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PAPR reduction in LTE network using both peak windowing and clipping techniques

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Abstract
Multicarrier technique orthogonal frequency division multiplexing (OFDM) modulation is a solution to provide high-speed and secured data transmission requirement in 4G technologies. Peak-to-average power ratio (PAPR) is one major drawback in OFDM system. Researches described several PAPR reduction techniques, notably peak windowing and clipping. The aim of this paper is to use these techniques to reduce PAPR. The research work describes clipping and windowing techniques such as quadratic amplitude modulation (QAM) and additive white Gaussian noise (AWGN) as channel condition. The simulation results show that in those techniques with clipping threshold level of 0.7, there is a reduction of PAPR of 8 dB, and the reduction of PAPR for the peak windowing when considering Kaiser window is about 11 dB.

Keywords: PAPR, Clipping techniques, Peak windowing, OFDM, LTE

Introduction

The demand for data transmission in mobile communication has increased consistently. OFDM system has gained interest in the fourth-generation mobile communication due to its ability to provide high bandwidth efficiency and high data rate in both digital audio and video broadcasting wireless communication.

The basic principle of OFDM is to split a high-data rate stream into a number of lower data rate streams in parallel using several orthogonal subcarriers. When the subcarriers have appropriate spacing and satisfy the orthogonality, their spectra will overlap [1–3]. The use of orthogonal subcarriers allowed the subcarrier's spectra to overlap, thus increasing the spectral efficiency. As long as orthogonality is maintained, it is possible to recover the individual subcarriers' signal despite their overlapping spectra. If the product of two deterministic signals is equal to zero, these signals are said to be orthogonal to each other [1]. OFDM offers many advantages over carrier modulation; however, the major difficulty with the scheme is the high peak-to-average power ratio (PAPR) that distorts the signal if the transmitter contains nonlinear components such as power amplifier, affects the signal and results in the attenuation of the received signal [4].

The high PAPR of OFDM means that if the signal is not to be distorted, many of the components in the transmitter and receiver must have a wide dynamic range. The output amplifier of the transmitter must be very linear over a wide range of signal levels. In wireless system, the expense and power consumption of these amplifiers are often the important design constraints [5, 6]. Moreover, the presence of a large number of subcarriers with varying amplitude results in high peak-to-average power ratio of the system (OFDM) and has implication in the efficiency of the radio frequency amplifier. This degrades the bit error rate and increases the cost of the system.

To respond to the abovementioned problems, different methods and techniques were proposed by researchers such as coding techniques, tone injection, filtering, oversampling and multiple signal representation. The main purpose of this study is to propose techniques for the reduction of peak-to-average power ratio in OFDM system with emphasis on 4G network. In this paper, two techniques are proposed to solve the problem observed when using the OFDM system: the peak windowing and the clipping techniques.

The behavior of the peak-to-average power ratio and bit error rate using reduction techniques were emphasized in this paper: first, this study considered the clipping technique by analyzing the performance of the system by allocating different clipping levels in the system, and analyzing the bit error rate and signal-to-noise ratio for clipped and conventional OFDM; second, designed and analyzed the reduction on PAPR using peak windowing technique. The results of the analyses are examined and a scheme for the reduction of PAPR in OFDM using peak windowing along with clipping is proposed. The tool used to perform simulations was MATLAB-R2015 and 2011b.

The paper is organized as follows: "Related study" discusses the results of various studies relevant to this study. "Methods" propose the technique introduced. "Discussion" presents the simulation results and the final section concludes the paper.

