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An Improved Orthogonal Frequency Division Multiplexing System-Based Image Steganography Technique

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Highlights:

- *Enhanced Steganography: New image steganography via improved OFDM system.*
- *Improved Security: Advanced embedding/extraction with minimal image distortion.*
- *OFDM Integration: Leveraging OFDM for reliable, secure image data hiding.*

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Abstract: OFDM technology is one of the most promising digital modulation methods to achieve the highest data transmission rates in all communication systems. However, the CFO problem constitutes one of the obstacles in-building wireless communication systems, as it leads to the ICI problem, especially in OFDM systems. Moreover, CFO causes orthogonal loss between the sub-carriers in the case of divergent sub-carriers. In addition, the ICI causes a frequency mismatch in the transmitting and receiving stages. In this paper, the effect of the CFO on the performance of the OFDM system is analyzed by suggesting a CFO compensation method to reduce the ICI that occurs in OFDM systems. In the case of an additive white Gaussian noise channel, the computer simulation results demonstrated that the CFO was reduced by approximately 5.2 dB and 7.15 dB in QPSK and 64QAM, respectively, compared to the original variance method. In this context, a coding method was proposed to hide secret data in an image before the OFDM generation process based on the Least Significant Bit (LSB1 &LSB2) technology. Then, the data was extracted from the image upon receipt. Several methods can be used to estimate CFO to compensate for that change in OFDM, including measuring the error rate (BER) as an indicator of the effect of ICI. Moreover, the transmitted signal will be of high quality due to the ICI reduction, leading to channel normalization and reducing the receiving complexity.

تحسين أنظمة تعدد الإرسال بتقسيم التردد المتعامد باستخدام تقنيات إخفاء الصور

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الخلاصة

تعد تقنية تضمين التردد التعامدي متعدد الارسال OFDM إحدى طرق التضمين الرقمي الواعدة لتحقيق أعلى معدلات نقل البيانات في جميع أنظمة الاتصالات. إلا أن مشكلة ازاحة تردد الموجة االحاملة CFO تشكل إحدى معوقات بناء أنظمة الاتصالات اللاسلكية كونها تسبب مشكلة تداخل ترددات الموجات الحاملة ICI خاصة في أنظمة. OFDM علاوة على ذلك، فأن CFO تسبب فقدان التعامد بين الموجات الحاملة الفرعية وخاصة في الموجات الحاملة الفرعية المتباعدة. بالإضافة إلى ذلك، يتسبب ICI في عدم تطابق التردد في مرحلتي الإرسال والاستقبال. في هذا البحث، تم تحليل تأثير ظاهرة انحراف تردد الموجه الحاملة CFO على أداء نظام OFDM من خلال اقتراح تعويض CFO لتقليل ICI في أنظمة.OFDM بأستخدام قناة ضوضاء غوسية بيضاء المضافة، حيث توضح نتائج المحاكاة الحاسوبية أن CFO قد تم تخفيضه بنحو dB٥,٢ و dB٧,١٥ في QPSK و QAM-٦٤ ، على التوالي، عند مقارنتها بالطريقة التقليدية. وفي هذا السياق، تم أيضًا اقتراح التشفير لإخفاء البيانات السرية في صورة ما قبل عملية إنشاء OFDM بالاعتماد على تقنية البتات الأقل اهمية (LSB1 &LSB2)، ومن ثم يتم استخراج البيانات من الصورة عند استلامها. هناك عدة طرق لتخمين تعويض CFO بغرض تقليل الاخطاء في نظام OFDM، بما في ذلك قياس معدل البت الخطأ (BER) كمؤشر لتأثير. ICI علاوة على ذلك، ستكون الإشارة المرسلة ذات جودة عالية بسبب تقليل ICI، مما سيؤدي إلى تطبيع القناة وتقليل تعقيد الاستقبال.

الكلمات الدالة: التداخلات بين الموجات الحاملة، إزاحة تردد الموجة الحاملة، تعدد الإرسال بالتقسيم المتعامد، إخفاء المعلومات.

