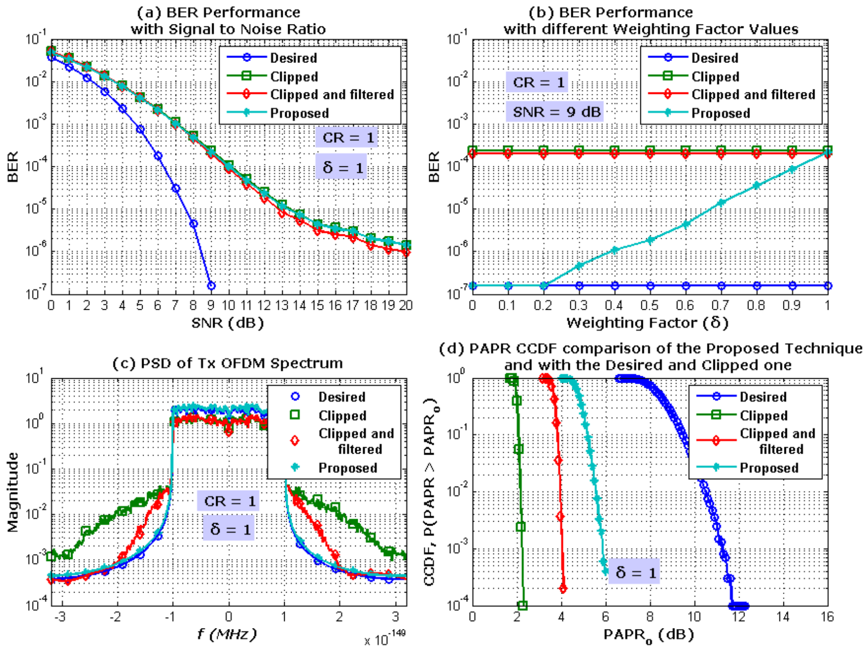

Fig. 5. *BER* performance evaluation and PSD illustration without optimizing the error signal

Fig. 5c shows the PSD of the transmitted OFDM signal. A Power Spectral Density (PSD) plot is introduced to illustrate the out-of-band radiation due to the different assessment parameters used in this paper for both unclipped and clipped OFDM signals.

The clipped signal shows higher side loops power due to the out-of-band radiation resulting from clipping the OFDM signal. Using low pass filter (LPF) at the base band (BB) decreases the out-of-band radiation, and the adjacent channel interference (ACI) which affects other systems. In the proposed technique, side loops are replaced by zero sub-carriers; and the desired data subcarriers are selected with weighting values to optimize the BER and the PAPR reduction.

Fig. 5d illustrates the CCDF as a function of a threshold value ($PARP_0$). Complementary Cumulative Distribution Function (CCDF) is one of the most frequently used PAPR reduction techniques. It is a better approximation of PAPR reduction performance in OFDM system, which denotes the probability that the PAPR of a data block exceeds a given threshold (z). The CCDF of the PAPR of a data block of N symbols with Nyquist rate sampling is given by:

$$P\left(PAPR > z\right) = 1 - P\left(PAPR \leq z\right) = 1 - \left(1 - e^{-z}\right)^{N} \quad (14)$$

Fig. 5d compares the PAPR reduction (Table 2) between the original ODFM signal and the clipped version, clipping and filtering version and the proposed technique at the same weighting factor of unity (δ=1). The difference of PAPR reduction between the clipping techniques and our proposed technique is due to eliminating the out-of-band radiation of the error signal, which influences the reduction of the PAPR as a result of the clipping technique.

Fig. 6 shows the behaviour of the system for unity CR and different values of the weighting factor (δ). The unity value of CR results in a constant performance for the unclipped signal, while the proposed clipping technique shows a better performance for different values of (δ).
Fig. 6a shows improvement on the BER performance as the weighting factor (δ) decreases because of the amount of error signal $\left(S_k^E\right)$ added to the in-band of the desired signal at the frequency domain side.
In Fig. 6b, the PAPR improved as the weighting factor (δ) increased. The PAPR approaches that of the clipped and filtered one when (δ=1), which returns $\left(S_k^E\right)$ to the original values, resulted from the clipping process.