Related study

To come out with a good reduction in PAPR, researchers proposed the recursive Golay complementary sequence [7] and the results showed that the PAPR of the sequence is bounded up to 3.6 dB and the information rate is bounded up to 3.6 dB. The author of [8] proposed a PAPR reduction method with low computation complexity based on a combination of cuckoo search optimization algorithm with peak windowing scheme in OFDM system. In [9], the author proposed that new segmentation schemes to enhance the PAPR mitigation performance of the peak windowing algorithm rely upon the number of partitioned sub-blocks, the number of the phase rotation vectors, and the kind of the segmentation scheme utilized. The results demonstrate that the PAPR values at the complementary cumulative distribution function (CCDF) 10^{-3} are 10.96 dB for original OFDM, 7.62 dB for random search algorithm, 7.45 dB for PSO algorithm, 6.8 dB for cuckoo search algorithm and 6.37 dB for optimum algorithm.

A systematic comparison of different PAPR reduction methods in OFDM systems was conducted [10]. The research proposed simple techniques for the reduction of high peak-to-average power ratio based on clipping and differential scaling, in orthogonal frequency division multiplexing (OFDM). The proposed up- and downscaling techniques were to achieve PAPR reduction of the order of 8.5 dB from 12 dB PAPR initially. A reduction of 3.5 dB was achieved for PAPR when maintaining the bit error rate (BER) within a margin of three times the BER value at the performance bound at signal-to-noise ratio (SNR) of 10 dB. The performance comparison of two clipping-based filtering methods for PAPR reduction in OFDM signal [11] was proposed to solve the major generic problem of OFDM techniques which is high peak-to-average power ratio defined as the ratio of the peak power to the average power of the OFDM signal [12].

To solve the main problem in OFDM, the high peak-to-average power ratio, using windowing technique and to improve the BER, the technique proposed is Kaiser and Hamming which uses cumulative distribution function. The result simulation shows that Hamming and Kaiser have a lot of differences on the same spectrum characteristic [13]: in Hamming windowing technique, at normalized frequencies −1 and 0.9989 MHz, the spectral densities are −81.5 and −46.05; in Kaiser windowing technique, at normalized frequencies −2 and 1.998, the spectral densities are −81.5 and −46.05. The power spectral frequency is same for different normalized frequency but they are equal for maximum value.

Methods

Mathematical model

In OFDM system, the analysis of the PAPR performance is similar to the OFDM system with single antenna. The PARP of the entire system is defined as the maximum of the PAPRs among all the transmit antennae [14, 15]. Equation 1 gives a mathematical representation of PARP where $s(n)$ is peak-to-average power ratio of OFDM signals or the ratio between the maximum instantaneous power and its average power:

$$s(n) = 1 \Big/ \sqrt{N} \sum_{K=0}^{N-1} e^{j2\pi kn/N}. \tag{1}$$

$X(N)$ represents the transmitted information in the nth subcarriers and N the number of subcarriers. Normally, the instantaneous output of the OFDM system has a large fluctuation compared to single carrier system.

Therefore, the peak-to-average power ratio is defined as

$$\mathrm{PAPR} = \max|s(n)|^2/E|s(n)|^2, \tag{2}$$

where $\max|s(n)|^2$ is the maximum power ratio of the OFDM and $E|s(n)|^2$ is the average power ratio of the OFDM signal.

Windowing

Windowing consists of multiplying the signal by finite length window with amptitude that varies smoothly toward zero at the edges [15]. In this study, we considered three windows:

Hamming window

$$\begin{aligned} \mathrm{Whamm} =\ & 0.54 + 0.46\cos\left(\tfrac{2\pi n}{N} - 1\right) \quad \text{for } 0 \le n \ge N-1 \\ =\ & 0 \ \text{otherwise}, \end{aligned} \tag{3}$$

where N represents the width in samples of a discrete time of window function.

Hanning window

$$\mathrm{Hann} = 0.5 + 0.5\cos\left(\frac{2\pi n}{N} - 1\right) \quad \text{for } 0 \le n \ge N-1, \tag{4}$$

where N represents the width in samples of a discrete time of window function.

Kaiser window

$$\begin{aligned} \text{Wkaiser} &= I0\left(\sqrt[\pi\alpha]{1-\left(\frac{2n}{N-1}-1\right)2} \right) \Big/ I0(\pi\alpha); \quad 0 \le n \ge N-1 \\ &= 0 \text{ otherwise,} \end{aligned} \tag{5}$$

where N is the length of the sequence, $I0$ is the zeroth-order modified Bessel function and α is the arbitrary non-negative real number that determines the shape of the window.