1.INTRODUCTION

Orthogonal frequency division multiplexing (OFDM) is a popular method for communication systems as it allows high data rates and reduces the complexity of the transceiver. Despite its benefits, OFDM has a disadvantage in that it is sensitive to carrier frequency offset (CFO), causing inter-carrier interference (ICI) [1, 2]. ICI is a problem that occurs at the output of the IFFT/FFT blocks, degrading the OFDM system's bit error rate (BER) performance [3, 4]. The main reason for ICI is the CFO, affecting the OFDM system in several ways, including attenuation and rotation of subcarriers, signal distortion, and loss of orthogonality in the signal spectrum. The loss of orthogonality in the OFDM signal spectrum is a critical issue, as it results in the overlap of sub-carriers and leads to significant degradation in system performance because orthogonality is a fundamental requirement for the proper functioning of OFDM, as it enables the demodulation of individual sub-carriers without interference from other sub-carriers [5, 6]. To address the ICI problem, various methods have been proposed to improve the performance of OFDM systems in the presence of frequency offset errors in the transmitted signal. One such method is time domain windowing, which involves pulse shaping filtering at the transmitter and receiver. This method reduces the ICI by limiting the overlap between the sub-carriers and reducing the impact of the frequency offset errors [7- 9]. There are different sources of CFO in OFDM systems. For example, CFO can be introduced by the transmitter and receiver devices and signal processing or by the radio channel due to the Doppler Effect and multipath fading. The different types of CFO problems are illustrated in Fig. 1. In general, the main goal of OFDM systems is to minimize the impact of CFO and ICI to improve the overall performance and reliability of the system.

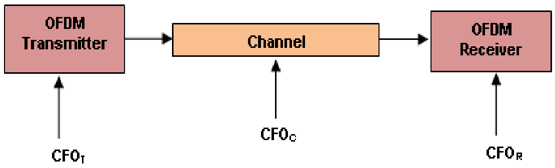


Fig. 1 The Comprehensive Frame of the CFO Problem Occurrence in OFDM System.

The proposed technique achieves ICI reduction at the expense of a high complexity OFDM system, long processing time, and high cost; however, it produces high-quality OFDM signal. Among these techniques, the compensation of carrier frequency offset CFO [7] efficiently reduces ICI. Many applications have used data hiding (steganography) to integrate systems and benefit from these techniques [10]. Many fields of knowledge, including military, medical, and scientific, are the most important in which communications use data hiding in multiple media types, including audio, video, text, protocol, and images, as in the proposed system [11]. The secret data, which is always represented by 0 and 1 in the LSB1 of the image pixels, is hidden so that it is not visible to intruders, which is the main purpose of hiding data. The present study aims to increase the imperceptibility of secret data by a new contribution represented in the sequence of embedding two LSBs in one image pixel.

2.RELATED WORKS

The resolution of Carrier Frequency Offset (CFO) in Orthogonal Frequency Division Multiplexing (OFDM) systems involves various techniques, such as Self-ICI Cancellation [12], Polynomial Cancel Coding OFDM (PCC-OFDM) with partial response coding, frequency domain equalization [13], diversity (multi-antenna) method, Maximum Likelihood Estimation (MLE), Extended Kalman Filtering (EKF), and Data Conjugate ICI Self Cancellation. These techniques aim to reduce the Inter-Carrier Interference (ICI), i.e., a common issue faced in OFDM systems due to the residual frequency offset. However, some estimation errors are expected to still exist even after implementing these techniques, persisting frequency offset [7, 14]. To overcome this issue, researchers have explored the error-correction properties and offset estimation of CFO in OFDM systems. This idea is based on [15, 16]. The ultimate aim is to reduce the ICI in the coded OFDM signals by estimating and correcting the residual frequency offset. However, it still requires a high computational complexity and processing time. This approach satisfies transmitted OFDM signals with minimum interference reduction and less complexity because it avoids the estimations and optimization techniques. Many previous studies relied on hiding the data sent by OFDM and choosing several media to transfer the information and include the secret data through it. There are many ways to hide data, such as using spatial and frequency domains, and some hybrid methods that led to good results. The term steganography is commonly used with OFDM, particularly in transmitting secret data in images in a physical layer. Securing communication in OFDM is done in several ways, including using hardware and software methods. Through this, a lot of data hiding occurs at the network layer stage. It is worth noting that the physical layer also had a role in securing secret data and communication [17]. Many criteria are considered when applying steganography, such as payload capacity, imperceptibility, and accuracy of data security [18]. Next, the ICI is computed in terms of normalized CFO to transmit the OFDM signal with the minimum ICI. Therefore, where this work reduces the ICI of the transmitted OFDM signal, it focuses on sending OFDM signal with minimum ICI based on the CFO compensation scheme, resulting in a higher quality transmitted signal than conventional signal and other methods [18]. The objective of this paper is to improve the quality of signaling in Orthogonal Frequency Division Multiplexing (OFDM) systems by mitigating the Inter-Carrier Interference (ICI) problem through a new approach of canceling Carrier Frequency Offset (CFO) at the transmitter side. The proposed method is a simple solution to reduce the sensitivity of OFDM systems to CFO by compensating for frequency errors and data coding using steganography to hide information. Orthogonal frequency-division multiplexing (OFDM) is a popular method for transmitting digital signals, especially in wireless communication systems. Steganography is the practice of hiding information in plain sight by embedding it in other media, such as images or audio files [19, 20]. Combining OFDM with steganography allows for the concealment of secret data within the subcarriers of an OFDM signal. The data can be encrypted before embedding to ensure its security. Using the OFDM method, the data can be transmitted over a channel with high bandwidth utilization, while the steganography technique helps to prevent the detection of hidden information. However, it is important to note that the embedding process can potentially impact the OFDM system's performance and affect the quality of the transmitted signal. Thus, finding a balance between the amount of information that can be embedded and the impact on the signal quality is crucial in this application [21, 22]. In conclusion, combining OFDM with steganography can provide a secure way to transmit secret data; however, the impact on the OFDM signal quality must be carefully considered [23]. Combining orthogonal frequency-division multiplexing (OFDM) and steganography has been explored in various research works in the field of communication and security [24]. Hemalatha et al. proposed a new steganographic method that enhances the security of hidden information by using the OFDM system with multiple subcarriers [25]. Pandey et al. investigated the trade-off between the amount of hidden data and the degradation of the signal quality in an OFDM system with steganography [26]. Using OFDM for steganography has been proposed for various applications, including wireless communication systems, digital image and audio transmission, and covert communication. Combining these two techniques provides a way to conceal secret information within the subcarriers of an OFDM signal, making it more difficult for an eavesdropper to detect the presence of hidden information [27, 28]. Research in this area has focused on optimizing the data embedding process to minimize the impact of signal quality and maximize hidden data capacity. For example, Grzesiak et al. proposed a novel steganography method based on the cyclic prefix of OFDM signals [29]. In conclusion, using OFDM with steganography has received significant attention in literature; various works have explored the potential applications and limitations of this combination in terms of secure communication and information hiding.

