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PAPR Reduction an effective approach for next frontier MIMO-OFDM systems

Balram DamodharTimande* and Dr. Manoj Kumar Nigam**

**Research scholar, MATS University, Raipur-Arang 493441 Chhattisgarh (India)*

*** Department of EEE, MATS University, Raipur-Arang 493441 Chhattisgarh (India)*

**Email: balramtimande71@gmail.com; Corresponding Author.*

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ABSTRACT

The 'Orthogonal frequency division multiplexing (OFDM)' is a well-accepted and effective technology employed today and in future wireless communication systems. The combinations of OFDM and 'multiple-input multiple-output (MIMO') offer high quality of services and better throughput. The multicarrier OFDM system experiences a high 'peak-to-average power ratio (PAPR'), which is the major issue in the OFDM scheme and must be truncated to achieve trustworthy communication. Due to high PAPR in a signal to be transmitted, the power amplifier in the transmitter section enters into saturation region and amplifies the signal nonlinearly, resulting in loss of orthogonality and ultimately in 'inter-carrier interference (ICI)'. In this article, the 'iterative clipping and filtering (ICF)' method is proposed to minimize the PAPR in the OFDM system. The simulation is carried out using MATLAB (version 2014b). The result of the proposed ICF method and the 'selective mapping (SLM)' scheme is analyzed and compared. From the analysis, it is shown that the proposed ICF technique is more suitable for minimizing the PAPR effectively without affecting 'bit error rates (BER)' much and the simplicity of the system. The simulation result of the proposed ICF scheme using 'Quadrature Phase Shift Keying (QPSK)', FFT size of 128, and clipping and filtering level up to 6 shows that the proposed ICF scheme for clipping level of 6 reduces PAPR to 5dB. Also, the BER is minimized at the level of 3×10^{-5} at 12 dB SNR.

Key words: Clipping; filtering; OFDM; PAPR; and Wireless communication.

INTRODUCTION

The PAPR is defined as the ratio of the maximum signal power to the average signal power of the OFDM symbol in the time domain (Chiueh *et al.*, 2012). The PAPR is given by equation (1),

$$PAPR = \frac{max\{|x(k)|^2\}}{E\{|x(k)|^2\}} \qquad (1)$$

The most important issue in the OFDM system is the presence of large PAPR in OFDM symbol (Han and Lee, 2005). High PAPR in OFDM scheme caused by the logical summation of the subcarriers of the OFDM system via 'inverse fast Fourier transform (IFFT)' transformation. When K number of symbols from N subcarriers is added together in the same phase, generates high peaks in the time domain. This high peak power is approximately N times the average power of the transmitted symbols. Therefore, a wireless communication system employing OFDM schemes produce a high PAPR. High peak power requires a good dynamic range in the following amplifier circuits of the transmitter. More specifically the 'power amplifier (PA)' should be self-motivated to accommodate such peak power. The PA must be biased properly otherwise they entering to saturation and cause nonlinear amplification of signals with large PAPR. Even highly linear amplifiers enforce distortion in their outputs when applied input is much greater than its normal value, due to saturation characteristics of such amplifiers (Cho *et al.*, 2010). Because of the nonlinear characteristic when High Power Amplifiers are energized with a large input signal, results in out of the band emission which interferes with symbols in neighboring bands, and in-band distortion. In fact, due to high PAPR the analog devices like 'analog to digital converter (ADC)' and 'digital to analog converter (DAC)', also behaves non-linearly which decreases 'signal to quantization noise ratio (SQNR)' of these devices (Han and Lee, 2005; Bao *et al.*, 2016**)**. In the transmitter section, high PAPR diminish the efficiency of PA which is the most critical issue for up-linking in the case of mobile handsets due to battery limitation. Hence it is worth reducing the PAPR at the desired level to have trustworthy communication (Cho *et al*., 2010).