Considering the envelop of the OFDM signal to be Se(t) and the window function Wf, the function is expressed as [16, 17]

$$\text{Sp}(t) = \text{Se}(t) * \text{Wf}. \tag{6}$$

The PAPR after peak windowing is expressed as

$$\text{PAPR} = \max|\text{Sp}(t)|^2 / E|\text{Sp}(t)|^2. \tag{7}$$

Clipping method

The clipping techniques used reduce PAPR by clipping the high peak of the OFDM signals by limiting the peak amplitude value to the threshold value [18]. Mathematically, clipping techniques can be defined as

$$B(x) = \begin{cases} X \le C_\text{L} \\ C_\text{L} \text{ else} \end{cases}, \tag{8}$$

where $B(x)$, C_L, and X are clipped signal, clipping level, and input signal, respectively. The modified PAPR resulting from clipping can be expressed as

$$\text{PAPR} = C_\text{L}^2 / E\left\{ |B(x)|^2 \right\}. \tag{9}$$

Amplitude above the threshold value is clipped and information is lost. Due to the nonlinear operation, clipping causes the in-band distortion and out-band radiation. Due to the in-band distortion, BER performance is reduced [19, 20].

Discussion

PAPR reduction using clipping method

To come out with comprehensive results in the OFDM system, 256 subcarriers operating in 2 bits/s using the quadrature amplitude modulation were considered and the output was oversampled when passed through the inverse fast Fourier transformer. The clipping method was used to eliminate the peak values of the power and consider the BER performance. Table 1 shows the simulation parameters used.

The results highlighted in Fig. 1 present the performance of the OFDM system when considering the clipping techniques and also when the reduction techniques are not considered.

The tool used for the evaluation of the PAPR is the complementary cumulative distribution function (CCDF) to estimate the bound for the minimum number of redundancy bits. From the results above, one can observe the contribution of the clipping technique when comparing with the conventional OFDM. Quantitatively, there is reduction of

Table 1 Simulation parameters for the clipping technique

Parameters	Values used
Number of subcarrier	256,512
Oversampling rate	4
Bit per symbol	2
FFT size	1024
Number of OFDM block	10,000
Clipping levels	0.7
Modulation	QAM
Channel	AWGN

