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Improving Wireless Communication OFDM systems based on image processing

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Abstract

One of the most common methods used in modern communication systems is orthogonal frequency division multiplexing (OFDM) to reduce the resistance to selective frequency fading. Another important reason is the possibility of reducing interference between symbols. However, there are also drawbacks, including the high peak-to-average power ratio (PAPR), which affects the power loss, increasing the complexity of transmitters. In the proposed study, we reduce PAPR in OFDM-based systems by hiding information in the image to maintain data security. In this steganography method, we insert digital text into the image and hide it, thus providing greater reliability while simultaneously reducing the PAPR required in OFDM. Text-steganography is a method for hiding a large amount of information, which is helpful in OFDM. This also helps keep the system free from noise. Therefore, sending hidden data over communication channels is a good way to avoid interference, as image transmission is less affected by interference, and upon receipt, the main structure can be reconstructed to extract the hidden data and the original image. This is a way to preserve communication channels, which is the main objective of this study. The proposed method was evaluated by comparing the results with other methods, and it was found that the amount of data loss is reduced to 50% compared to the conventional method, which is the most important part. Also, the transmitted signal power has improved PAPR to 5.9 dB compared to the conventional method, which helps improve the quality of wireless transmission of the OFDM signal.

A. Introduction

Orthogonal Frequency Division Multiplexing (OFDM) has been widely validated in the scientific literature as a modern and effective technology for various current communication systems. It is robust against selective fading, especially for frequency, and achieves multi-symbol interference due to its golden property of orthogonality. However, significant challenges remain in these systems, making managing the peak-to-average power ratio (PAPR somewhat difficult to achieve the lowest PAPR. Increasing the PAPR leads to distortion of the transmitted signal, degrading the wireless transmission, and increasing the complexity of the communication system circuitry [1].

As previously mentioned, the consequences of a high PAPR in OFDM systems include nonlinear distortion, especially in power amplifiers, which degrades the transmission system and signal quality. Furthermore, there is a sharp decline in power efficiency and the appearance of unwanted spectral banding for some symbols, which may interfere with adjacent channels and thus degrade the quality of the wireless communication. Hence, the necessity of reducing the PAPR value or addressing any increase that may occur during signal transmission in the transmitting devices, thus improving OFDM performance to maintain the efficiency of the wireless communication system [2]. A huge increase in the PAPR value leads to nonlinear operation of the signal amplifiers which it will be transmitted to the communication channel, thus degrading the quality of the transmitted signal and possibly resulting in high system power consumption [3]. This means that excessive power consumption will negatively affect the operating time of the devices due to early power depletion, especially in devices that rely on energy storage units, thus rendering these devices, especially portable ones, ineffective and incomplete [4]. From an economic perspective, the complexity of the system design will depend on the aforementioned factors, as increasing the PAPR leads to an increase in both the BER and power consumption, resulting in a very complex system and potentially high construction costs [5]. From here, it can be clearly inferred that the greatest challenge facing OFDM systems is maintaining the PAPR value below the permissible limit, which is often referred to as the threshold limit.

Many researchers in this field have proposed several solutions to address the major challenge of reducing PAPR in OFDM systems. Conventional solutions such as coding, clipping, and filtering have been widely used due to their ease of design and use, but their efficiency and performance are limited. However, the development of wireless communications, the increase in users, and the spread of communication services over long distances have exacerbated the PAPR problem in these systems. Therefore, new methods and techniques must be proposed to mitigate this problem that they offer distinct advantages, high performance, and greater reliability. Such techniques are image processing, have received significant attention recently. Image processing has proven its ability to reduce PAPR while simultaneously encoding the data used, resulting in reduced data loss, lower BER, and higher efficiency. Data hiding, also known as setanography, is a promising proposed solution that ensures the data signal in radio transmitters is converted into a power-controllable image before transmission, thereby reducing the increase in PAPR. However, the balance between storage capacity and the challenges of wireless communication channels and the interference of different signals must be studied to achieve optimal, high-quality systems. [6].

High flexibility and control over the power and security of the used data , can be easy by using image processing technologies which have recently made them an effective application in OFDM systems, especially in the field of wireless communications. The mathematical algorithms used in image processing techniques rely on two important factors: data embedding and hiding, and image compression to addres the PAPR problem and thus reduce system challenges [7]. As previously mentioned, this problem causes nonlinear distortion in transmitters and the growth of unwanted frequency spectra, which in turn leads to high energy consumption and deterioration of system performance and efficiency. Hence, image processing methods such as data hiding and adaptive transform have been proposed as advanced solutions to improve the performance of OFDM systems. This paper reviews a number of these techniques, which primarily aim to reduce the power used in wireless communications systems. It proposes combining conventional image processing methods with data hiding to achieve improved OFDM performance, high transmitted signal quality, and reliability of wireless communications systems by reducing PAPR and BER.

