OFDM-PAPR Reduction using Statistical Clipping and Window based Noise Filtering

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Abstract

This paper presents an alternate approach for the iterative clipping and filtering (ICF) method used for the peak-to-average-power-ratio (PAPR) reduction in OFDM systems. As the resultant in-band noise due to clipping after *Z* consecutive iterations is approximately proportional to the clipping noise generated in the single iteration, therefore this in-band noise obtained after first iteration is statistically scaled to measure the in-band clipping noise of *Z* iterations. This approximated in-band clipping noise may be further used for refining the OFDM signal by using statistical clipping (SC) approach [1]. However, the out-of-band clipping noise is also a significant drawback for OFDM systems, which restricts the efficiency of transmitter.

Therefore, the main focus of presented research work is on the out-of-band clipping noise suppression using the Kaiser window based filtering, in addition to the in-band clipping noise excision using SC method, which may be termed as statistical clipping and window based filtering approach (SC-W). The simulation results are presented to compare the bit-error-rate (BER) performance of the underlying wireless OFDM systems using the ICF, SC, SC-W techniques for PAPR reduction. The complementary cumulative density function (CCDF) and power spectral density (PSD) characteristics are also investigated to infer the results, which depict that the proposed SC-W PAPR reduction technique meets the requirements of transmit mask specified in IEEE 802.11a. The exclusive advantage of SC-W method over ICF approach is low computational complexity and reduced out of band clipping noise.

Keywords: *orthogonal Frequency division multiplexing, peak to average power reduction, statistical clipping, clipping and filtering, window method*

1. Introduction

Orthogonal Frequency Division Multiplexing (OFDM) is a popular modulation technique used in many new and emerging broadband technologies, wired like ADSL (asymmetric digital subscriber line) or wireless as in DAB (digital audio broadcasting), DVB-T(digital video broadcasting-terrestrial), WLAN (Wireless LAN), and so forth [2-7].

The main advantage of OFDM is its robustness to multi-path fading, its great simplification of channel equalization and its low computational complexity implementation based on using discrete fourier transform (DFT) technique [5]. Despite of many advantages, a major drawback of OFDM is its high Peak to Average Power Ratio (PAPR) problem, which makes the system performance very sensitive to nonlinear distortions. The OFDM signal consists of large number of independently modulated subcarriers, it produces severe Peak to Average Power Ratio (PAPR) due to Gaussian distribution of the composite OFDM signal as compared to single-carrier signals. This signal when passes through a nonlinear device or High Power Amplifier (HPA), the signal may suffer significant nonlinear distortions [8] and severe power penalty which is unaffordable for battery powered portable wireless terminals, so it is required to reduce the PAPR of the OFDM signal before transmission [9].

In the literature PAPR in OFDM systems can be reduced through number of approaches explained in [10], selective tone reservation [11], application of Haar wavelet transform [12], by efficient circuit design in FPGA system [13], and also by utilizing Pade approximation in combination with exponential companding [14]. But their computational complexity is significantly high. Therefore, the main focus of the presented research work will be on the development of efficient PAPR reduction technique with low computational complexity based on statistical signal processing approach. For the statistical approach clipping technique for reducing PAPR is exploited because of its simplicity and good practicality.

Clipping of OFDM signal cause both in-band and out of band noise (OOB). If clipping is performed on a Nyquist sampled signal, all the clipping noise will fall in-band which cannot be filtered or removed and results in degradation in the BER performance. So, it is suggested that the clipping operation should be performed on oversampled signal.

Due to oversampling peak re-growth and in-band noise is reduced after Digital to Analog conversion (D/A) but out of band noise will be introduced which reduces the spectral efficiency and may cause interference to other channels [15,16,17]. So, frequency domain filtering is necessary to attenuate out of band power or to remove the out of band components [18,19]. Further, filtering introduces some in band noise and peak re-growth which cannot be removed by further filtering.