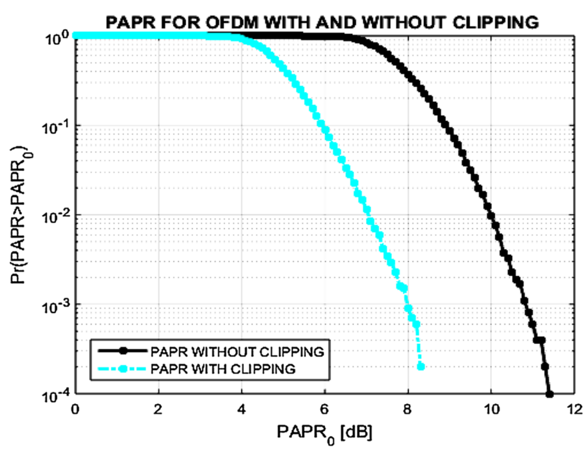

Fig. 1 Representation of CCDF of PAPR of clipping and conventional OFDM

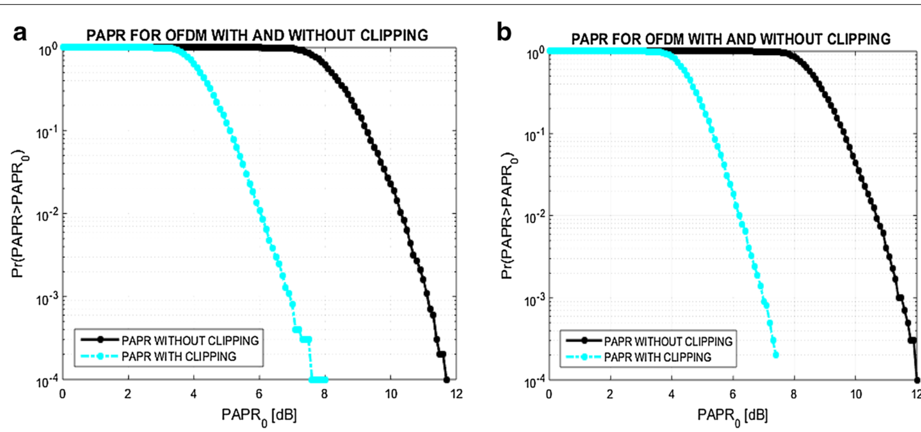

Fig. 2 **a** The number of subcarriers = 512; **b** number of subcarriers = 1024

more than 2 dB of PAPR when considering a probability of 10^{-4}. Another important observation is that the effect of clipping level on the reduction of PAPR and on the BER.

As mentioned previously, one of the parameters that can influence the PAPR is the number of subcarriers; from Fig. 2a, when considering the number of subcarriers to

Table 2 Simulation parameters on the effect of threshold clipping level

Parameters	Values used
Number of subcarrier	256
Oversampling rate	4
Bit per symbol	2
FFT size	1024
Number of OFDM block	10,000
Clipping levels	0.6:0.7:0.8:0.9
Modulation	QAM
Channel	AWGN

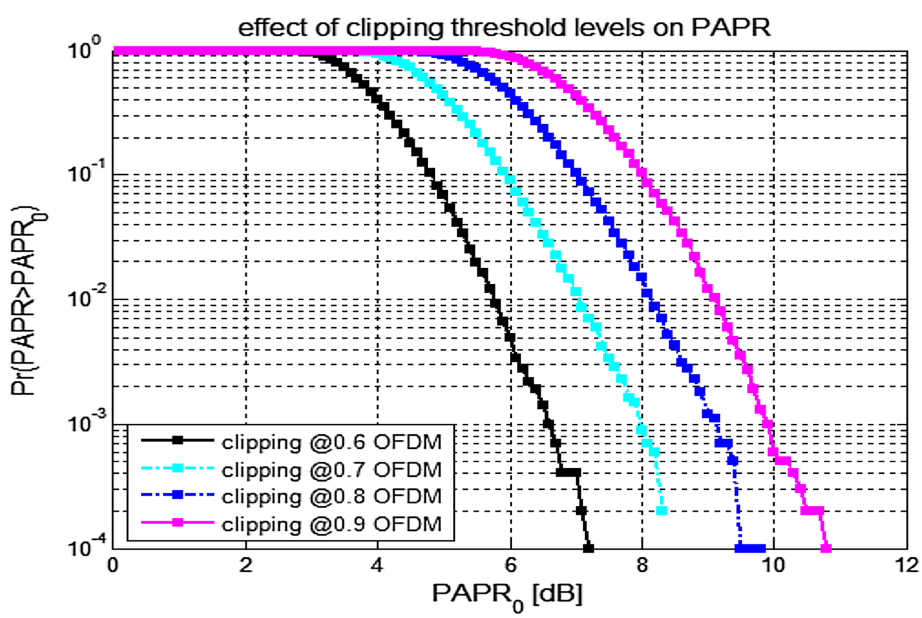

Fig. 3 CCDF of PAPR at different clipping levels

be equal to 512 at the probability of 10^{-4}, the value of PAPR is reduced compared to the value obtained in Fig. 1.

In a similar comparison considering the number of subcarrier to be equal to 1024 (see Fig. 2b), there is an improvement in PAPR using the clipping techniques. Therefore, when increasing the number of subcarriers, the OFDM signal degraded and then distortion and noises were observed. Table 2 shows the simulation parameters used.

