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Proposed Hybrid Technique for Improving PAPR in LTE-SISO-OFDM Systems

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Abstract: The increasing use of wireless data has been created a need for continuous innovations in wireless data technology to provide greater capabilities and higher quality services. OFDM is one of the most important modulation techniques in wireless communication systems and is the fundamental technology in modern communication systems such as 5G cellular networks and WiMAX. In this research, the LTE-SISO- OFDM system has been studied and then has been improved by reducing the Peak to Average Power Ratio (PAPR) of the signal. A hybrid technique has been proposed, combining several techniques including New Error Function Companding (NERF), Absolute Exponential Companding (AEXP), and Discrete Sine Transform (DST). Based on the obtained results, the effectiveness of the proposed technique has been proved through the reduction of PAPR and Bit Error Rate (BER) for different values of Signal to Noise Ratio (SNR), thereby improving the reliability and quality of service of the system. All simulation experiences have been performed using the MATLAB program.

Keywords: LTE-SISO-OFDM, PAPR, BER, SNR, NERF, AEXP, DST.

1 Introduction

Wireless mobile communications have evolved historically from the first generation when this system was analog and only provided voice services security. Then came the second generation of digital mobile communication systems that had better performance using TDMA or FDMA technologies, but it was limited by the bandwidth. After that, the third generation appeared to enhance the data rate, but the continuous development in multimedia applications made the data rate used insufficient. Wireless communication must have high spectral efficiency and resistance to channel fading in a multi-path environment, which is difficult to achieve with traditional modulation techniques. The LTE- SISO-OFDM system is one of the most common systems in wireless communication systems, adopted in many wireless standards, and in the fifth generation of cellular communication systems due to its spectral efficiency and high data transmission rates it provides [1].

As the LTE-SISO-OFDM system is one of the most important technologies in wireless networks, it has received significant attention from researchers due to the improvements it provides in increasing data transmission rates and the reliability of this data. There are many literatures that have studied the LTE-SISO-OFDM system and methods to improve it by reducing PAPR. Seven new hybrid methods based on a ZCT mix with different signal compression techniques, including RCT, NERF, AEXP, Log R, COS, and Tanh R, have been proposed in [2]. Additionally, the seventh hybrid method, ZCT with the proposed Advanced AEXP technique, has been developed. Results showed that these hybrid methods performed better in reducing PAPR, with the best results achieved using the ZCT method with AAEXP compared to other techniques.

The Airy Companding Transform technique has been studied to reduce PAPR in LTE uplink SC-FDMA systems and has been compared with NERF and u-law techniques [3]. Results showed that using the Airy Companding Transform reduced PAPR to 7.14dB when a = 2 and 6.94 dB when a = 2.5. Researchers have been found the proposed method effective in LTE communication systems due to its simplicity and ability

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to reduce PAPR without increasing the transmitted signal power.

The performance of various signal compression techniques, including NERF, AEXP, A-law, and u-law, have been studied to reduce PAPR in OFDM systems [4]. These techniques were compared in terms of BER, PAPR, and average power. Results showed that the AEXP technique achieved the best system performance compared to other techniques, reducing PAPR to dB4.25.

In [5], the researchers have been proposed three techniques, T-SLM, T-PTS-I, and T-PTS-II, to reduce PAPR in OFDM systems. These techniques improved performance and reduced PAPR on traditional SLM and PTS schemes while also reducing computational complexity by 20% compared to traditional techniques that use fast Fourier transform (FFT).

The IMADJS technique has been proposed to reduce PAPR in OFDM systems and has been compared it with AEXP, NERF, and u-law in terms of PAPR, BER, and power spectral density (PSD) [6]. The IMADJS technique was found to have the least impact on the original signal's spectral power, achieved the lowest BER, and had the best result in reducing PAPR compared to other techniques.

The NERF technique has been proposed to reduce PAPR in LTE uplink SC-FDMA systems and compared with u-law [7]. This technique was applied in two systems, Distributed FDMA (DFDMA) and Localized FDMA (LFDMA), and the results showed its effectiveness in reducing PAPR, with a reduction of 3.61 dB in LFDMA and 3.33 dB in DFDMA, and a clear improvement in BER compared to u-law.