So, we require to attenuate the out of band power maximally and to reduce spectral re-growth. This can be achieved by Iterative Clipping and Filtering (ICF). ICF can greatly reduce the PAPR, while the filtering processing (DFT + treating OOB with Kaiser window + IDFT) causes no distortion to the in-band and filters the out of band noise. However ICF increases the computational complexity. Moreover, iterative clipping operations would bring more in-band noise (in particular, when the clipping threshold is set small), which degrades the BER performance. After several iterations of clipping and filtering, the residual in-band distortions can be restored by iterative estimation and cancellation of clipping noise [20]. Also the convergence of the clipping and filtering iterations to pre-determined clipping level decreases after three iterations, so large number of iteration processes could be avoided.

The in-band noise added due to conventional iterative clipping and filtering operations [21] can be scaled using parabolic approximation of clipping pulse. Using the approximation the clipping noise obtained after *Z* clipping and filtering iterations, where *Z* is the number of iterations, can be approximated proportional to that generated in first iteration. This approximation works well in case of clipping at high thresholds [22].
The performance degrades, using low clipping thresholds. The performance can be enhanced by reducing the spectral re-growth in out-band using frequency domain filtering of OOB components using Kaiser window i.e. SC-W PAPR reduction approach.

This paper is organized as follows: Section 2 characterizes the OFDM signal and PAPR modeling. Section 3 characterizes the ICF method and the proposed SC-W PAPR reduction technique. In section 4, simulation results are shown comparing SC-W method with previous ICF and SC technique. Computational complexity of SC-W method is compared with C-PTS and DSI-PTS method [23]. The conclusion of this paper is given in section 5.

2. OFDM Signal and PAPR Modeling

2.1 Orthogonal Frequency Division Multiplexing (OFDM)

In order to have a channel that does not have ISI, the symbol time *T* has to be larger than the channel delay spread *t*. Digital communication system simply cannot function if ISI is present – an error which quickly develops as *T* approaches or falls below *t*, the bit error becomes intolerable. For wideband channels that provide high data rates needed by today's applications, the desired symbol time is usually much smaller than the delay spread, so ISI is severe. The special form of Multi Carrier Modulation (MCM) i.e. OFDM is a good solution for minimizing severe ISI and multipath effects.

The basic concept of OFDM is to divide the total bandwidth into many narrowband sub-channels which are transmitted in parallel. The sub-channels are chosen narrow enough so that the effects of multipath delay spread are minimized i.e. high rate transmit bit-stream is divided into *K* lower-rate bit-streams or sub-channels, each of which has $T/K >> t$, and is hence ISI free. These individual sub-streams can then be sent over *K* parallel sub-channels, maintaining the desired data rate. The sub-channels are orthogonal to each other under ideal propagation conditions, in this special case MCM is referred as OFDM.

The data rate on each of the sub-channels is much less than the total data rate, so the corresponding sub-channel bandwidth is much less than the total system bandwidth. The number of sub-streams i.e. *K* is chosen to ensure that each sub-channel has a bandwidth less than the coherence bandwidth of the channel, so the sub-channels experience relatively flat fading. Thus the ISI on each sub-channel is small.

In OFDM system, a block of *K* symbols $\{X_k, k=0,1,\ldots, K-1\}$, is formed with each symbol modulating one of a set of subcarriers, $\{f_n, n=0,1,\ldots, K-1\}$ with equal frequency separation $1/T$, where *T* is the original symbol period. An Inverse Discrete Fourier Transform (IDFT) can efficiently generate the multicarrier symbols. The IDFT of vector $X[k]=[X_0,X_1,\ldots X_{K-1}]^T$ results in T/K spaced discrete time signal $x[n]=[x_0, x_1, \ldots x_{K-1}]^T$. Thus, the transmitted OFDM signal is

$$x_n=\frac{1}{\sqrt{K}}\sum_{k=0}^{N-1} X_k\, exp\left(j\frac{2\pi kn}{K}\right) \quad 0\leq k\leq K-1 \qquad (1)$$

2.2. Peak to Average Power Ratio (PAPR)

One major difficulty with OFDM with a large number of sub-channels a large Peak to Average Power Ratio (PAPR) which distorts the signal if the transmitter contains nonlinear components.
Large PAPR occurs due to Gaussian or Rayleigh (in case of zero mean and variance ½) distribution of the composite OFDM signal as compared to single-carrier signals [24]. The PAPR of the OFDM transmitted signal can be written as

$$PAPR=\frac{\max_{0\le n\le k-1}|x_n|^2}{E\{|x_n|^2\}} \quad (2)$$

Such signal with large PAPR when passed through a non-linear transmitter, the signal suffers significant spectral spreading and in-band distortions. The conventional solution to this problem is to use a linear amplifier with large dynamic range which is very expensive and inefficient or to back off the operating point of a non linear amplifier; both approaches results in significant power efficiency penalty.