The effect of threshold clipping level was obtained using the above simulation parameters. From Fig. 3, considering the threshold clipping level at 0.6, 0.7, 0.8 and 0.9 implies good performance in the reduction of PAPR.

For the threshold clipping level at 0.6, compared to the threshold level at 0.9, there is an impressive reduction of PAPR of about 3.5 dB; however, this does not mean that the system has a good performance in BER. Figure 4 shows the comparison between SNR vs BER of a clipped signal and conventional OFDM.

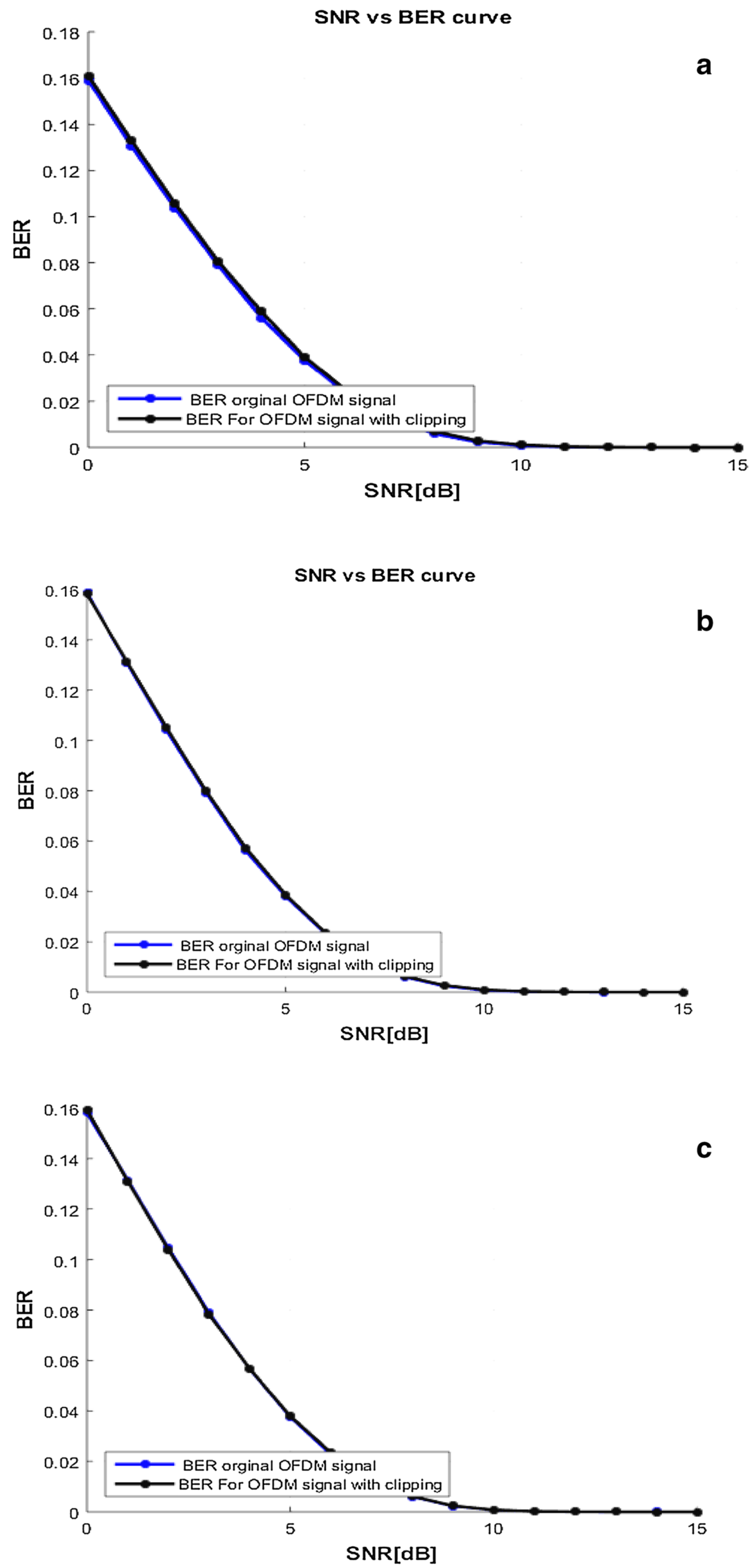

Fig. 4 **a** SNR vs BER for clipped and conventional OFDM signals, clipping level 0.7; **b** SNR vs BER for clipped and conventional OFDM signals, clipping level 0.8; **c** SNR vs BER for clipped and conventional OFDM signals, clipping level 0.9

When comparing the results obtained in Fig. 3 when allocating different values of clipping threshold levels with the results obtained in Fig. 4a–c, the following conclusion can be made: in clipping techniques, allocating a small value of clipping level reduces the PAPR considerably. At a clipping threshold of level 0.7 in Fig. 3, a reduction of PAPR value of more than 8 dB was observed and when comparing to the performance of the BER, a slight change introduced by clipping can be observed.

PAPR reduction using peak windowing

Peak windowing consists of removing larger peaks at the cost of increased BER and out of band radiation. It provides better PAPR migration with better spectral properties. Large signal is multiplied with a specific window. The window size should be narrow; otherwise, it affects the number of signal samples, which increases the BER (Table 3).