THE MIMO-OFDM SYSTEM

The OFDM scheme employs *N* number of orthogonally and closely spaced subcarriers within the available bandwidth. The signal on these subcarriers is transmitted simultaneously in parallel. Before transmission, each subcarrier is modulated using various modulation schemes like 'binary Phase Shift Keying (BPSK)', 'Quadrature amplitude modulation (QAM)', and QPSK. However these subcarriers are modulated at the lower symbol rate, the *N* subcarrier together offers the same data rate as a single carrier system within the same bandwidth. The OFDM scheme is broadly used in new generation high-speed wireless communication systems due to its good spectral efficiency. Also, it is less susceptible to inter-symbol interference, but the key issue that the OFDM system performance is greatly affected by the presence of high PAPR (Wang and Luo, 2010). The high PAPR in the OFDM system makes the following power amplifier enter into saturation and enforces them to produce nonlinear distortion (Han and Lee, 2005). Hence it is vital to lessen the PAPR to the desired level to have trustworthy communication but an attempt to reduce PAPR reduces the power efficiency of the transmitted signal increases the BER value (Anoh *et al.*, 2017-1). The amalgamation of spectrum efficient OFDM with multiple antenna system MIMO provides high data rate, robust and trustworthy wireless communication in current as well as next-generation wireless system (Rateb and Labana, 2019). The basic MIMO-OFDM system is shown in figure1. Typically, the OFDM transmitter section comprises modulators at different carrier frequencies, serial to parallel converter, IFFT processing, insertion of 'cyclic prefix (CP)', parallel to serial converter, and DAC. Similarly, the OFDM receiver section includes exactly opposite blocks like ADC, serial to parallel converter, Cyclic prefix removal block, FFT processing, parallel to serial converter, and demodulator. Additional blocks or schemes may be added to overcome different weaknesses of OFDM like BER, 'inter symbol interference (ISI)', ICI, and PAPR (Chiueh *et al.*, 2012).

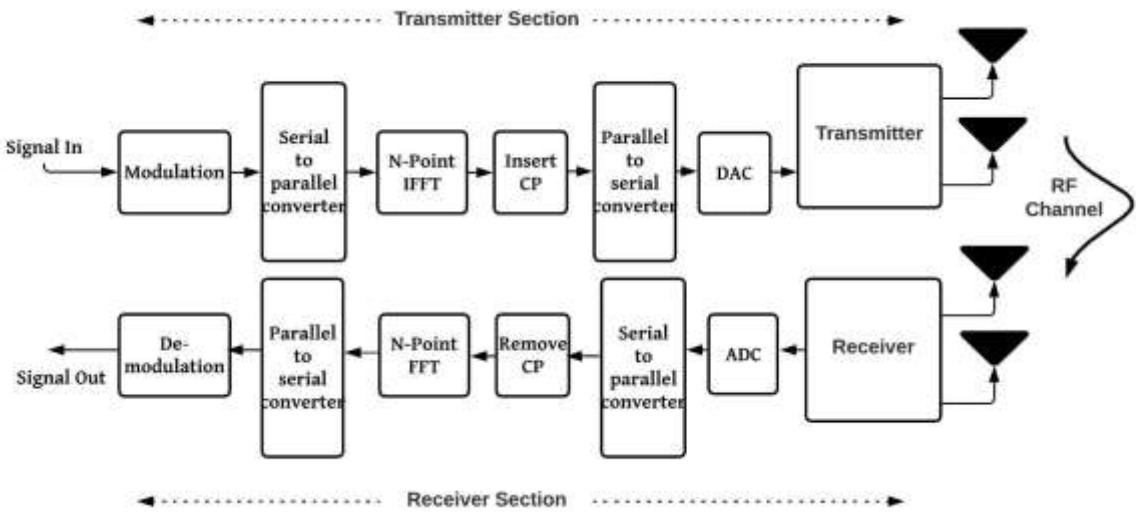

Fig 1. The basic MIMO-OFDM System

THE PAPR IN OFDM SYSTEM

Assuming information symbols $X(0), X(1), \dots . X(N-1)$ equals to $\pm a$. The information symbols are loaded onto the subcarriers and transmitted through *N* point IFFT. Let the IFFT samples are $x(0), x(1), \dots . x(N-1)$. The K^{th}symbol from IFFT is