3. Clipping based PAPR reduction method

3.1 Iterative Clipping and Filtering Technique (ICF)

Clipping can be performed in two ways, one is to clip the complex envelope of OFDM signals and other is to clip the In-phase and Quadrature phase signal separately. Clipping the complex envelope method is more effective in reducing PAPR [25]. In this paper clipping of complex envelope is chosen. The peak envelope of the input signal (1) is clipped to a predetermined threshold *A*, or otherwise passed unperturbed, that is

$$\bar{x}_n = \begin{cases} A\cdot e^{j\theta(t)}, |x_n| > A \\ x(t),\ |x_n| \le A \end{cases} \quad (3)$$

Where $\bar{x}_n$ is the clipped signal and $\theta(t)$ represents the phase of x_n. In clipping algorithm clipping ratio (*CR*) is an important parameter also referred as normalized clipping level, defined as

$$CR = A/\sigma \quad (4)$$

or in decibels as

$$CR(dB)=20\cdot log_{10}\frac{A}{\sigma} \quad (5)$$

Where σ is the root mean square (rms) value of signal x_n. Therefore *CR*=1 means that signal is clipped at rms power level. A *CR* of 1.4 means that the clipping level is about 3*dB* higher than the rms level and *CR* of 1.995 means that the clipping level is 6*dB* higher than the rms level. In this paper 3*dB* and 6*dB* clipping is chosen assuming that the maximum limit of linear range of HPA is 7*dB* higher than the rms level.

Clipping is done digitally on the OFDM signal (1) at the transmitter as described in [17]. If the digitally clipped samples are trigonometric interpolated the peak power will re-grow over clipping threshold, also all clipping noise will fall in-band which will increase the BER [26]. To reduce the peak power re-growth and in-band noise, the time domain signal is oversampled by a factor $I \ge 2$ by adding *K*(*I*-*1*) zeros after the data vectors in x_n. The factor should not be too large as it increases computational complexity. Let *N*=*K*·*I*, since *N* is large the real and imaginary components of OFDM signal x_n have Gaussian distribution, thus by extending Bussgang's theory to complex case it is possible to show the clipped signal $\bar{x}_n$ as the aggregate of an attenuated signal components and clipping noise d_n, subject to certain conditions [27].

$$\bar{x}_n = \alpha\cdot x_n + d_n \quad n=0,\ldots\ldots\ldots,N-1 \quad (6)$$

The clipping process described above is a non-linear process. Since clipping is done on an oversampled signal, most of the clipping noise falls in OOB which reduces the spectral efficiency. Filtering after clipping is necessary and required to reduce the OOB noise and spectral splatter. The FIR filters used in many papers are very complicated like in [19], makes spectral side-lobes 50*dB* lower than the signal side-lobes and introduces in-band ripple of 1*dB* which may boost the power of some sub-channels while suppressing others. Such filters are complicated and expensive, in addition they cause peak re-growth and significant distortion in in-band.

For efficient filtering i.e. adding minimum noise in in-band, peak re-growth and maximally attenuate the OOB power, there is a technique called "Frequency Domain Filtering" of the clipped signal. In the conventional ICF method explained in [21] the filtering consist of two DFT operations. The forward DFT transforms the clipped signal back into discrete frequency domain $\bar{X}_n$. The in-band discrete frequency components of $\bar{X}_n$ are passed unchanged to the inputs of the second IDFT while the OOB components are nulled. The process is same as multiplying $\bar{X}_n$ by rectangular window function (7).