To evaluate the performance of types of peak windowing on the reduction of PAPR, Hamming, Hanning and Kaiser windowing were considered. The complementary cumulative distribution functions indicated that when a probability of value 10^{-4} is considered, the reduction of PAPR for the peak windowing when considering Kaiser window is about 11 dB and more compared to other techniques. If comparing the three techniques, Kaiser window is proposed to reduce the PAPR (Fig. 5 and Table 4).

Figure 6 shows that the Hamming and Hanning techniques provide the same BER; however, as per the result, Hanning window gives better PAPR performance.

Conclusion

The orthogonality principle allows the best use of bandwidth; however, this does not prevent the system to suffer from high peak-to-average power ratio. The large peak-to-average power ratio in OFDM is degrading due to low power efficiency in nonlinear power amplification. To minimize this drawback, clipping and peak windowing techniques were proposed to improve the performance of the OFDM system. Simulation results showed that with a clipping threshold level of 0.7, there is a reduction of PAPR of 8 dB and the reduction of PAPR for the peak windowing when considering Kaiser window is about 11 dB. Therefore, having an improved BER reduces the complexity of

Table 3 Parameters considered for peak windowing techniques

Parameters	Values used
Number of subcarrier	256
Oversampling rate	4
Bit per symbol	2
FFT size	1024
Number of OFDM block	10,000
Clipping levels	0.8
Window size	QAM
Window function	Hamming, Hanning and Kaiser
Channel	AWGN