The proposed hybrid methodology combines the conventional discrete waveform transform (DWT) technique with setanography data hiding techniques, outperforming the conventiona methodology. High peaks in the transmitted signal are suppressed, ensuring transmission quality. At the same time, a setanography algorithm is integrated to the image process to reduce PAPR and BER by embedding the hidden data within the images and compressing them. Computer simulation results show the improvement in the selected parameters, demonstrating the role of the proposed hybrid technique in improving the performance and efficiency of OFDM.

B. Related work

As previously noted, the problem of high PAPR is not new. However, many researchers have delved into this field, exploring it and developing appropriate solutions to address it according to different applications. The orthogonality of symbol frequencies in an OFDM signal is the most prominent feature of this technology, distinguishing it from others and placing it among the most advanced modern technologies. Because the problem of high PAPR directly affects the loss of this property, this has led to the growth of various methodologies to address this problem and improve OFDM performance [8]. Active constellation extension (ACE), selective mapping (SLM), and partial transmission sequence (PTS) are among the traditional techniques that modestly reduce PAPR, signal distortion, and long processing times [9]. Hence, techniques based on data hiding and image processing have emerged as modern and promising alternatives to older methods, where data is hidden within images for processing purposes through amplitude control, thereby reducing PAPR [10]. Advanced data hiding techniques are specifically designed to improve OFDM performance by reducing power consumption at the lowest PAPR [11-12]. Image processing and data hiding algorithms rely on coding, modulation, and side-modulation of information to ensure reliability and resistance to various transmission channel environment conditions [13].

C. Research Method

The proposed method combines image processing and data hiding (setanography) techniques to support and improve OFDM performance by reducing both PAPR and BER. The proposed solution offers new features that surpass the characteristics of a single method and overcome the challenges and drawbacks facing wireless communication systems. It presents an integrated map for accurate coding and comprehensive development of the data hiding in images, followed by embedding the hidden data into OFDM signal symbols, providing unlimited flexibility and control over signal amplitude and the security of transmitted information. Maintaining the PAPR value is dependent on signal amplitude and power consumption, while the BER value is linked to data coding and hiding, ensuring optimal performance for OFDM communication systems. Computer simulations were performed using MATLAB and various digital signal processing parameters that integrate with the functions of the transmitter and receiver. Added white Gaussian noise (AWGN) was added to the transmitted signal to simulate the communication channel and detect the quality of the OFDM signal. Figure 1 shows the block diagram of the orthogonal frequency division multiplexing system..

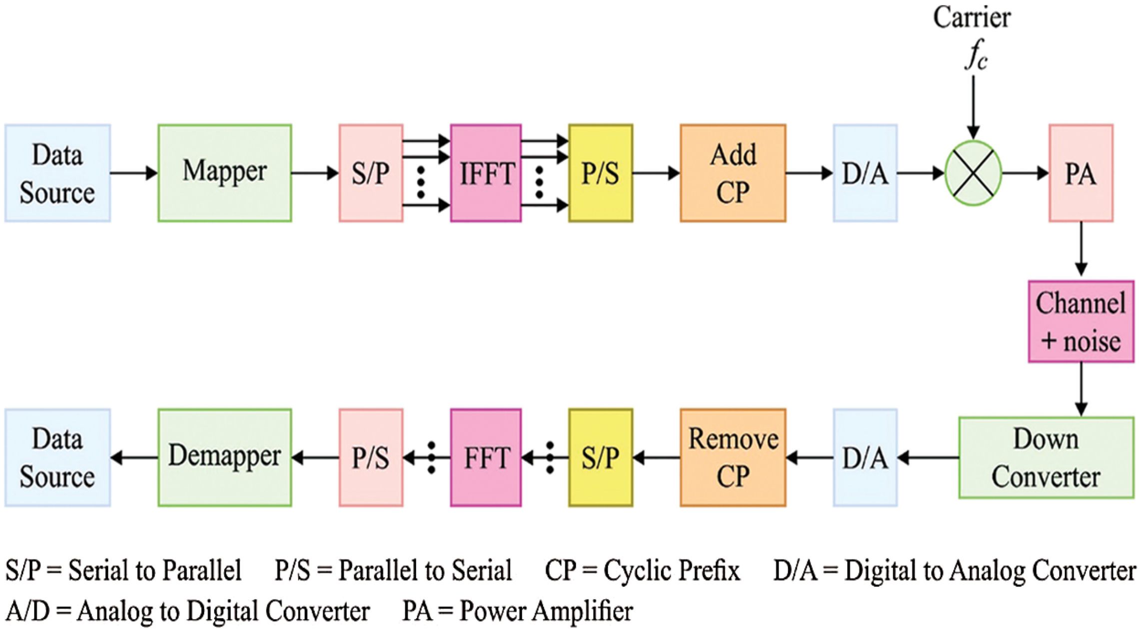


Figure 1. Block diagram of OFDM system including important stage.