$$R_K(m)=\begin{cases}1 & 0\le m\le K-1\\ 0 & otherwise\end{cases} \quad (7)$$

In this paper we have modified the filter action by replacing rectangular window function by Kaiser window function (8). Only OOB components are multiplied by Kaiser window function and in-band components are passed unperturbed (SC-W method) (8-10). The probability of peak re-growth reduces as the side-lobes of the clipped peaks in $\bar{x}_n$ offset each other. Mathematically Kaiser window function can be represented as

$$H(m)=\begin{cases}1 & 0\le m\le K-1\\ \dfrac{i_0\left(\beta\cdot\left[1-\left(2\cdot\frac{m}{N-1}\right)^2\right]^{1/2}\right)}{i_0(\beta)}\cdot R_N(m) & K\le m\le N-1\end{cases} \quad (8)$$

Where $R_N(m)$ is

$$R_N(m)=\begin{cases}1 & 0 \le m \le N-1 \\ 0 & otherwise\end{cases} \quad (9)$$

i_0 is the zero order modified Bessel function of first kind and β is the ripple control parameter. $i_0(x)$ is calculated by power series expansion $i_0(x) = 1 + \sum_{k=1}^{L}[\frac{\left(\frac{x}{2}\right)^k}{k!}]^2$
Where L<25. So, signal after clipping and filter operation is

$$\hat{x}_n(n) = IDFT(\bar{X}_n(n) \cdot H(n)) \quad (10)$$

The resultant filter is a time dependent filter, which passes in-band and attenuates OOB components. This means that it causes no distortion to the in-band of clipped signal $\bar{x}_n$. Since the filter operates on a symbol by symbol basis, it causes no ISI. This filtering technique also causes peak re-growth, but less and compared to rectangular window filtering and FIR filters.
To reduce the peak re-growth iterative clipping and filtering can be performed [21]. ICF technique greatly reduces peak re-growth, attenuates OOB power but adds more clipping noise in in-band with subsequent iterations.

3.2 Proposed method: Statistical Clipping and Window Based Filtering Approach (SC-W)

To mitigate the problem of peak re-growth, the above explained ICF method at the transmitter side is of good practicality. But the convergence of PAPR reduction decreases after the few iterations. Each iteration requires two DFT or IDFT operations and after the last iteration, one extra IDFT is required to convert the clipped and filtered OFDM symbol to time domain. As a Z iteration process requires $2 \cdot Z+1$ DFT/IDFT, the increased number of iterations implies increased computational complexity, especially when the number of sub-carriers are very large. Other PAPR reduction methods given by [29-31] also require several iterations to suppress the high PAPR. Also in clipping noise cancellation technique explained in [20, 32] requires same number of iterations as of transmitter side at receiver side to cancel the clipping noise. Thus, the computational complexity increases with number of iterations both at transmitter and receiver side.
SC-W method is of one iteration which obtains the same PAPR reduction as of ICF with several iterations. Each clipping pulse is approximated as a parabolic function. The in-band noise obtained after first iteration is statistically scaled to measure the in-band clipping noise for Z iterations. This approximated in-band clipping noise may be further used for refining the OFDM signal and called as statistical clipping (SC).
But still after scaling of clipping noise OOB power is very high and requires to be attenuated improve spectral efficiency. OOB of SC OFDM signal is then treated with Kaiser window (8) to filter the OOB components and called as statistical clipping and window based filtering approach (SC-W).

Based on the central limit theory, x_n can be approximated as complex Gaussian process when N is large. If x_n has zero mean and variance σ^2, then its absolute value or magnitude $|x_n|$ is a Rayleigh process and real and imaginary parts of x_n are identically distributed Gaussian signals with zero mean and variance σ^2.
Now considering equation (3) where $\bar{x}_n$ is the clipped signal and $\theta(t)$ represents the phase of x_n. The clipping noise x_n - $\bar{x}_n$ is a series of pulses. In this case each pulse can be approximated as a parabolic arc [33, 34]. So, according to the approximation, B is defined as

$$\text{B} \triangleq \frac{\text{total clipping noise after } Z \text{ iterations}}{\text{clipping noise generated in first iteration}} \quad (11)$$

When A is assumed to be large, mean of B can be approximated as

$$\overline{\text{B}} \approx \frac{1-(1-a)^{\frac{3Z}{2}}}{1-(1-a)^{\frac{3}{2}}} \quad (12)$$

Where

$$a = \frac{2\sqrt{2}\cdot\sigma}{\sqrt{3\pi}\cdot A} \quad (13)$$

The proof for equation (12) and (13) is shown in [22].