2 PAPR of LTE OFDM System

Multiple carrier systems suffer from the problem of high peak-to- average power ratio (PAPR), which occurs when independent carriers overlap with each other. This results in a signal with high power compared to the average signal power, and the difference between these two values is known as PAPR, as shown in figure 1 [8].

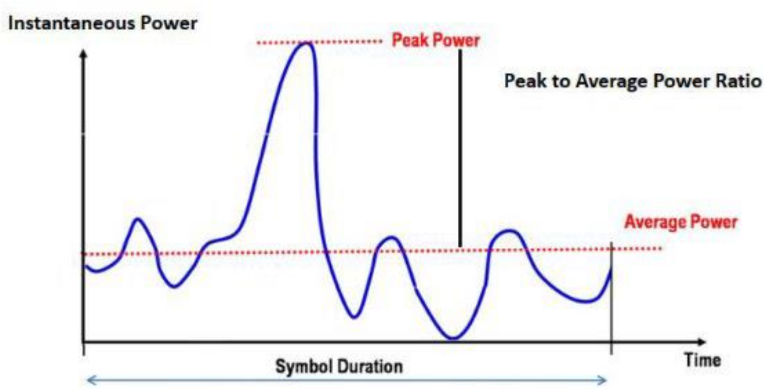

Figure 1: PAPR in OFDM

Figure 1, illustrates the difference between the high energy value and the average energy value of a signal, which is known as Peak-to- Average Power Ratio (PAPR). This phenomenon occurs in multi-carrier systems when independent carriers interfere with each other.

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The PAPR ratio for a continuous-time OFDM signal can be defined as the ratio between the maximum power of the signal at a specific time and the average power of the signal, assuming that x(t) represents the transmitted OFDM signal. Therefore, the PAPR can be calculated as:

$$PAPR[x(t)] = \frac{MAX_{0\le t\le T_s}[|\mathrm{x(t)}|^2]}{P_{av}} \tag{1}$$

Where p_{av} is the average power of the signal x(t) and can be calculated in the frequency domain because the inverse Fourier transform (IFTT) is very useful for OFDM symbols [9].
For an intermittent OFDM signal, the PAPR is equal:

$$PAPR[x(n)] = \frac{\underset{0\le n\le N_L}{MAX}[|\mathrm{x(n)}|^2]}{E[|\mathrm{x(n)}|^2]} \tag{2}$$

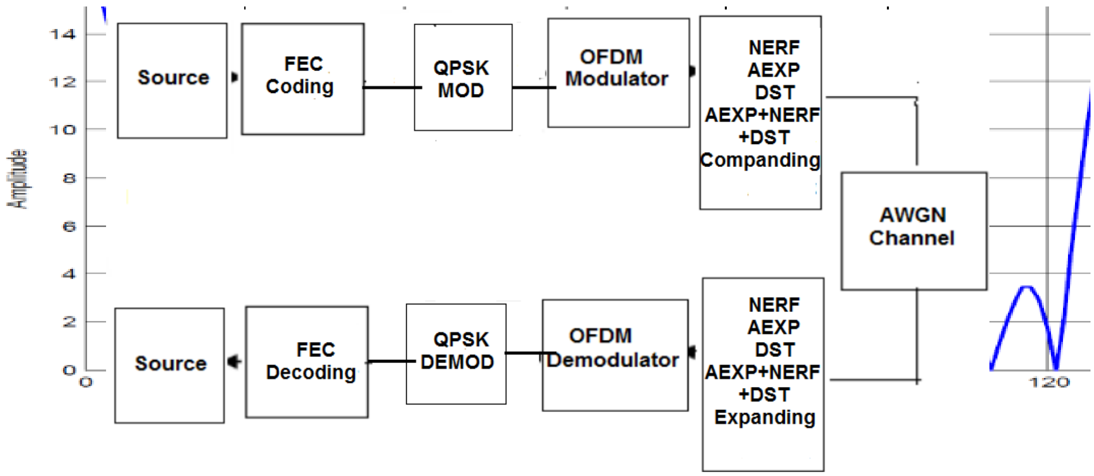
$$PAPR[x(n)]\ at\ (\mathrm{dB}) = 10log_{10}\frac{\underset{0\le n\le N_L}{MAX}[|\mathrm{x(n)}|^2]}{E[|\mathrm{x(n)}|^2]} \tag{3}$$

Where E[ ] denotes the mathematical expectation and N represents the total number of subcarriers.