$$x(k) = \frac{1}{N}\sum_{i=0}^{N-1} X(i)e^{(j2\pi ki/N)} \qquad (1)$$

The average power is given by equation (2)

$$P_{avg} = E\{|x(k)|^2\} \qquad (2)$$

$$P_{avg} = \frac{1}{N^2}\sum_{i=0}^{N-1} E\{|X(i)|^2\}\, E\left\{\left|e^{(j2\pi ki/N)}\right|^2\right\} \quad (3)$$

Since, the phase factor $E\left\{\left|e^{(j2\pi ki/N)}\right|^2\right\} = 1$ we have

$$P_{avg} = E\{|x(k)|^2\} = \frac{1}{N^2}\sum_{i=0}^{N-1} E\{|X(i)|^2\} \quad (4)$$

We have assumed that information symbols $X(i) = \pm a$

$$P_{avg} = E\{|x(k)|^2\} = \frac{1}{N^2}\sum_{i=0}^{N-1} a^2 \quad (5)$$

$$P_{avg} = \frac{1}{N^2} a^2\, N = \frac{a^2}{N} \quad (6)$$

Now let us find the peak power of the transmitted symbol. From equation (1)

$$x(0) = \frac{1}{N}\sum_{i=0}^{N-1} X(i) \;\; , for\ k = 0 \quad (7)$$

Since, $X(0), X(1), \ldots .X(N-1)$ equals to$\pm a$.

$$x(k) = \frac{1}{N}\sum_{i=0}^{N-1} a \; = \frac{aN}{N} \; = a \quad (8)$$

Hence, the peak power

$$max\{|x(k)|^2\} = a^2 \quad (9)$$

Therefore PAPR in the OFDM system from equation (1), (6) and (9) is,

$$PAPR = \frac{a^2}{a^2/_N} = N \quad (10)$$

The equation (10) shows that the peak power is approximately *N* times the average power of the transmitted symbols. And it is also observed that the PAPR in OFDM system essentially arises due to IFFT transformation. Many methods lessening PAPR have been employed including ICF, SLM, "iterative companding transform and filtering (ICTF)', 'partial transmit sequence (PTS)', Bayesian method and so on. PAPR lessening techniques can be employed at the beginning or the end of OFDM modulation (Rahmatallah and Mohan, 2013).

ITERATIVE CLIPPING AND FILTERING (ICF) TECHNIQUE

Among different schemes employed for lessening PAPR, the iterative clipping, and filtering of OFDM signal to desire threshold level, ICF is the most prominent PAPR lessening scheme. Clipping and filtering of the OFDM symbol are performed in the time domain and frequency domain respectively. The main application of filtering is to minimize spectral growth (Armstrong, 2002). The clipping of the OFDM signal results in spectral re-growth and hence the in-band distortion. Further, it may affect BER performance too. Filtering the clipped signal in time domain considerably reduce the spectral growth but results in peak re-growth in the time domain. So to have desired PAPR result ICF method employed many iterations. Figure 2 shows the ICF scheme of minimizing PAPR (Sharma *et al.*, 2011; Zhu *et al.*, 2013). Where c_0 is the original OFDM symbols and after processing c (in the frequency domain) and x (in the time domain) are OFDM symbols and *m=1, 2….M* denotes the number of iterations. The conventional ICF PAPR reduction scheme can be expressed as

$$\mathrm{x\hat{}(n)} = \begin{cases} \mathrm{Ae^{j\emptyset(n)}}, \text{if } |\mathrm{x(n)}| > A \\ \mathrm{x(n)}, \;\; \text{Otherwise} \end{cases} \quad (11)$$

Where x^(n) is the clipped OFDM symbol, A is the amplitude of OFDM symbol, γ is clipping ratio ($\gamma = \frac{A}{\sqrt{P_{avg}}}$), P_{avg} , and $\emptyset$(n) is the phase angle (Anoh *et al.*, 2017-1).