Algorithm for SC-W method is as follows

1. { X_k, $k=0,1,\ldots, K-1$} be the complex Quadrature Phase Shift Keying (QPSK) modulated symbols, where K is the number of subcarriers. Then we can get $\{X_k=[X_0,\ldots, X_{k-1}, 0,\ldots,0,0,0]_N\}$ through the operation of oversampling ($N=K\cdot I$, where I is the oversampling factor). So the oversampled discrete time domain OFDM signal.

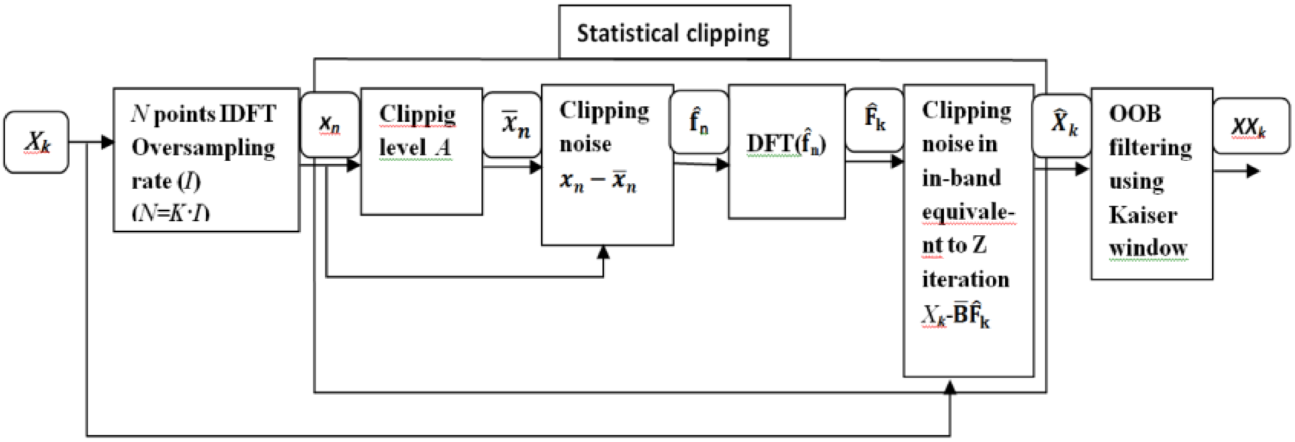

Fig.1. Block diagram for statistical clipping and window filtering

2. Convert the OFDM symbol to time domain as x_n = IDFT(X_k).
3. Clip x_n to the threshold A and calculate the clipping noise $\hat{f}_n = x_n - \bar{x}_n$.
4. Convert $\hat{f}_n$ to frequency domain to obtain $\hat{F}_k$ by taking DFT($\hat{f}_n$).
5. The clipped OFDM signal then becomes $\hat{X}_k \approx X_k - \bar{B} \cdot \hat{F}_k$.
6. Treat the OOB by Kaiser window. We can also let only a part of OOB or whole OOB treated by window function $XX_k = \hat{X}_k \cdot H(k)$.
7. Convert the treated signal XX_k to time domain and transmit it.

4. Simulation Results

The proposed PAPR reduction technique SC-W is investigated by considering two cases of clipping level (A) for 3dB and 6dB case, assuming maximum limit for linear range of Solid State Power Amplifier (SSPA) as described in [22] be 7dB above rms level of transmitted OFDM symbol. The input-output relationship of SSPA can be written as

$$y_n = \frac{|x_n|}{\left(1+\left(\frac{|x_n|}{C}\right)^{2p}\right)^{\frac{1}{2p}}} e^{j\phi_n} \qquad (14)$$

Where $|x_n|$ is the input, and y_n is the output of SSPA. The SSPA becomes linear when p is infinity. Usually p=2 or 3 is taken for practical SSPA and C is taken 3 or 6dB according to the clipping case. Cyclic prefix is not used with an assumption that it doesn't affect the results.