The energy characteristics can also be described by determining the crest factor (CF), which is defined as the ratio between the peak capacity of the OFDM signal, x(t), and the root-mean-square (RMS) of the waveform. It can be written as follows:

$$CF = \frac{MAX|\mathrm{x(t)}|}{E[||\mathrm{x(n)}|^2|]} = \sqrt{PAPR} \tag{4}$$

In most cases, the peak value of the signal, |x(t)|, is equal to the peak capacity. However, from figure 2, it can be observed that the occurrence of peak widening is very rare. Therefore, it is not practical to use the maximum value of |x(t)| to represent the peak value in real-time applications. Instead, the peak-to-average power ratio (PAPR) of OFDM signals is usually measured using specific descriptive statistics related to probability [10].



3 Complementary Cumulative Distributive Function (CCDF)

The CCDF (Complementary Cumulative Distribution Function) is a practical indicator for evaluating the PAPR. It measures the ability to reduce the PAPR by reducing the CCDF value. The CCDF represents the probability that the envelope of an OFDM signal exceeds a certain value of PAPR. It is defined as [11]:

$$CCDF[PAPR(X^N(t))] = prop[PAPR\big(x^n(t)\big) > \delta] \tag{5}$$

According to the central limit theory, the OFDM signal follows a Rayleigh distribution, and therefore its power follows an exponential distribution. As a result, the cumulative distribution function of the OFDM signal is given by:

$$CDF = 1 - e^{-\delta\delta} \tag{6}$$

The probability that the PAPR value of the OFDM signal with N carriers is below a threshold δ is the probability that all samples of the signal (N samples) are below the threshold δ. Assuming that the OFDM samples are independent, we can express this relationship as follows:

$$prop(PAPR < \delta\delta) = (1 - e^{-\delta\delta}) \tag{7}$$

$$CCDF\big[PAPR\big(x^n(t)\big)\big] = 1 - (1 - e^{-\delta\delta})^N \tag{8}$$

4 Proposed PAPR of LTE SISO OFDM System

A block diagram for LTE SISO-OFDM system model is shown in figure 3, where the source generates 2.4 Mbps stream of bits that have equal probability and After applying the FEC encoding, this data modulated with QPSK modulation scheme producing frequency domain symbols X = [X0, X1, ..., XN−1]^T, and then X passes through the OFDM modulator and then PAPR reduction techniques are applied.

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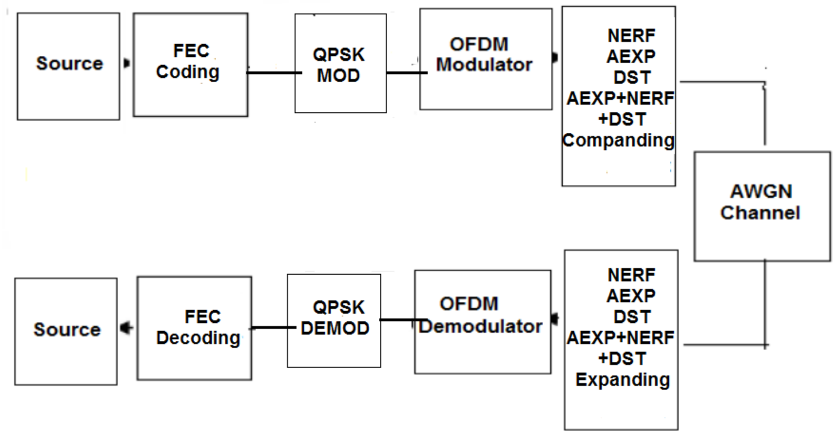

Figure 3: The studied LTE SISO-OFDM Model

5 PAPR reduction techniques

As mentioned earlier, high values of PAPR lead to saturation in the power amplifier at the transmitter, causing inter-symbol interference (ISI). This also results in a collapse in the bit error rate. One proposed solution to the power amplifier problem is to reduce the average power value so that the signal's range is confined within the linear region of the power amplifier. However, this solution leads to a decrease in signal-to- noise ratio and consequently an increase in bit error rate.