3.PROPOSED CFO COMPENSATION METHOD

In Orthogonal Frequency Division Multiplexing (OFDM) systems, a block of symbols is formed by modulating each symbol, with N being the number of sub-carriers. The transmitted OFDM signal can be expressed [30] as follows:

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

The time-domain data samples of x are x_n, with $0 \le n \le N-1$, where dk is the data sequence, N is the number of sub-carriers, and $j = \sqrt{-1}$. The block diagram of an OFDM transmitter is shown in Fig. 2. The data sequence d_k is converted into a parallel signal with N sub-carriers and then passes through the Inverse Fast Fourier Transform (IFFT) block. After that, the IFFT block is used to process the time-domain signal x_n. Before being transmitted over the channel, the digital-to-analog converter (DAC) transforms the signal S_n into an analog signal.

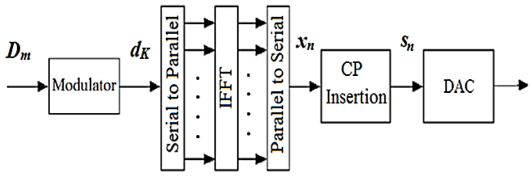
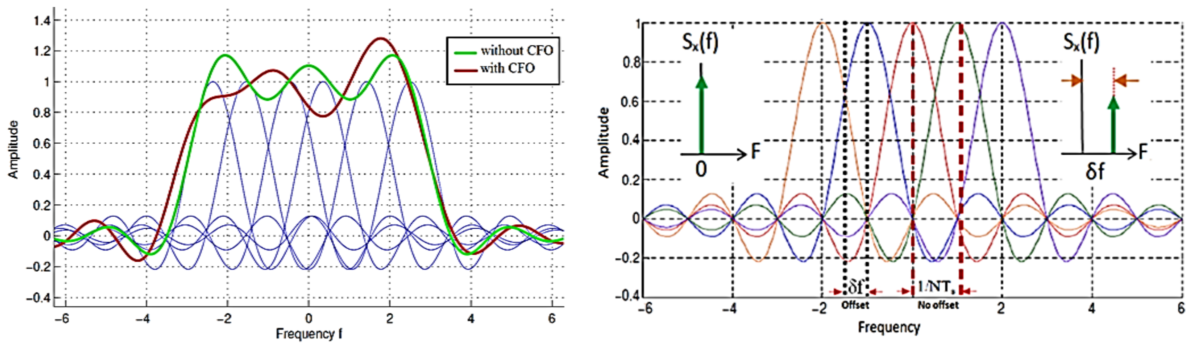


Fig. 2 OFDM Transmitter Block Diagram [19].