Parameters for simulation taken,

Number of subcarriers (K) = 256
Oversampling factor (I) = 4
Total sub-channels (N=K·I) =1024
Ripple control parameter (β) = 6
Digital modulation technique = QPSK (Quaternary Phase Shift Keying)
Maximum OFDM symbols for CCDF curve = 10,000
Approximation to number of iterations (Z) for SC-W = 3
Channel taken for measuring BER v/s Eb/No performance = AWGN
Parameter p for SSPA amplifier = 3

4.1 Complementary Cumulative Distribution Function (CCDF)

The complementary cumulative distribution function (CCDF) is one of the most frequently used performance measures for PAPR reduction techniques, which denotes the probability that the PAPR of a data block exceeds a given threshold A. The CCDF of the PAPR of a data block of N symbols with Nyquist rate sampling is derived as [35].

$$P(PAPR > A)=1-P(PAPR \le A)=1-(1-e^{-A})^N \qquad (15)$$

CASE- I: 3dB (A=1.4· σ)

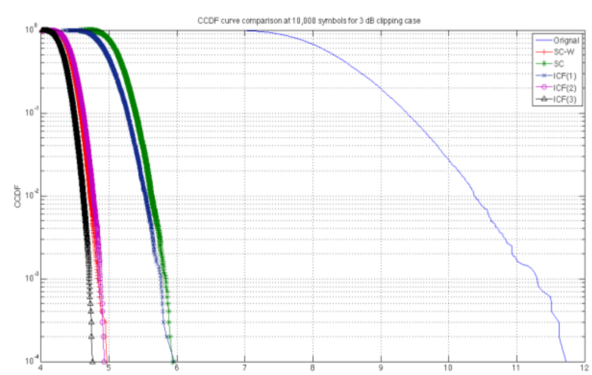

Fig.2. CCDF curve comparison at 10,000 symbols

CASE- II: 6*dB* (*A*=1.9953· σ)

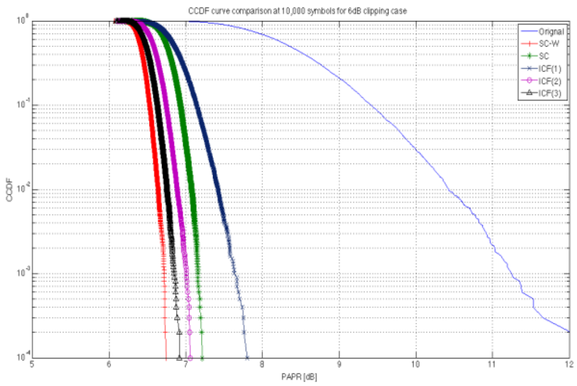

Fig.3. CCDF curve comparison at 10,000 symbols

4.2. Power Spectral Density (PSD)

CASE- I: 3*dB* (*A*=1.4· σ)

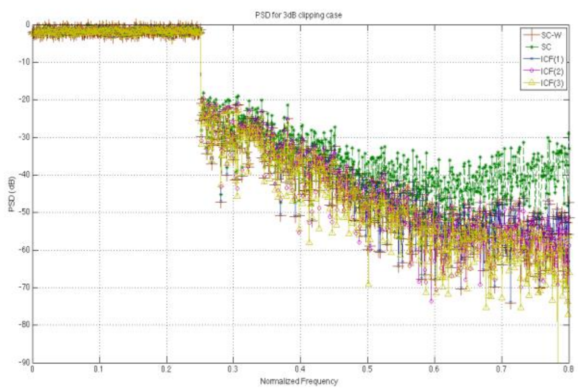

Fig.4. PSD comparison for SC-W, SC, ICF(1), ICF(2), ICF(3)

CASE- II: 6*dB* (*A*=1.9953· σ)