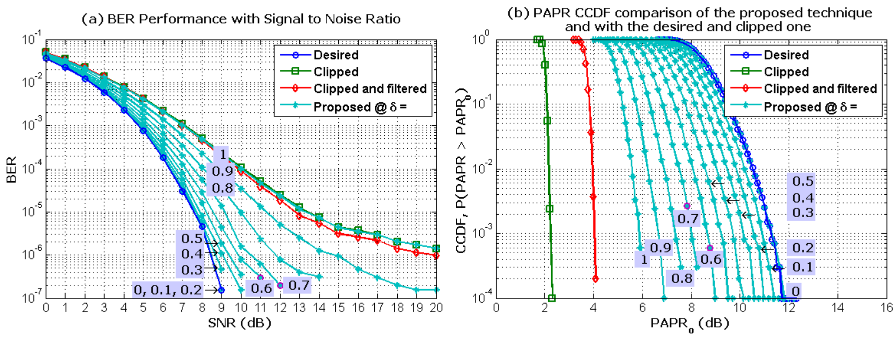

Fig. 6. BER performance for unity CR and changing the weighting factor δ

The PAPR reduction due to clipping is better than that of the clipping and filtering technique for the adjustment of the out-of-band radiation by the LPF. The same reason is considered by the proposed technique since the out-of-band radiation is ignored completely.
For optimization between PAPR reduction and good BER performance, the weighting factor (δ) should be $(\delta \geq 0.6)$ for better PAPR reduction as shown in Fig. 6b and for a better BER performance when $(\delta \leq 0.8)$ as shown in Fig. 6a. The results shown in Fig. 6b are emphasized in Fig. 7 which illustrates the probability density function of the OFDM signal power before and after PAPR reduction techniques.
The PAPR in dB is the difference between the maximum and average power values obtained from the output of the IFFT process as given in (3) above. The PAPR values shown in Fig. 7 are obtained as follows:

$$\begin{aligned} PAPR_{dB} &= \max_{dB} - \text{mean}_{dB} \\ PAPR_D &= (-19.8306)-(-32.1442)=12.3136\ dB \\ PAPR_C &= (-32.1442)-(-34.4563)=2.3121\ dB \\ PAPR_{CF} &= (-30.3819)-(-34.5178)=4.136\ dB \\ PAPR_P &= (-26.2674)-(-33.9138)=7.6464\ dB \end{aligned} \quad (15)$$

Table 3 shows the PAPR reduction values due to the different values of δ. For a better BER performance and PAPR reduction value, (δ= 0.8) is the chosen value for the proposed technique with the assumed OFDM system parameters under the conditions of the AWGN channel. The PAPR reduction is calculated as follows:

$$\begin{aligned} PAPR_{Reduction} &= PAPR_{Desired} - PAPR_{Proposed} \\ PAPR_{Reduction} &= 12.3136 - 7.6464 = 4.667\ dB \end{aligned} \quad (16)$$