Therefore, it is better to solve this problem using methods that reduce the peak value of the signal, i.e., reducing the PAPR value. We can generally classify PAPR reduction techniques into the following types:

1. Signal Distortion techniques: These techniques involve distorting the signal to reduce its peak value.
2. Multiple Signaling and Probabilistic techniques: These techniques involve using multiple signals or probabilistic methods to reduce the peak value of the signal.
3. Coding Techniques: These techniques involve using coding schemes to reduce the peak value of the signal.
4. Figure 4 illustrates the different techniques used under the aforementioned categories [11].

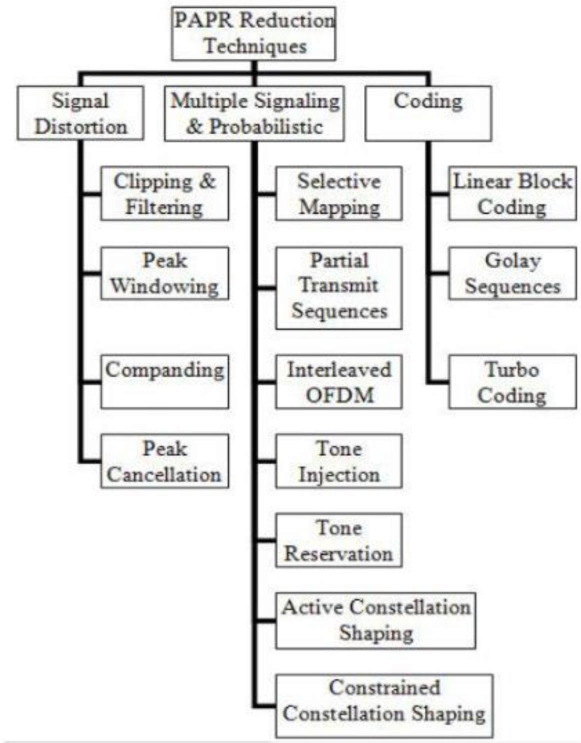

Figure 4: Different techniques for reducing PAPR

6 PAPR techniques used in simulation

6.1 AEXP (Absolute Exponential companding)

The equation of the AEXP technique is given according to the relation [12]:

$$h(x) = sgn(\mathrm{x})\sqrt[d]{\alpha[1 - \mathrm{Exp}(\frac{|x|^2}{\sigma^2})]} \tag{9}$$

Where sgn(x) is sign function, Exp represents constant which change from 2.7 to 1000, $\sigma 2$is the variance of the input signal, and the positive constant α determines the average power output signals in order to keep the input and output signals at the same average power level, d is the pressure rank and α is given according to the relationship [12]:

$$\alpha = \left(\frac{E\{|X|^2\}}{E\left\{\sqrt[d]{\left[1 - \exp\left(\frac{|x|^2}{\sigma^2}\right)\right]^2}\right\}}\right)^{\frac{d}{2}} \tag{10}$$

The inverse transformation of the AEXP technique is given by the relation [12]:

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$$h^{-1}(x) = sgn(x)\left|\sqrt{-\sigma^2 log_e\left(1-\frac{|x|^{\frac{2}{d}}}{\propto}\right)}\right| \quad (11)$$

The best value for d, which gives the lowest value for PAPR, is 1.3 [4].

6.2 NERF (New error function Companding)

This technique is based on the error function erf, the NERF equation is given by the relation [13]:

$$\mathrm{h}(x) = 2\sigma\,\mathrm{erf}\left(\frac{|x|}{\sqrt{2}\,\sigma}\right)\mathrm{sgn(x)} \quad (12)$$

The inverse transformation of NERF is given by the relation [12]:

$$\mathrm{h}(x)^{-1} = \sqrt{2\sigma}\,\mathrm{erf}\left(\frac{|x|}{2\,\sigma}\right)\mathrm{sgn(x)} \quad (13)$$

6.3 DST (Discrete Sine Transform)

The DST transformation relation is given according to the following [14]:

$$X_k = \sum_{n=0}^{N-1} x_n \cos\left[\frac{\pi}{N+1}(n+1)(k+1)\right] \; k = 0,1,\ldots.n-1 \quad (14)$$

A hybrid technology has been proposed, which is an integration of previous technologies (AEXP + NERF + DST).