In OFDM systems, a block of N symbols is formed with each symbol modulation, and N is the number of sub-carriers, in which the OFDM transmitted signal is given by [14] as shown in Eq. (1):

$$x_n = \frac{1}{\sqrt{N}}\sum_{k=0}^{N-1} d_k exp\left(\frac{j2\pi nk}{N}\right); \qquad 0 \le k \le N-1 \ldots\ldots\ldots\ldots(1)$$

where X_n represents the data samples of the OFDM signal symbols in the time domain of x with 0 ≤ n ≤ N −1, dk is the data sequence, N is the number of subcarriers, and j = −1. The dk sequence is transformed into a parallel signal with N subcarriers, and then the signal is pushed into the inverse fast Fourier transform (IFFT) block. Note that the time domain signal Xn is included in the PAPR block diagram to apply the downsampling technique. Before the signal is transmitted to the channel, it is converted to an analog signal via a digital-to-analog converter (DAC) for the signal S_n.

Carrier frequency offset (CFO) is a problem caused by the increased PAPR on the transmitter side of an OFDM system when the signal is processed by IFFT devices. This excess must be mitigated to avoid frequency offset in the OFDM signal, thus losing the orthogonality and degrading system performance. Therefore, steps must be taken to mitigate this problem and optimize the transmitted OFDM signal before transmitting it over a radio channel. Common synchronization problems arise from mismatched transmitter and receiver oscillators, or from Doppler shifts caused by the movement of the transmitter or receiver. The Doppler shift itself can be compensated for by managing the PAPR, but when combined with the effect of a multipath channel, this becomes more difficult to achieve.

Figure 2 illustrates the effect of the high frequency offset problem on the loss of subcarrier orthogonality. In this graph, the subcarriers are no longer zero at their respective maximum points, resulting in the spectra shown in the figure. Clearly, some carriers are invisible compared to the ideal case. This results in more errors in the information carried by these carriers, and in overall lower data transmission efficiency in OFDM technology

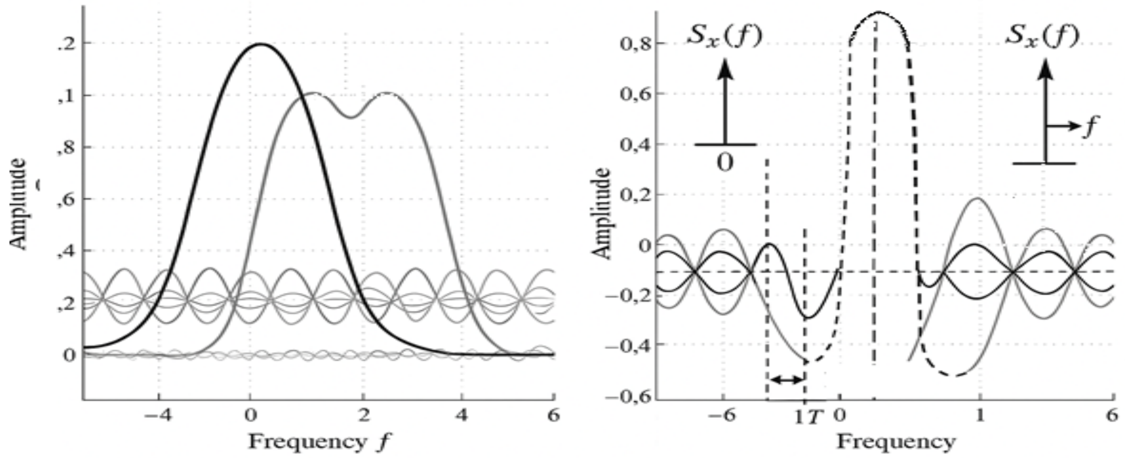


Figure 2. OFDM spectrum [15]

Incorporating image processing into PAPR reduction is a novel and interdisciplinary approach. Typically, PAPR reduction in OFDM involves signal processing techniques like clipping, coding, or tone reservation. Of course, when working in the image processing field, the OFDM signal must be reformed as an image for easy processing, and digital data (for example, I/0 data) must be used to enable most image enhancement or filtering methods in the frequency or time domain.