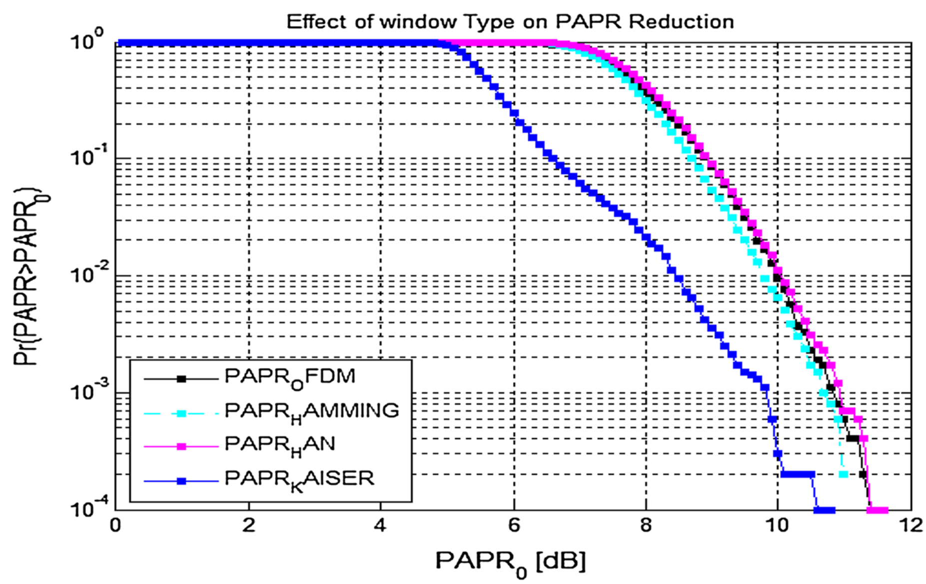

Fig. 5 CCDF performance for PAPR reduction for Hamming, Hanning and Kaiser windows

Table 4 Parameters considered for BER

Parameters	Values used
Number of subcarrier	512
Oversampling rate	4
Bit per symbol	2
FFT size	1024
Number of OFDM block	10,000
Clipping levels	0.8
Window size	QAM
Window function	Hamming, Hanning and Kaiser
Channel	AWGN

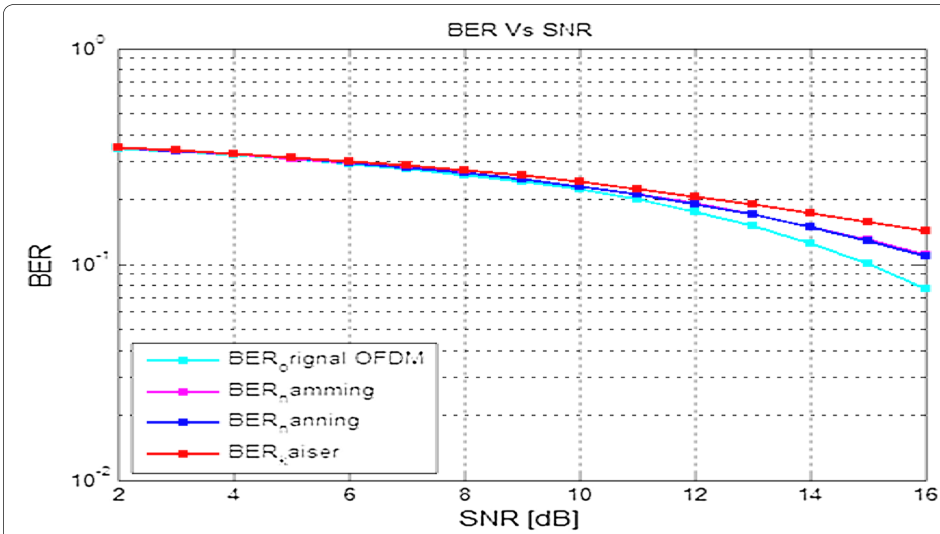

Fig. 6 BER performance for different windowing from the result presented

OFDM system, facilitates the implementation cost and improves the power consumption. Future direction of this work is to further investigate two techniques using different modulation schemes.

Abbreviations

OFDM: multicarrier technique orthogonal frequency division multiplexing; PAPR: peak-to-average power ratio; QAM: quadratic amplitude modulation; AWGN: additive white Gaussian noise; CCDF: complementary cumulative distribution function (CCDF); BER: bit error rate; SNR: signal-to-noise ratio.

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Authors' contributions

RM is the corresponding author, and was involved in data collection, data analysis, mathematical model design and simulation setup. ML was responsible for analyzing the related work and determining the simulation components needed to setup the simulation experiments. MA was responsible for simulation result analysis. JN was responsible for overall writing of the manuscript and putting together all needed formats for journal submission. GB was responsible for organizing filed visits and coordinating the linkage with telecom companies. All authors have contributed to the content of this paper and have agreed to submission policy of this journal. All authors read and approved the final manuscript.

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Availability of data and materials

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Competing interests

To the best of our knowledge, all authors have no conflict of interest whether financially or any other thing.

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