7 Simulation Results

This part of the work demonstrates the impact of applying PAPR reduction techniques on an OFDM system. The work was implemented using the MATLAB programming environment with the simulation parameters shown in Table 1 as follows:

Table 1: parameters used in the simulation

FFT size	128
Spacing frequency	15 KHz
BW	1.25MHz
No symbol	1000
Sampling frequency	192MHz
Modulated type	QPSK
Channel type	AWGN
SNR range	0 dB to 30 dB

Initially, the performance of an OFDM system was evaluated without using PAPR reduction techniques in order to compare it with the performance after using these techniques and find the amount of improvement in each technique and its impact on the bit error rate (BER). The PAPR of the transmitted OFDM signal was measured according to the following equation for a discrete signal x(n):

$$PAPR(X[N]) = \frac{max|x[n]|^2}{E(|x[n]|^2)} \quad (15)$$

After performing the simulation parameters shown in table 1, we get the figure 5 and the figure 6.

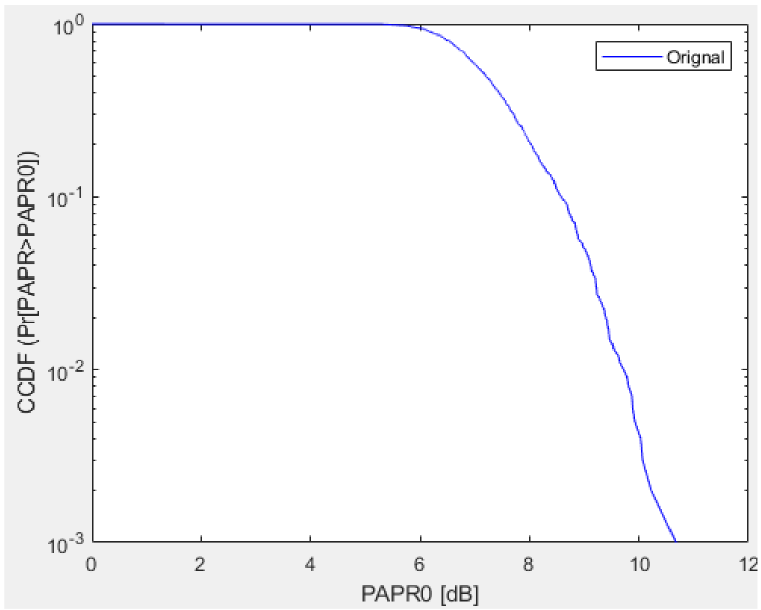

Figure 5: CCDF of PAPR in the LTE-SISO-OFDM system without the use of PAPR reduction techniques

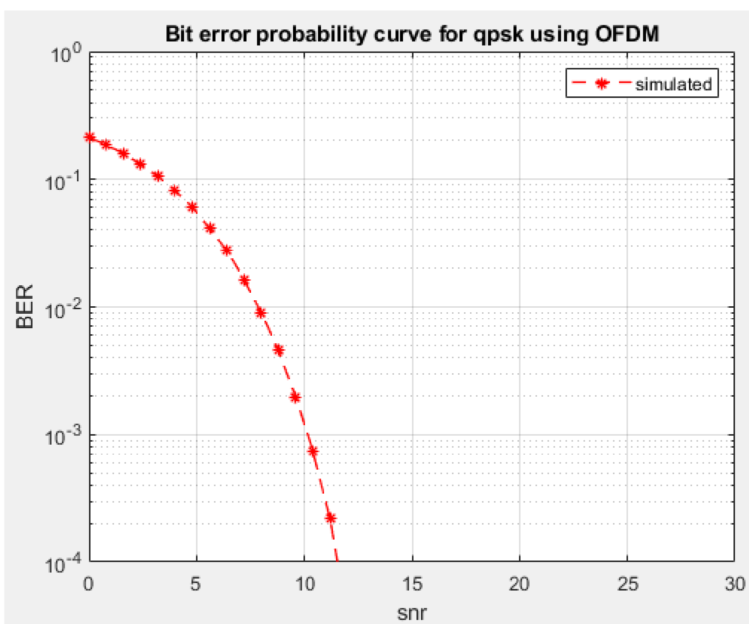

Figure 6: BER for the LTE-SISO-OFDM OFDM system without using PAPR reduction techniques