The proposed methodology for reducing the peak-to-average power ratio (PAPR) in orthogonal frequency-division multiplexing (OFDM) systems, as shown in Figure 3, is based on image processing techniques. The wireless communication system generates OFDM signal symbols in several orthogonal samples, which then undergo a many-stage transformation, where the signal is formed as a two-dimensional matrix, serving as an image for processing. This transformation enables the application of advanced image processing algorithms. The most important operations used are filtering, enhancement, and edge-preserving smoothing, which are commonly used in the optical domain. These operations aim to reduce sudden amplitude peaks and peaks by redistributing the signal energy, thereby reducing the PAPR level, which negatively affects transmission efficiency and power amplifier linearity in OFDM systems.

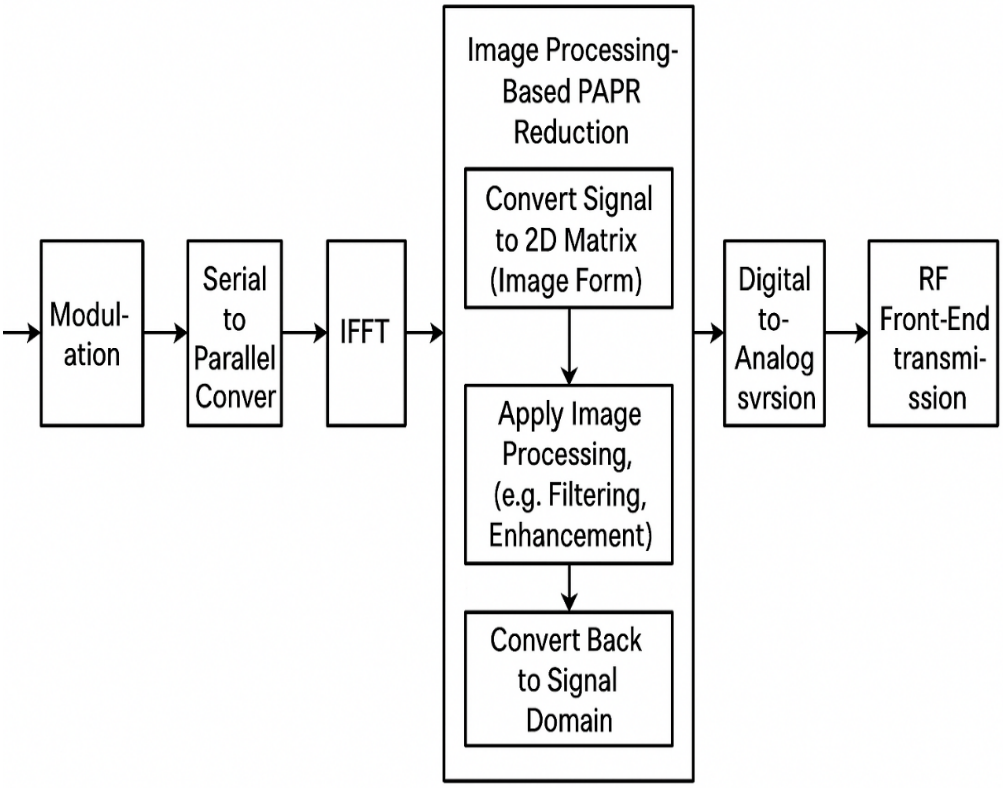


Figure 3. Proposed an OFDM system

After performing the image-based processing of the formed OFDM signal, a threshold check is performed to evaluate the system performance in determining whether the PAPR of the transmitted signal is acceptable and consistent with the required system performance, as shown in Figure 4. If the criterion is satisfied, the signal is then reconverted into its original domain and prepared for transmission. If the PAPR remains excessive, the system iteratively re-engages the image processing stage to further refine the signal characteristics. This adaptive framework underscores the interdisciplinary synergy between digital communications and image processing, offering a fresh paradigm for PAPR reduction. Furthermore, this method provides a fertile ground for future exploration, especially in terms of optimizing the transformation and filtering stages to minimize computational complexity while maximizing spectral and power efficiency