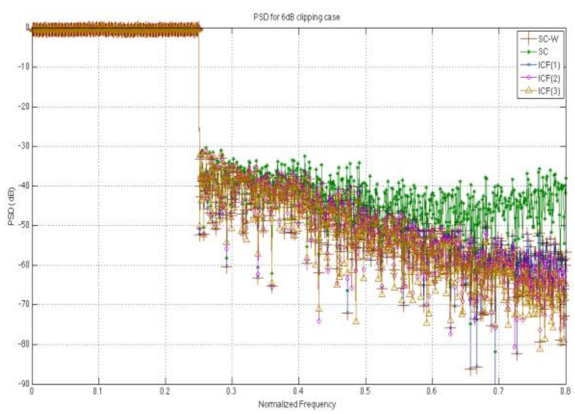

Fig.5. PSD comparison for SC-W, SC, ICF(1), ICF(2), ICF(3)

4.3. Bit Error Rate (BER)

CASE- I: 3*dB* (*A*=1.4· σ)

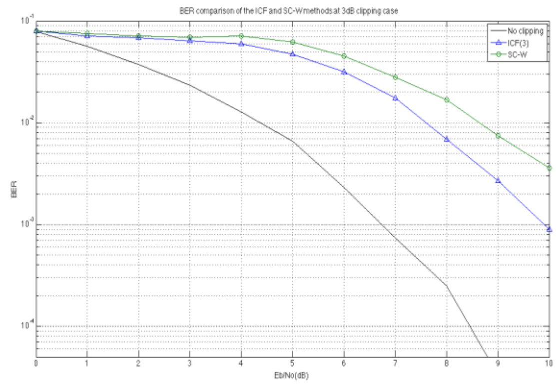

Fig.6. BER comparison for SC-W and ICF(3)

CASE- II: 6*dB* (*A*=1.9953· σ)

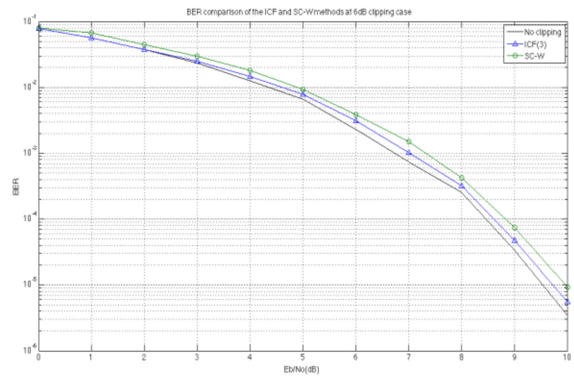

Fig.7. BER comparison for SC-W and ICF(3)

4.4. Transmit spectrum of OFDM signal based on IEEE 802.11a

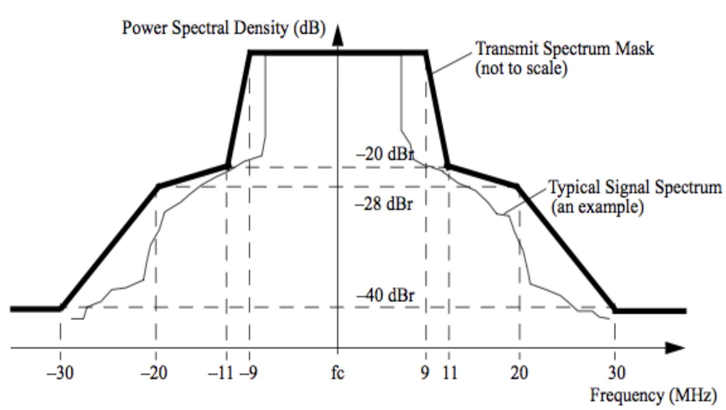

Fig.8. Transmit spectrum of OFDM signal based on IEEE 802.11a [36]

4.5 Statistical data obtained during simulation

CASE- I: 3*dB* (A=1.4$\cdot\sigma$)

Table I. PAPR reduction comparison

	Original	ICF(1)	ICF(2)	ICF(3)	SC	SC-W
PAPR(*dB*)	11.81	5.878	4.956	4.814	5.99	4.92

Table II. Average attenuation comparison

Average attenuation(dB)	ICF(1)	ICF(2)	ICF(3)	SC	SC-W
In-band	1.4371	1.6805	1.7962	2.4286	2.4286
Out-band	47.3264	51.5524	54.4816	34.6375	47.4616