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Figure 5, shows that the value of CCDF is dB10.676, and figure 6 shows that when the bit error rate (BER) = 10^{-4}, the signal-to-noise ratio (SNR) is 11.4314 dB, and the PAPR value is dB25.6015 in the case of no application of any PAPR reduction techniques, which is a high value.

PAPR reduction techniques and the proposed hybrid technique mentioned earlier were applied. Figure 7, shows the CCDF of PAPR before and after applying these techniques, and table 2 compares the CCDF values and PAPR values among all techniques.

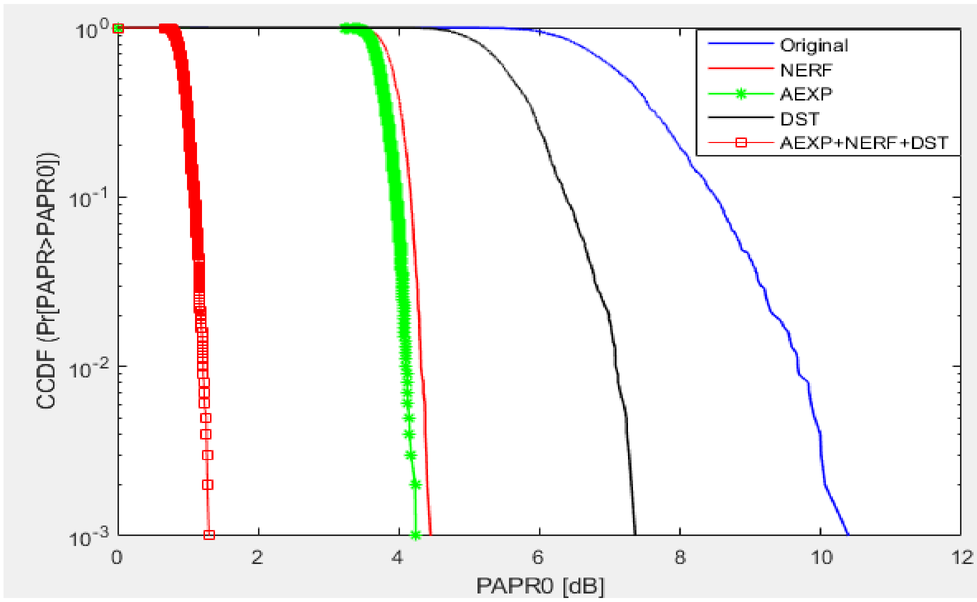

Figure 7: F performance for proposed hybrid (AEXP+NERF+DST) scheme compared to AEXP, NERF, DST and original for LTE SISO-OFDM system

Table 2: Comparison of CCDF and PAPR values between all technologies

	Original	NERF	AEXP	DST	AEXP + NERF + DST
PAPR (dB)	25.6015	10.17	9.61	.182	2.75
CCDF of PAPR (dB)	10.676	4.43	4.14	7.66	1.29

From figure 7 and table 2, we observe that the proposed hybrid technique achieved better performance in terms of PAPR and CCDF of PAPR. The PAPR was reduced to 2.75 dB when using the AEXP+NERF+DCT technique, resulting in an improvement of 22.8515 dB. The CCDF of PAPR value was 1.29 dB, indicating an improvement of 9.386 dB.

The bit error rate (BER) was also studied for different SNR values before and after applying PAPR techniques. Figure 8 and table 3 show the results obtained.