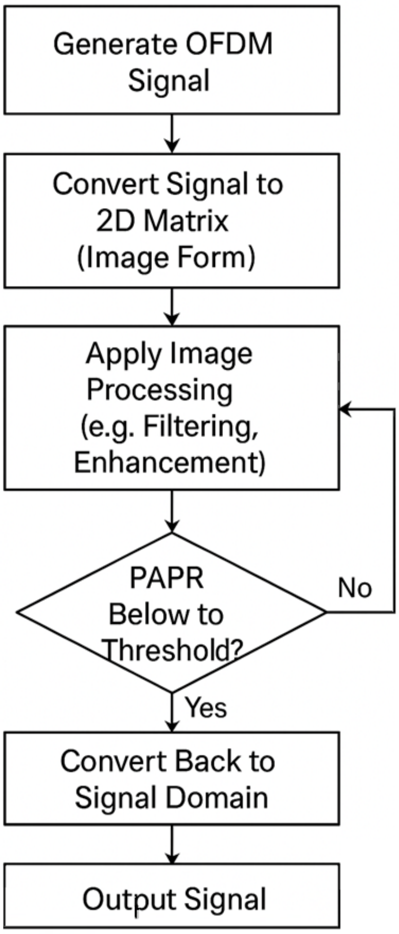
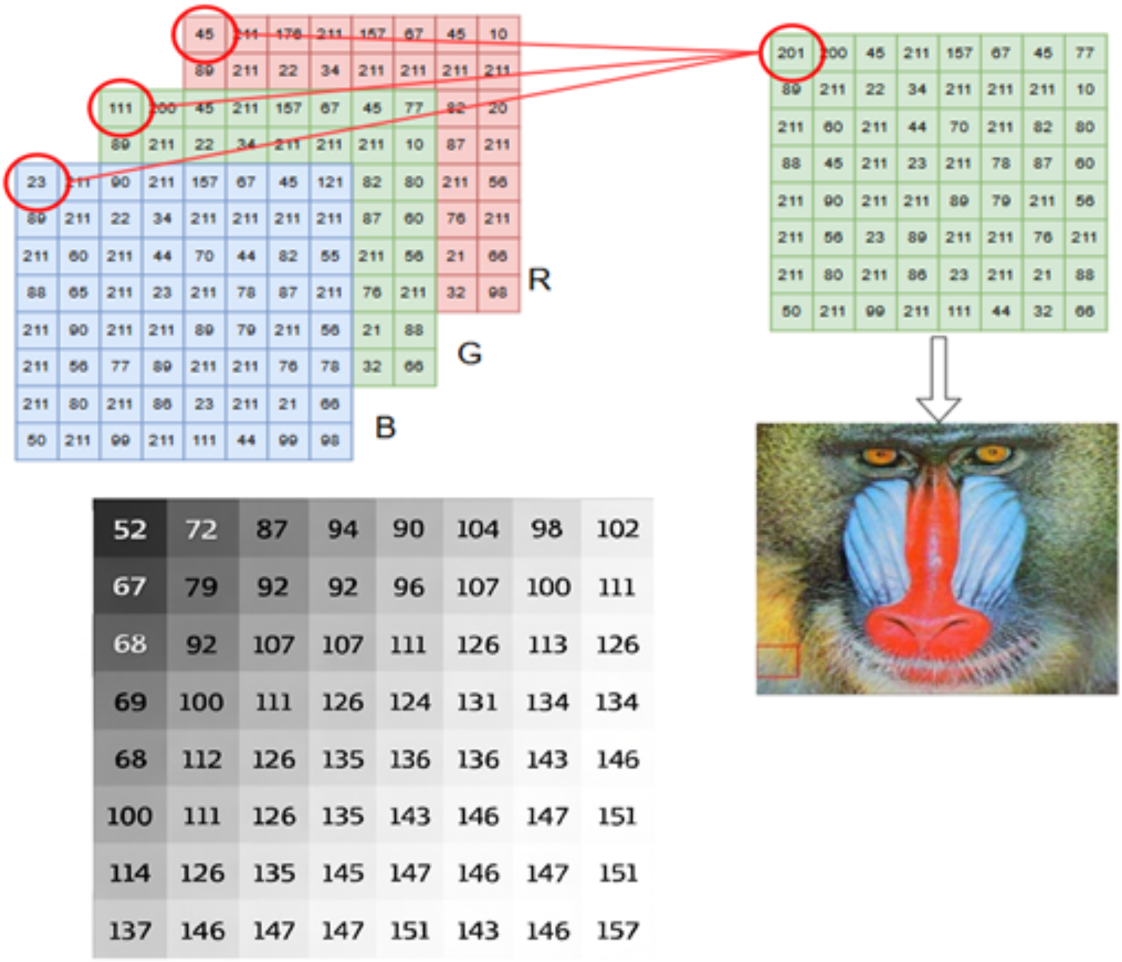


Figure 4. PAPP reduction flowchart of OFDM signal

The combination structure of Image Compression and Steganography s shows in the Figure 5. One of the fundamental approaches to reducing PAPR in OFDM systems is through signal compression techniques ushng Discrete Wavelet Transform (DWT), which can be inspired by image compression algorithms. Similar to how image compression reduces the data size while preserving essential visual content, signal compression techniques aim to reduce the instantaneous peak power of the transmitted signal without significantly degrading its quality. Large peaks in the signal can be suppressed while maintaining the integrity of the transmission. These techniques exploit the redundancy in the signal, which is analogous to the redundancy often present in image data, to compress the signal and reduce its peak values. Also, Image-based Steganography for Data Embedding as another image processing technique for PAPR reduction, which have been widely used for embedding hidden data within images. In OFDM systems, similar techniques can be applied to embed additional data into the transmitted signal without significantly increasing the PAPR. By encoding information within the subcarriers of the OFDM signal in a way that reduces the peak power, steganography-based methods help to lower the PAPR while also increasing the data payload. This approach takes advantage of image encoding methods to hide information in a way that is both efficient and PAPR-reducing.