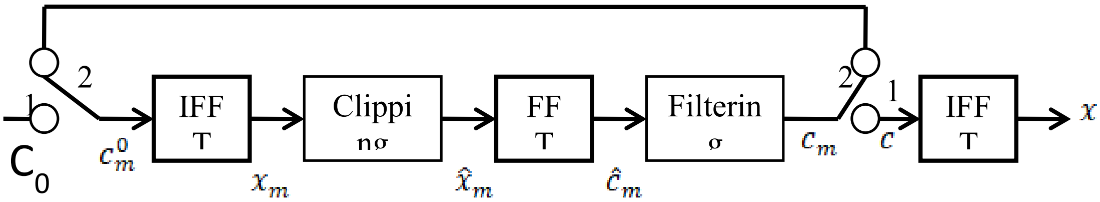

Fig 2. Conventional Iterative Clipping and Filtering block diagram

The amplitude clipping of the OFDM signal results in spectral re-growth and distortion within the band. So, to eliminate spectral re-growth, a rectangular window-based filter is employed to a baseband signal in the frequency domain, but it results in peak re-growth in the time domain. It is observed that the rate of convergence of iterative clipping and filtering becomes sluggish after first little iteration, and in-band distortion cannot be fully eliminated. After several iterations also clipping noise remains available in the output signal (Zhu *et al*., 2013). A new optimized ICF technique the rectangular-window filter in the conventional ICF method is replaced with a new convex optimization technique. This technique surprisingly reduces the number of iteration to accomplish the desired level of PAPR. The other advantages of said optimization technique are the sharp drop in CCDF; relatively a reduced amount of distortion and minimum emission out of the band is achieved (Armstrong, 2002).

ITERATIVE COMMANDING TRANSFORM & FILTERING (ICTF) TECHNIQUE

To lessen the effect of high PAPR the ICTF technique can be effectively implemented. This method is also used to improve BER while diminishing PAPR. ICTF technique can offer better BER performance without de-companding at the receiver of the OFDM system. First of all, peaks of original signals are compressed or attenuated at a specific level using companding. Secondly filtering is implemented in the frequency domain to minimize the 'out of band interference (OBI)'. Filtering in the frequency domain may introduce spectral regrowth, so to suppress these peaks both ICTF schemes can be implemented to have good PAPR performance and better BER (Wang *et al.*, 2015).

Companding transform is a proficient and less complex technique to diminish the PAPR for OFDM systems. But at the receiver end when inverse companding transform is employed on the OFDM signal, the output signal may produce severe distortion within the band and spectral regrowth. Using companding transform the original multi-carrier modulated signals converted into uniformly distributed signals, this method efficiently decreases PAPR. This technique can be efficiently used for various modulation schemes and sub-carrier sizes (Jiang *et al.*, 2006; Anoh *et al.*, 2017-2). Authors suggested that applying roots to nonlinearly increasing amplitude distribution, would change PDF function and thus minimize PAPR. The well-known 'µ-law companding (MC)' scheme for diminishing PAPR in multi-carrier modulated signals involves low power signal amplitude is expansion without affecting the signals with high amplitude. This confines the PAPR lessoning performance of the suggested ICTF technique. This technique includes concurrent suppression of high amplitudes and amplification of low amplitudes. For this purpose, Anoh et al., (2017-2) referred and suggested a root-based MC (RMC) scheme which can be effectively implemented for simultaneous compression and expansion of high amplitude and low amplitude signals respectively.