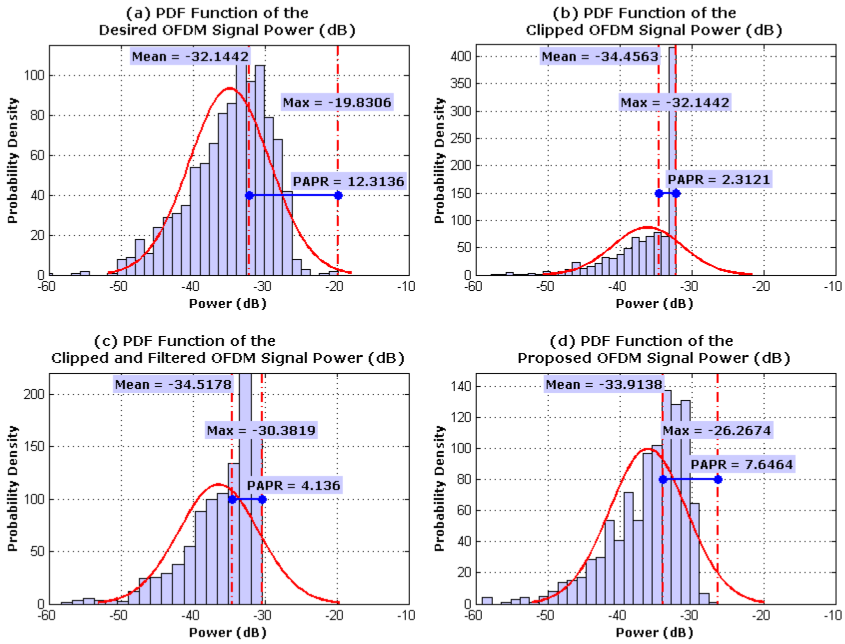

Fig. 7. PDF function of the OFDM signal power at weighting factor δ= 0.7

TABLE 3
PAPR REDUCTION AND BER PERFORMANCE FOR DIFFERENT δ VALUES

	PARP	*PARP* Reduction	*BER* @ *SNR*=9dB	*SNR* @ *BER*=2x10^{-4}
Desired	12.31dB	0 dB	1.6x10^{-7}	6dB
Clipped	2.31dB	10dB	2.3x10^{-4}	9dB
Clipped and Filtered	4.1dB	8.21dB	2x10^{-4}	9dB
Proposed @ δ=				
0	12.21dB	0.1dB	1.6x10^{-7}	6dB
0.1	11.8dB	0.51dB	1.6x10^{-7}	6dB
0.2	11.4dB	0.91dB	1.6x10^{-7}	6dB
0.3	11dB	1.31dB	4.7x10^{-7}	6dB
0.4	10.36dB	1.95dB	1.1x10^{-6}	7dB
0.5	9.72dB	2.59dB	1.9x10^{-6}	7dB
0.6	9dB	3.31dB	4.4x10^{-6}	7dB
0.7	8.28dB	4.03dB	1.4x10^{-5}	7dB
0.8	7.65dB	4.66dB	3.6x10^{-5}	8dB
0.9	6.9dB	5.41dB	8.6x10^{-5}	8dB
1	6dB	6.31dB	2.1x10^{-4}	9dB

V. CONCLUSIONS

The time domain OFDM signal is constructed from a large number of samples based on the size of the IFFT process, where each sample results from adding all sub-carriers at that sample time. Large peaks result from this addition if the sub-carriers happen to be in-phase, thus producing large Peak to Average Power Ratio (PAPR) values. High peak values will be clipped by High Power Amplifier (HPA) when it passes through for transmission. This clipping introduces in-band distortion, which decreases the OFDM system performance, and out-of-band radiation, which introduces ACI to other systems.

In our proposed technique, an improved clipping technique is presented to reduce the PAPR and ensure good BER performance. The proposed technique extracts the in-band distortion from the OFDM time domain signal, which converted to the frequency domain and applied to the desired signal with a weighting factor that reduces the amount of interference to the original sub-carriers.

Using a weighting factor of (δ=0.8) ensures a peak to average power ratio reduction of $\left(PAPR_{\text{Reduction}} = 4.66\ dB\right)$ and $\left(BER = 3.6\times10^{-5}\ @\ SNR = 9\ dB\right)$. For lower SNR values, the BER decreases, i.e. $\left(BER = 2\times10^{-4}\ @\ SNR = 8\ dB\right)$. This is an acceptable BER performance for communication systems such as Terrestrial Digital Video Broadcasting (DVB-T).

The assessment of the improved clipping technique is carried out using MATLAB/SIMULINK simulation under the conditions of AWGN channel. The assessment uses multiple values of (δ) and shows their effect on the BER performance and the PAPR reduction in OFDM system.

REFERENCES

[1] R. Prasad, *OFDM for Wireless Communications Systems*, Artech House Universal Personal Communications Series, 2004.

[2] R. Nee and R. Prasad, *OFDM for Wireless Multimedia communications*, Artech House Publisher, 2000.

[3] K. Samarah, "High bit rate air interface for next generation mobile communication systems," *PhD Thesis*, University of Bradford, Bradford, 2007.

[4] K. Samarah and S. Jones, "Assessment of high bit rate mobile OFDM systems using the codit channel model," *Proceedings of First European Conference on Antennas and Propagation*, pp. 1-6, 2006.

[5] J. Walker, *Fast Fourier Transforms*, Second Edition, Taylor and Francis, 1996.

[6] R. Nee, G. Awater, M. Morikura, H. Takanashi, M. Webster, and K. Halford, "New high-rate wireless LAN standards," *IEEE Communications Magazine*, vol. 37, no. 12, pp. 82-88, 1999.

[7] M. Doelz, E. Heald, and D. Martin, "Binary data transmission techniques for linear systems," *Proceedings of IRE*, vol. 45, no. 5, pp. 656-661, 1957.

[8] R. Chang, "Synthesis of band-limited orthogonal signals for multichannel data transmission," *Bell System Technical Journal*, vol. 45, no. 10, pp. 1775-1796, 1966.

[9] B. Saltzberg, "Performance of an efficient parallel data transmission system," *IEEE Transactions on Communication Technology*, vol. 15, no. 6, pp. 805-811, 1967.

[10] S. Weinstein and P. Ebert, "Data transmission by frequency-division multiplexing using the discrete Fourier transform," *IEEE Transactions on Communication Technology*, vol. 19, no. 5, pp. 628-634, 1971.

[11] A. Peled and A. Ruiz, "Frequency domain data transmission using reduced computational complexity algorithms," *Proceedings of Acoustics, Speech, and Signal Processing, IEEE International Conference*, pp. 964-967, 1980.

[12] O. Mino, T. Fujiwara, H. Nishizawa, and K. Takayama, "Development of north America terrestrial digital audio broadcasting receiver (HD radio)," *Fujitsu Ten Technical Journal*, pp. 42-53, 2005.

[13] L. Cimini, "Analysis and simulation of a digital mobile channel using orthogonal frequency division multiplexing," *IEEE Transactions on Communications*, vol. 33, no. 7, pp. 665-675, 1985.