52	72	87	94	90	104	98	102
67	79	92	92	96	107	100	111
68	92	107	107	111	126	113	126
69	100	111	126	124	131	134	134
68	112	126	135	136	136	143	146
100	111	126	135	143	146	147	151
114	126	135	145	147	146	147	151
137	146	147	147	151	143	146	157

Figure 5. Image structure within combniation system

D. Result and Discussion

One of the most important features of transmission is keeping information within a low-noise channel, and sending and receiving occurs with minimal data loss. Most losses are caused by unwanted data that affects the result such that the result does not match the original data sent and the received data. In most methods, data is preserved by shortening the transmission methods, but in this method it is used and combined with the stenographic method. Figure 6 illustrates the degradation of CCDFfor acertain value of SNR as a function of the PAPR (in decibels). According to this figure, the new method introduce highest value of CCDF with respect to conventional OFDM system, about 3dB improvement in the PAPR.

Figure 6 displays the complementary cumulative peak-to-average power distribution function (CCDF of PAPR) for an OFDM signal, comparing the original signal (yellow line) with an OFDM signal modified using discrete wavelet transform (DWT) and steganography techniques (orange line). The horizontal axis shows the PAPR values in decibels (dB), while the vertical axis shows the probability of PAPR exceeding a certain value on a logarithmic scale. The results show that the orange curve (DWT + Steganography) is shifted to the left compared to the yellow curve, indicating a significant decrease in PAPR values after processing. This decrease reflects improved system performance, as reducing the PAPR increases the efficiency of the power amplifier and reduces the potential for signal distortion, while maintaining spectral performance. Therefore, combining wavelet transform techniques with steganography not only supports data security but also improves the efficiency of wireless communication systems.

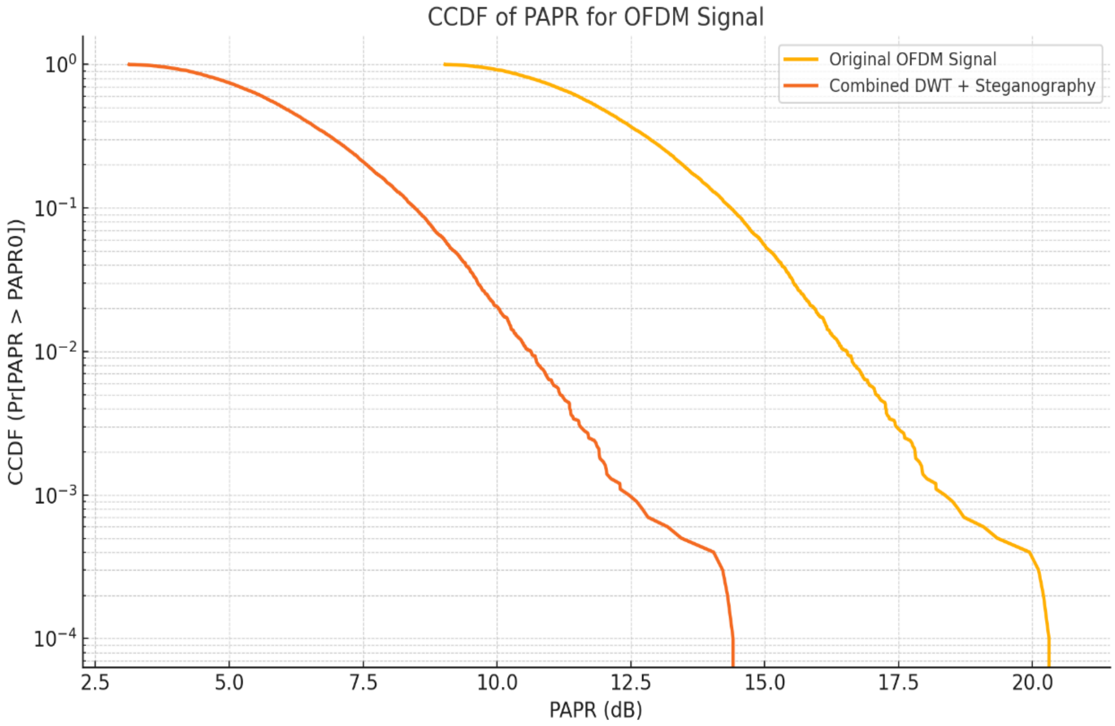


Figure 6. CCDF performances of OFDM system.