Selective mapping (SLM) technique

Many methods have been implemented and tested for reducing PAPR from the transmitted OFDM signal. The selective mapping technique has been observed most proficient method of PAPR reduction. The SLM can efficiently diminish PAPR at the desired level without introducing distortion in the transmitted OFDM signal (Gupta *et al.*, 2019; Badran and EI-Helw, 2011). Figure 3 shows the block diagram for conventional SLM, PAPR reduction scheme, where the input signal $X(n) = [X(0), X(1) \dots \dots X(N-1)]$ is multiplied with S number of phase sequences $P^s = [P_0^s, P_1^s \dots \dots P_{N-1}^s]^T$, here $p = e^{j\emptyset}$ and $\emptyset \in (0, 2\pi)$ for $s = 1,2 \dots .. S$, that generate alternative OFDM signal $X^s = [X^s(1), X^s(2), \dots \dots . X^s(N-1)]^T$. The IFFT of S phase sequences using N-point IFFT is used to produce independent OFDM sequences $X^s = [x^s(0), x^s(1), x^s(2) \dots \dots . x^s(N-1)]^T$. Among these X^s independent sequences $\hat{X} = X^{\hat{s}}$ with the lowest PAPR is chosen for transmission (Cho *et al.*, 2010).

$$\hat{X} = \underset{s=1,2,\dots S}{argmin} \left(\underset{n=0,1,2\dots N-1}{max} |x^s(n)| \right) \qquad (12)$$

In SLM technique distinctive phase sequences are chosen for diminishing the PAPR which very complex and monotonous process of locating optimal phase sequences (Gupta *et al.*, 2019). The SLM technique several independent OFDM signals are generated. From several independent data signals, the signal with optimum PAPR is chosen for transmission (Gupta and Singh, 2015). The 'side information (SI)' index of the chosen signal with minimum PAPR is transmitted to the receiver section for the recovery of the original data signal. But this results in data rate loss or reduction in throughput. (Badran and EI-Helw, 2011; Le Goff *et al.*, 2009). When the set of SI bits are transmitted along with the selected independent signal, the chances of flawed SI index detection have a significant effect on the error performance of the OFDM system.

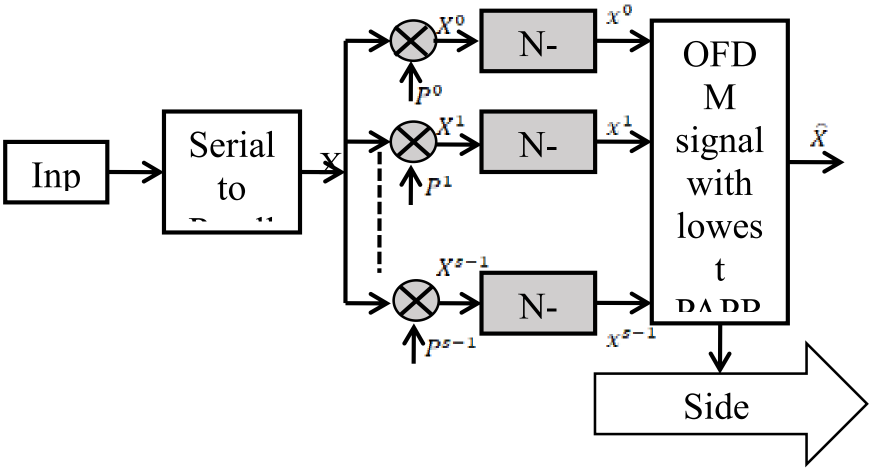

Fig 3. Block diagram of a conventional SLM scheme

Every time whenever incorrect SI index is detected complete data block is omitted or lost. Hence to protect SI index bits channel coding must be used, but this may result further into a complex system and delay in transmission (Le Goff *et al.*, 2009). One of the disadvantages of the SLM scheme is high computational complexity as a result of the generation of several alternative OFDM signals through IFFT (Heo *et al.*, 2007).