The significant Inter-Carrier Interference (ICI) issue at the transmitter side of Orthogonal Frequency Division Multiplexing (OFDM) systems arises from the processing of signals through the transmitter's blocks, which introduces Carrier Frequency Offset (CFO) [2]. To enhance the OFDM transmitted signal prior to transmission over a radio channel, measures must be taken to mitigate this problem caused by the CFO. Frequency synchronization is crucial for successfully implementing an Orthogonal Frequency Division Multiplexing (OFDM) system. Accurate synchronization between the transmitter and receiver results in low error rates. With higher offsets, frequency offsets can decrease the efficiency of data transmission and increase the number of errors. Inter-Carrier Interference (ICI) occurs when the orthogonality of the sub-carriers is reduced by the frequency deviation between the transmitter and receiver. Synchronization issues can arise from mismatched transmitter and receiver oscillators or Doppler shifts due to the movement of either the transmitter or the receiver. While the Doppler shift effect can be compensated, it becomes challenging when combined with the impact of a multipath channel.



(a) (b)

Fig. 3 Concept of the Effects of Frequency Offset (a) OFDM Spectrum and (b) OFDM Signaling [14].

Figure 3 depicts the effect of the frequency offset on the subcarrier orthogonality. The spectrum depicted by the red line results from the sub-carriers no longer being zero at the point of maximum for each subcarrier in that plot. The first spectrum is depicted by the green line. It is evident that some carriers have lost their color compared to the ideal circumstance. As a result, the OFDM data transmission will be less efficient overall, and the information carried by those carriers result in more errors. Additionally, the primary disadvantage of OFDM is frequently cited as the sensitivity to frequency offset [2]. The OFDM signals gain an additional phase factor thanks to the carrier frequency offset (Δε), which serves as an explanation. Phase Factor (PF),

$$PF = e^{j2\pi\Delta\varepsilon t} = e^{j2\pi\varepsilon f t} \quad (2)$$

where f is the SC spacing, ε is the normalized CFO by f,. the fractional and integer parts of the normalized frequency (ε) can be stated as follows[31]:

$$\varepsilon = \varepsilon_i + \varepsilon_f \quad (3)$$

The transmitted signal experiences a cyclic shift in the integer part, whereas it experiences phase distortion and an increase in its amplitude in the fractional part. Figure 4 illustrates a typical block diagram of the OFDM system with generating the offset frequency and comensating CFO in the transmitter. Therefore, the CFO introduces the ICI into the system, and ICI increases with the frequency offsets [31]. The frequency shift (δf) in the receiver signal occurs when CFO occurs at the transmitter. Figure 3 demonstrates that the received frequency domain subcarriers are shifted by (I×δf) if the frequency error is an integer multiple of the subcarrier spacing f [31]. Therefore, a new CFO compensation transmitter structure of CFO estimation/compensation for an OFDM system is represented in Fig. 4.

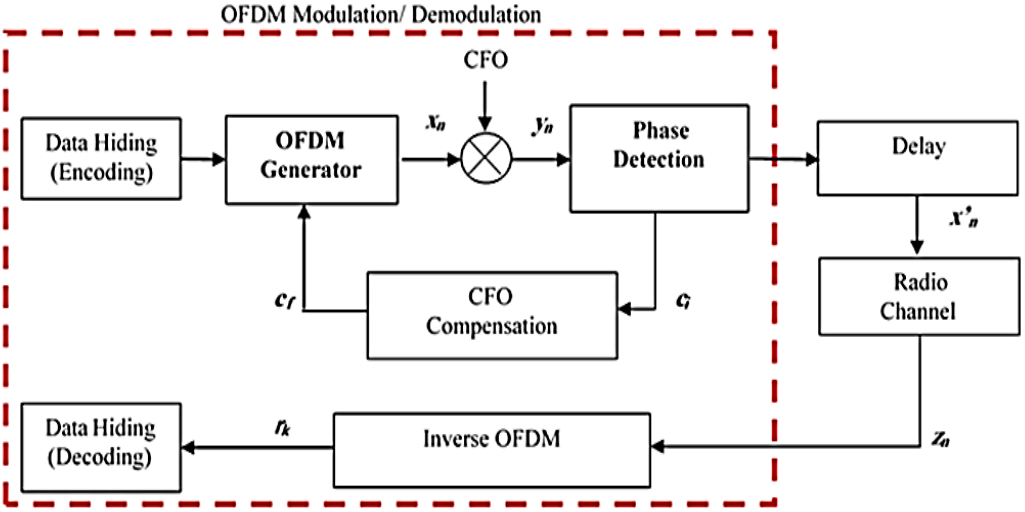


Fig. 4 Proposed CFO Compensation of an OFDM System.