[14] N. Arora, R. Kumar, A. Prakash, and V. Sharma, "Analysis of orthogonal frequency division multiplexing (OFDM) scheme for mobile radio channel," *Proceedings of Advances in Engineering and Technology Conference*, pp. 622-626, 2014.

[15] S. Singh, P. Kumar, and S. Prasad, "Reduction of PAPR by intelligently applying companding scheme with Kalman filter in OFDM systems," *The IUP Journal of Telecommunications*, vol. 6, no. 2, pp. 15-28, 2014.

[16] L. Wang and C. Tellambura, "An overview of peak-to-average power ratio reduction techniques for OFDM systems," *Proceedings of IEEE International Symposium on Signal Processing and Information Technology*, pp. 840-845, 2006.

[17] I. Abdullah, Z. Mahmud, S. Hossain, and N. Islam, "Comparative study of PAPR reduction techniques in OFDM," *ARPN Journal of Systems and Software*, vol. 1, no. 8, pp. 263-269, 2011.

[18] A. Jaber, L. Latiff, N. Ahmad, A. Abdalla, and A. Nahar, "Peak-to-average power ratio methods to improve the performance of multicarrier modulation systems," *Research Journal of Applied Sciences, Engineering and Technology*, vol. 11, no. 10, pp. 1091-1102, 2015.

[19] D. Singh, C. Singh, A. Singh, "Review paper on PAPR reduction techniques in OFDM system," *International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering*, vol. 3, no. 5, pp. 1-7, 2014.

[20] R. Bauml, R. Fischer, and J. Huber, "Reducing the peak-to-average power ratio of multicarrier modulation by selected mapping," *Electronics Letters*, vol. 32, no. 22, pp. 2056-2057, 1996.

[21] Y. Cho, J. No, and D. Shin, "A new low-complexity PTS scheme based on successive local search using sequences," *IEEE Communications Letters*, vol. 16, no. 9, pp. 1470-1473, 2012.

[22] R. Nee and A. Wild, "Reducing the peak-to-average power ratio of OFDM," *Proceedings of IEEE Vehicular Technology Conference*, pp. 2072-2076, 1998.

[23] W. Xianbin, T. Tjhung, and C. Ng, "Reduction of peak-to-average power ratio of OFDM system using a companding technique," *IEEE Transactions on Broadcasting*, vol. 45, no. 3, pp. 303-307, 1999.

[24] M. Mowla and S. Hasan, "Performance improvement of PAPR reduction for OFDM signal in LTE system," *Wireless and Mobile Networks*, vol. 5, no. 4, pp. 35-47, 2013.

[25] H. Ochiai and H. Imai, "On clipping for peak power reduction of OFDM signals," *Proceedings of IEEE Global Telecommunications Conference*, pp. 731-735, 2000.

[26] Q. Deng and H. Zhong, "An improved algorithm to reduce PAPR based clipping-and-filtering," *Proceedings of Conference on Wireless Communications, Networking and Mobile Computing*, pp. 1-4, 2008.

[27] Y. Rahmatallah and S. Mohan, "Peak-to-average power ratio reduction in OFDM systems: a survey and taxonomy," *IEEE Communications Surveys and Tutorials*, vol. 15, no. 4, pp. 1567-1592, 2013.

[28] M. Islam, N. Ahmed, N. Ahamed, M. Rahman, and S. Aljunid, "PAPR reduction in an OFDM system using recursive clipping and filtering technique," *WSEAS Transactions on Communications*, vol. 13, pp. 291-297, 2014.

[29] M. Mowla, M. Ali, and R. Aoni, "Performance comparison of two clipping filtering methods for PAPR reduction in OFDM signal," *Mobile Network Communications and Telematics*, vol. 4, no. 1, pp. 23-34, 2014.

[30] J. Armstrong, "Peak-to-average power reduction for OFDM by repeated clipping and frequency domain filtering," *Electronics Letters*, vol. 38, no. 5, pp. 246-247, 2002.

[31] A. Chakrapani and V. Palanisamy, "A novel clipping and filtering algorithm based on noise cancellation for PAPR reduction in OFDM systems," *Proceedings of the National Academy of Sciences, India Section A: Physical Sciences*, vol. 84, no. 3, pp. 467-472, 2014.

[32] K. Vidhya and D. Kumar, "BER performance of AWGN, Rayleigh and Rician channel," *Advanced Research in Computer and Communication Engineering*, vol. 2, no. 5, pp. 2058-2067, 2013.

[33] S. Saunders, *Antennas and Propagation for Wireless Communication Systems,* Wiley, 1999.

[34] J. Parsons, *The Mobile Radio Propagation Channel*, Wiley, 2000.