RESULTS AND DISCUSSION

Table1. Simulation parameters

Parameters used	**Description/Value**
Modulation scheme	QPSK
Number of Symbols (K)	64 and 128
Subcarriers per resource block (N)	4
Clipping Levels	1 to 6
Clipping Ratio (CR)	1.0, 1.2, 1.4, 2, 3 & 4
Cyclic Prefix / GI size	32
Bandwidth (BW)	1 MHz
Oversampling factor (L)	8
Sampling frequency, fs = BW*L	8 MHz
Carrier frequency, fc	2 MHz

This section is presenting simulated results for evaluating the performance of the proposed technique with others. Here we are considering only CIF and SLM schemes for reduction PAPR. The MATLAB software version 2014B is used for the simulation, including simulation parameters as depicted in table 1. Simulation outcomes portrayed in figure 4 and figure 5 shows that the proposed ICF technique shows the potential performance of minimizing PAPR compared to SLM schemes. It is observed from the simulation result that at the CCDF of 10^{-4}, the PAPR values for clip and filter levels: 1,2,3,4,5,6 are recorded as 8.5 dB, 6.7dB, 5.95 dB, 5.5 dB, 5.2 dB and 5.0 dB respectively. It is very clear from the figure 4 that, as the clipping level increases the PAPR decreases considerably. At the clipping level of 6, the proposed ICF scheme achieves notable reduction in PAPR up to 5 dB which is about 6.8 less than the original. Figure 5 shows Error performance with SLM reduction techniques where PAPR value is found to be 7.75 dB at the CCDF of 10^{-4}. Thus it is clear that proposed ICF scheme with 6 clipping and filtering levels outperform the SLM scheme by the PAPR of 2.75 dB. Figure 6 portrays the clipping and filtered OFDM signal. Figure 7 portrays the BER performance of proposed ICF scheme for PAPR reduction. It shows that at 12 dB SNR, the BER values for different clipping and filtering levels from 1 to 6 are 1.0×10^{-3} , 5.0×10^{-4} , 8.0×10^{-5}, 4.0×10^{-5} , 3.0×10^{-5} , and 3.0×10^{-5} respectively. At the clipping levels of 4 to 6, significant BER values are achieved.