CASE- 2: 6*dB* (A=1.9953$\cdot\sigma$)

Table III. PAPR reduction comparison

	Original	ICF(1)	ICF(2)	ICF(3)	SC	SC-W
PAPR(*dB*)	11.72	7.728	7.033	6.902	7.248	6.766

Table IV. Average attenuation comparison

Average attenuation(dB)	ICF(1)	ICF(2)	ICF(3)	SC	SC-W
In-band	0.2646	.3304	0.3679	0.4091	0.4091
Out-band	57.3619	60.5887	62.9992	44.658	57.482

From the CCDF curves shown in figure 2, 3 and data provided in table I, III PAPR decreases with number of iterations, but its convergence decreases in both 3*dB* and 6*dB* case. In 3*dB* case ICF(1) is quite superior than SC method and SC-W method is almost equal to ICF(2), .1*dB* degraded from ICF(3) and provides 1 *dB* improvement over SC. In 6 *dB* case SC method is far superior than ICF(1) and SC-W method provides .2*dB* and .48*dB* improved performance from ICF(3) and SC methods respectively.

From the PSD graphs shown in figures 4, 7 and data provided in table II, IV, as number of iterations increases in ICF in-band distortion and out-band attenuation increases. Due to the frequency domain filtering using Kaiser window in-band distortion is very less. In case of 3*dB* case in-band distortion is more and OOB attenuation is less as compared to 6*dB* case. In 3*dB* case SC-W method provides .7*dB* more in-band distortion and 7*dB* less OOB attenuation whereas in 6*dB* case SC-W provides equal in-band distortion and 5*dB* less OOB attenuation than ICF(3). In both cases ICF and SC-W meets the requirement of IEEE 802.11a transmit spectrum mask specified in figure 8.

From BER graphs shown in figures 8, 9, the increase in error floor, due to increase in iterations in ICF and filter affect in SC-W method is justified. Performance of SC-W method and ICF(3) is almost same with a difference of .32*dB* in 6*dB* case whereas in 3*dB* case SC-W is slight inferior with a difference of 1.3*dB* at 10^{-3} BER level.

For comparison, complexity of C-PTS (Conventional Partial Transmit Sequence) method is compared, which is also a promising technique for PAPR reduction. Complexity of C-PTS increases as the number of sub-blocks increases [10]. To reduce it many techniques have been suggested. In [19] DSI-PTS method is presented which offers low computational complexity. For 512 sub-carriers, 4 sub-blocks C-PTS has a computational complexity of 60416 and with D=1 DSI-PTS has a computational complexity of 30208. Since the SC-W method consist of only one IDFT and DFT, scaling, multiplication and differencing operations, its complexity is in order of $(2\cdot N\cdot \log_2 N + .076\cdot N)$ for 6*dB* case [37]. For 256 sub-carriers (K), oversampling factor (I) = 4 and clipping case 6*dB* complexity of SC-W is 20557 and for ICF(3) method the computational complexity is in order of $3\cdot(2\cdot N\cdot \log_2 N)$, i.e. 61440. Thus, SC-W offers low computational complexity as compared to C-PTS, DSI-PTS and ICF(3).

5. Concluding Remarks and Future Work

In this paper, we have proposed a new SC-W PAPR reduction method based on Kaiser window frequency domain filtering to reduce PAPR of OFDM signal. Compared with the conventional ICF method, this method can dramatically reduce the peak re-growth and computational complexity by avoiding ICF operations. SC-W method provides better PAPR reduction over SC method and out-of-band power attenuation very close to ICF for both small and large clipping cases with the expense of tolerable BER degradation especially in small clipping case.

SC-W PAPR reduction method meets the requirement of transmit mask specified in IEEE 802.11a and is completely compatible with other transmitter designs. It can be implemented by replacing transmitter IDFT with an oversize IDFT followed by clipping, scaling and filtering circuit. No changes are required at receiver side and can be adopted without any change to telecommunication standards. The future work includes the implementation aspects of the proposed scheme using FPGA systems [13].

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