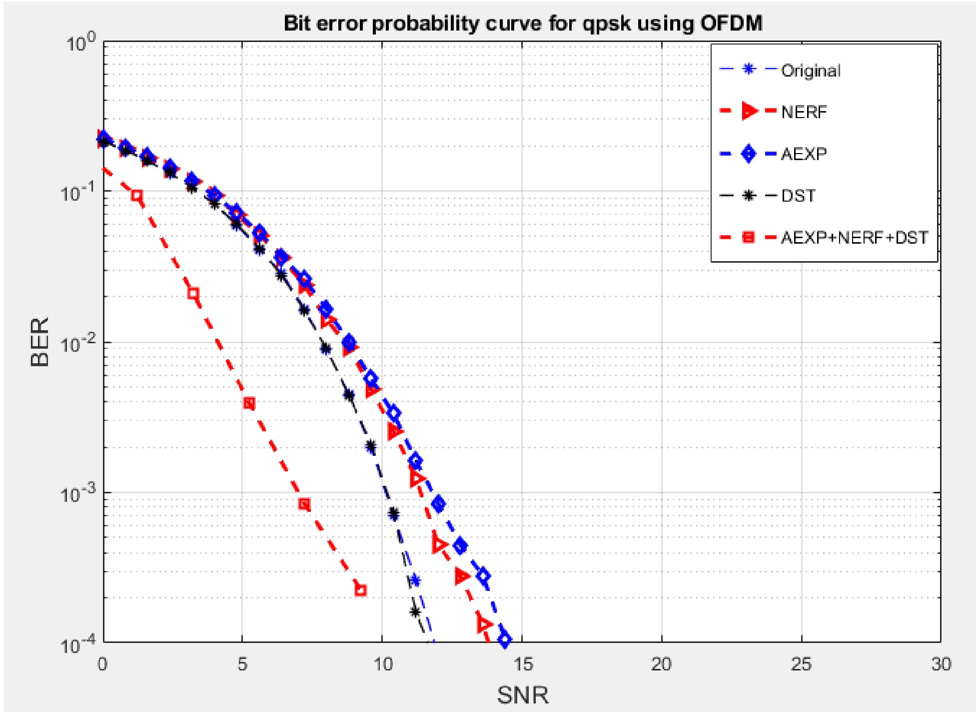

Figure 8: BER performance for proposed hybrid (AEXP+NERF+DST) scheme compared to AEXP, NERF, DST and original for LTE SISO-OFDM system

Table 3: R values in the LTE-SISO-OFDM systems before and after the application of PAPR technologies and for different SNR values

SNR (dB)	Original	NERF	AEXP	DST	AEXP + NERF + DST
1.22	0.184	0.183	0.183	0.183	0.0928
3.2	0.104	0.101	0.116	0.105	0.020
5.2	0.05	0.05	0.05	0.0417	0.0039
7.2	0.026	0.026	0.026	0.0161	0.0008

From figure 8 and table 3, we can conclude that the proposed hybrid technique achieved good performance in terms of bit error rate (BER). The AEXP+NERF+DCT technique resulted in the best improvement in BER.

8 Conclusions and recommendations

In this research, an analytical study of OFDM systems was conducted using Matlab software, and a hybrid technique was proposed to reduce PAPR. The technique involved the integration of three techniques, AEXP, NERF, and DST. The effectiveness of the proposed technique in reducing PAPR and improving system performance by reducing bit error rate (BER) was demonstrated.

The conclusion was that the proposed hybrid technique achieved improvement in the performance of the OFDM system in terms of PAPR and CCDF of PAPR. The PAPR was reduced by 2.75 dB when using the AEXP+NERF+DST technique, which represents an improvement of 22.8515 dB. The CCDF of PAPR value was 1.29 dB, which represents an improvement of 9.386 dB. The BER was also improved using the proposed hybrid technique, with the AEXP+NERF+DST technique achieving the best improvement

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compared to other proposed techniques.

Future research can explore other techniques such as Rooting Companding Technique (RCT) and integrate them with AEXP, NERF, and DST techniques. Additionally, other modulation types such as QAM and BPSK can be studied to investigate their impact on PAPR, and techniques for reducing PAPR in MIMO-OFDM systems can also be explored

Conflicts of Interest Statement

The authors certify that they have NO affiliations with or involvement in any organization or entity with any financial interest (such as honoraria; educational grants; participation in speakers' bureaus; membership, employment, consultancies, stock ownership, or other equity interest; and expert testimony or patent-licensing arrangements), or non-financial interest (such as personal or professional relationships, affiliations, knowledge or beliefs) in the subject matter or materials discussed in this manuscript.

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