Due to their power spectrums' overlap, ICI obstacles are created. The three sorts of overlapping are between SCs next to each other, between SCs themselves, or between SCs of different OFDM symbols. In addition, the main reasons for the ICI problem are represented by Tx, Rx, and Channel exactly at IFFT/ FFT blocks, as well as multipath fading channels with Doppler shift effects, respectively. On the other hand, many methods contributed to mitigating ICI applied at the transmitter and receiver sides, such as adding a cyclic prefix (CP), inserting the pilot's carrier frequency, and CFO estimation and/or compensation. The frequency offset model is portrayed in Fig. 4 as a multiplicative vector presented in the OFDM system's channel. After the transmitter applies the IFFT block, the discrete-time complex baseband OFDM signal is represented by [2],

$$x_n = \frac{1}{\sqrt{N}} \sum_{i=0}^{N-1} d_i e^{j2\pi in/N} \quad n = 0 \ \dots \ N-1 \quad (4)$$

t can present the effect of offset frequency on OFDM signal as:

$$y_n = \frac{1}{\sqrt{N}} \sum_{n=0}^{N-1} x_n e^{-j2\pi kn/N} \quad k = 0\ 1 \dots N-1 \quad (5)$$

The transmit OFDM signal, X_n, has a time delay due to the suggested CFO compensation mechanism for ICI cancelation, which is produced by the OFDM transmitter's processing and hardware.

$$x'_n = x_n \pm C_f \quad (6)$$

where cf is the OFDM transmitter's correction factor for CFO. Therefore, assuming that the OFDM signal was sent in response to the AWGN channel, the received signal can be constructed [32].

$$Z_n = x'_n \pm \eta_n \quad (7)$$

After removing the CP, the received signal samples are processed at the receiver side using a serial-to-parallel converter before being fed into the FFT to generate the decision variables r_{k_p}, which can be expressed as:

$$r_{k_p} = \frac{1}{\sqrt{N}} \sum_{n=0}^{N-1} z_n e^{-j2\pi kn/N} \quad k = 0\ 1 \dots N-1 \quad (8)$$

where r_{k_p} is received signal with implementing the proposed CFO technique. Therefore, Algo.1 shows the Strategy idea of the algorithm for proposed CFO compensation in an OFDM system [33].

```
Step1: Hide secret data in an image
  For each image do
    Read Secret bits
    Check Overload Capacity
    Embed in LSB1 &LSB2
  End file

Step2: OFDM Generation
  For each Frames do
    IFFT using Eq. (1) and Eq. (4) of xn
  End

Step3: Offset Frequency Detection
  For each Frame (n) do
    For each Symbol (k) do
      Compute the Offset Frequency of yn in Eq.(5)
      If normalize Frequency < ε0
        Go to Step 5
      End
      Else
        Go to Step4
      End
    End
  End

Step4: Offset Frequency Compensation
  For each Frame (n) do
    For each Symbol (k) do
      Compute the Offset Frequency of ci
      If normalize Frequency < ε0
        Go to Step 5
      End
      Else
        Compensation Offset Frequency by cf
      End
    End
  End

Step5: Transmission
  Transmit OFDM Frames
```

Algo. 1 Algorithm Strategy of the Proposed CFO Compensation Algorithm for OFDM System.

On the other hand, if it is assumed that the OFDM signal passes through the AWGN channel and neglects the offset frequency due to the processing signal at the receiver and without implementing the proposed CFO compensation at the transmitter, then rk will become as [34,35].