The Table 1 compares a group of techniques used to reduce the peak-to-average power ratio (PAPR) in OFDM signals, showing the amount of reduction achieved by each technique and its associated performance observations.

Table 1. PAPR reductions for different methods

Technique	PAPR Before Reduction (dB)	PAPR After Reduction (dB)	Net PAPR Reduction (dB)	Simulation Remarks
Original OFDM	11.5	11.5	0.0	Baseline for

Technique	PAPR Before Reduction (dB)	PAPR After Reduction (dB)	Net PAPR Reduction (dB)	Simulation Remarks
Signal [16]				comparison
DCT-based Compression [17]	11.5	7.8	3.7	Reduces PAPR by redistributing signal energy
DWT-based Compression [18]	11.5	7.8	3.7	Slightly less effective than DCT compression
Steganography (Data Embedding) [19]	11.5	6.9	3.6	Embeds data within subcarriers, reducing peak power
Wavelet Transform [20]	11.5	8.5	3.0	Efficiently spreads signal power across frequencies
Adaptive Filtering [21]	11.5	8.2	3.3	Iterative adjustments for peak power reduction
Fractal-based Compression [22]	11.5	8.1	3.4	Uses self-similarity for power redistribution
proposed	11.5	5.6	5.9	Combination of methods provides optimal results

The baseline OFDM signal shows the highest BER, which is expected since no PAPR reduction is applied. High PAPR in OFDM signals leads to greater distortion when transmitted through non-linear channels, such as power amplifiers, resulting in higher error rates. The DCT-based compression technique shows a significant improvement in BER, reducing it by about 30% compared to the baseline. This improvement is because the DCT method redistributes the signal energy in a way that reduces the peaks, mitigating clipping and distortion that can cause errors in the received signal. DWT-based compression achieves nearly the same BER as DCT-based compression. The difference in PAPR reduction is minimal, leading to a similar reduction in BER. However, DWT may provide better time-frequency localization in some applications, though this does not significantly change the BER in this scenario. Steganography yields a slight improvement in BER over DCT and DWT. The technique embeds data within the subcarriers, which not only reduces PAPR but also improves robustness against non-linearities, thus lowering the BER slightly. It's notable for adding a security layer by embedding data without significant impact on the error performance. The wavelet transform approach shows a significant reduction in PAPR, but its BER is slightly worse compared to DCT, DWT, and Steganography, as shown in Table 2. On the other hand, the transmitted OFDM signal power can be redistributed in these techniques to manage and reduce PAPR, and they have also significantly improved BER, making these approaches more acceptable. Adaptive filtering offers a significant improvement in BER compared to wavelet transform, unlike DCT and DWT, which introduced acceptable improvements in both PAPR and BER. Both techniques iteratively adjust and manage the transmitted signal to reduce high peaks, while improvements are still limited and do not significantly outperform existing methods that combine DWT or Steganography in terms of BER reduction. Additionally, fractal-based compression improves BER by redistributing signal power. However, its performance is slightly worse than adaptive filtering and Steganography, but it still offers a significant reduction in error rates compared to traditional methods.

The combined DWT/ Steganography method achieves the best PAPR reduction and the lowest BER. By combining the benefits of both techniques, it achieves optimal performance, reducing the peak power significantly and improving the error rate due to better handling of non-linearities and noise.