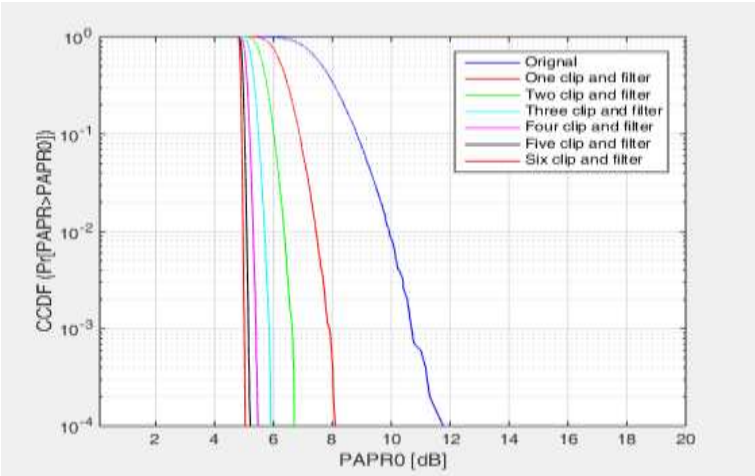

Fig 4. PAPR performance for clipping and filtering method

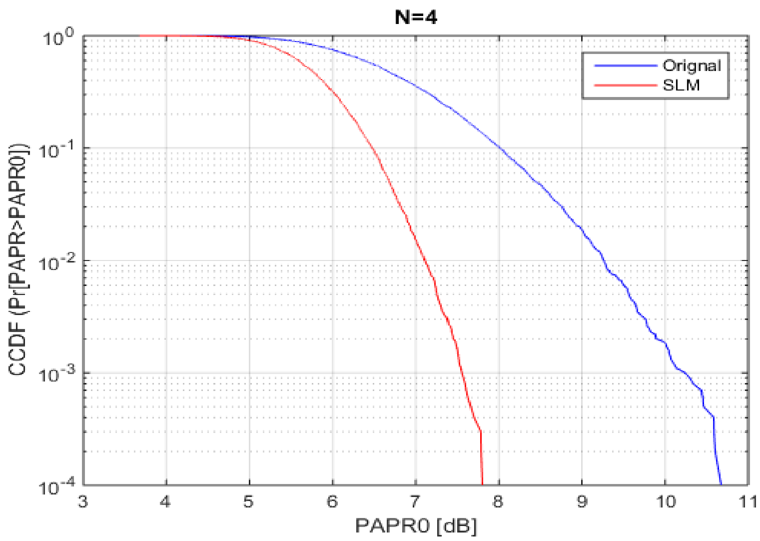

Fig 5. PAPR performance for Selective Mapping (SLM) scheme

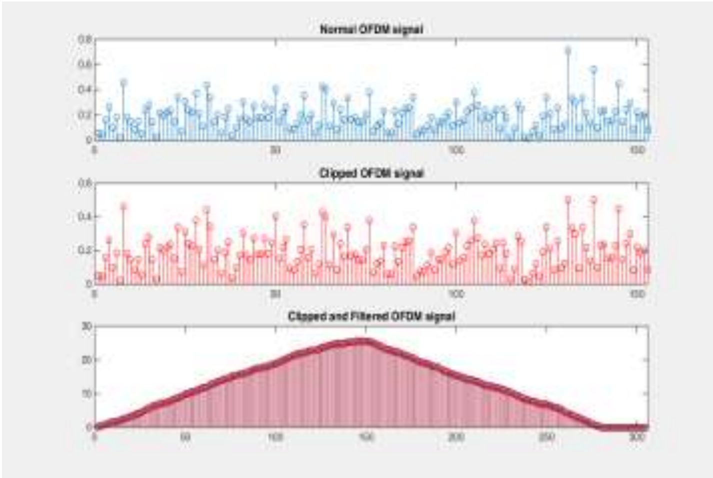

Fig 6. Cliping and fitered OFDM signal

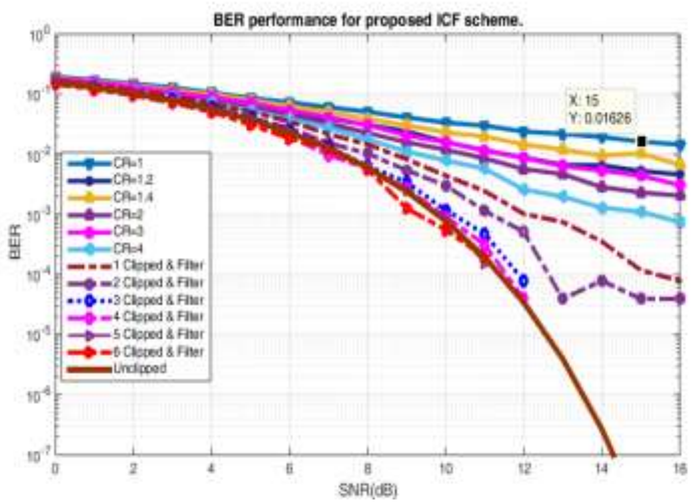

Figure 7. Error performances for different clipped ratio and clipped & filter

CONCLUSIONS

There are various schemes available for minimizing PAPR in the OFDM system including ICF, ICTF, SLM, PTS, Tone reservation, and many more. It is observed from the simulation outcomes that the ICF scheme still is the most favorable and less complex scheme that promises to optimize reduction in PAPR with minimum effect on system BER performance. It maintains the spectral efficiency without applying channel coding. Due to linear scaling, there is no need for the shaping of the signal. After analyzing both ICF and SLM schemes, the result shows that the ICF scheme is very successful and it has good prospects. From the simulation result of PAPR reduction using the ICF technique, it is very clearly seen that upon increasing the clipping and filtering level, the PAPR value decreases significantly but after a certain level (level 6) it decreases at slow rate. In the case of OFDM based system, there is a tradeoff between the PAPR and the BER, an attempt to reduce the PAPR may result in an increase of BER value. The same can be observed from figure 7, where at any SNR value the BER value due to the ICF scheme is slightly greater than that of the unclipped one. In the future, there is a scope for comparative study of ICF schemes with other techniques like ICTF, PTS, and so on.

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