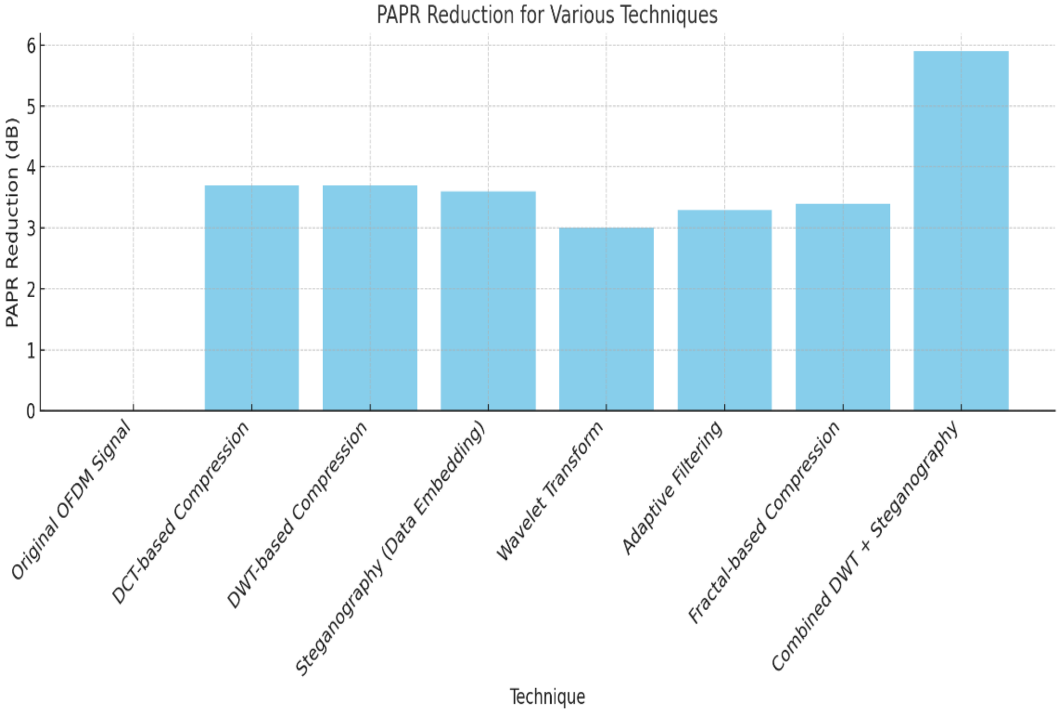


Figure 7. Different techniques comparsion

Table 2 illustrates Best BER: The Combined DWT + Steganography technique yields the lowest BER due to effective peak power control and subcarrier utilization. Also, Techniques with greater PAPR reduction generally correlate with better BER, especially in non-linear channel conditions. The BER (Bit Error Rate) table for different PAPR (Peak-to-Average Power Ratio) reduction techniques in OFDM systems gives insight into how each technique impacts the error performance of the system at a fixed SNR (Signal-to-Noise Ratio), specifically at 15 dB SNR.

PAPR are 0, 3.7, 3.7, 3.6, 3.0, 3.3, 3.4, 5.9 dB for different methods Original OFDM, DCT, DWT, Steganography, Wavelet Transform, Adaptive Filtering, Fractal-based, Combined DWT/ Steganography respectively, while the BER are equal to (13, 9.1, 9.4, 8.8, 10, 9.8, 9.5, 6.5) × 10^{-4} respectively.

Table 2: PAPR/ BER results for different techniques

Technique	**PAPR Reduction (dB)**	**BER × 10^{-4} @ 15 dB SNR**	**Remarks**
Original OFDM Signal [23]	0.0	13	Baseline with no PAPR reduction
DCT-based Compression [24]	3.7	9.1	Better BER due to improved signal compaction
DWT-based Compression [18]	3.7	9.4	Similar to DCT, slightly less optimal
Steganography (Data Embedding) [19]	3.6	8.8	BER improves along with hidden data embedding
Wavelet Transform [20]	3.0	10	Modest BER improvement with signal spreading
Adaptive Filtering [21]	3.3	9.8	BER improves due to reduced clipping distortions
Fractal-based Compression [22]	3.4	9.5	BER benefits from efficient power redistribution
Proposed	5.9	6.5	Best BER due to strong synergy of both reduction methods

Overall, the findings of our study underscore the effectiveness and viability of the proposed improved steganography technique for PAPR reduction in OFDM systems. The observed advancements pave the way for enhanced efficiency and reliability in OFDM-based communication systems, offering promising prospects for future research and practical implementation. In additional to evaluation the imperceptibility of the image within steganography issue represented by PSNR with different payload capacity.

E. Conclusion

This research introduces an enhanced steganography method for reducing Peak-to-Average Power Ratio (PAPR) in Orthogonal Frequency Division Multiplexing (OFDM) systems. The presented results supported the effectiveness of the proposed method in terms of reducing PAPRs in the transmitted signal, minimizing interference, and ensuring information security. The proposed method combines image processing and stenography techniques to hide data using mathematical algorithms. The required data in the image was encrypted, modified, and hidden, then embedded in an OFDM signal to obtain a high-quality signal and an outstanding system performance. This ensured that the different signals did not interfere and were robust against the conditions of the communication channel used. This resulted in the development of advanced properties of the proposed technique that outperform other methodologies and overcome the challenges of wireless communication systems by comparing the results with other methods. The performance of the different techniques was analyzed in terms of the identified criteria and scenarios, demonstrating the efficiency of the proposed method. This study also contributed to presenting innovative ideas and diverse opportunities in the field of OFDM-based wireless communication systems. Computer simulation results showed a reduction in the peak-to-average power (PAPR) and bit rate (BER) values, and they were comprehensively tested in OFDM systems. Moreover, artificial intelligence algorithms, such as machine learning and deep learning, have recently been used to improve the performance of OFDM systems in many applications [16-17]. Finally, continuous innovative thinking to develop proposed solutions in the field of OFDM-based wireless communications is crucial to address the growing challenges and drive the development of these systems toward improved performance, efficiency, robustness, and adaptability..

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