$$r_k = \frac{1}{\sqrt{N}} \sum_{n=0}^{N-1} \left[\left[\frac{1}{\sqrt{N}} \sum_{i=0}^{N-1} d_i e^{j2\pi i n/N} \right] e^{j2\pi \varepsilon n/N} + \eta_n \right] e^{-j2\pi k n/N} \quad (9)$$

and subsequently,

$$r_k = \frac{1}{N} \sum_{n=0}^{N-1} \sum_{i=0}^{N-1} d_i e^{j2\pi(\varepsilon+i-k)n/N} + w_k \quad (10)$$

where ω_k is the FFT of η_n. The first term in Eq. (10) can be expanded for $l = k$ and $l \neq k$; therefore, r_k can be rewritten as a Useful Signal,

$$r_k = \left[d_k \frac{1}{N} \sum_{n=0}^{N-1} e^{j2\pi \varepsilon n/N} \right] + \left[\frac{1}{N} \sum_{n=0}^{N-1} \sum_{\substack{i=0 \\ i\neq k}}^{N-1} d_i e^{j2\pi(\varepsilon+i-k)n/N} \right] + [w_k] \quad (11)$$

Finally,

$$r_k = \text{Generated OFDM signal} + CFO_T + Noise \quad (12)$$

Data transfer needs to be kept secret before it is proceeded to transfer it. Data hiding in the proposed method is based on hiding text in a digital image, which will be transmitted through communication channels. The image consists initially of a group of pixels representing the image's resolution, and one pixel consists of 8 bits to achieve the highest color intensity value, which is 28=256. Any change in the least significant bits of the LSB cannot be recognized by the human eye because it can distinguish the difference in chromatic intensities when it is more than 25. Therefore, this feature is exploited, and data is embedded in two bits, whose value is 22 = 4, as illustrated in (Fig. 5).

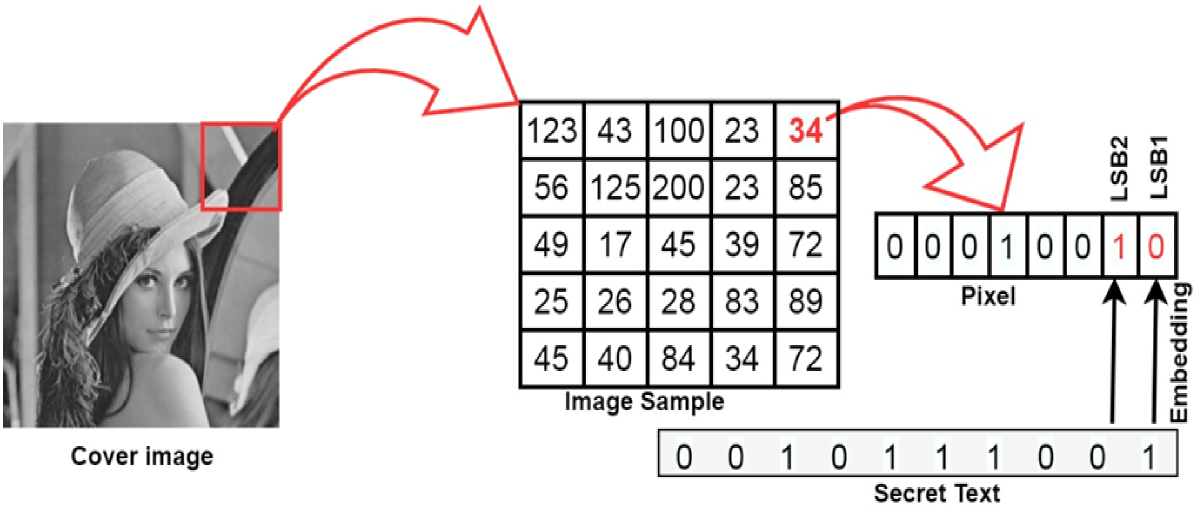


Fig. 5 Proposed Steganography Technique Through OFDM.

4.RESULTS AND DISCUSSION

Through CFO compensation, the improvements in bit error rate BER performance are demonstrated in this section. The simulation considers 128 subcarrier OFDM systems with different modulation techniques, including QPSK and 64QAM. The AWGN channel without CFO is assumed to be the channel used in the simulation, noting that the presence of CFO degrades the performance of a multi-carrier OFDM system with high sub-carrier modulation, having little CFO is a major drawback in these systems due to the sensitivity of the systems to frequency change. Fig. 6 shows how OFDM systems with 64-QAM modulation and N equal to 128 perform in terms of BER for various normalized frequency offset (ε) values. Furthermore, with conditions of transmitting OFDM signal through AWGN channel and the assumption that CFOc and CFO_r are absent, Figure 6 illustrates the effects of increasing frequency offset on system performance. To be clear, the standard performance threshold was $BER=10^{-3}$, as anything higher than that may make it challenging to attain acceptable system performances even at high SNRs. Also, it is clear from this figure that $\varepsilon \geq 0.042$ was enough to severely degrade the system under the above work conditions. On the other hand, it is possible to observe that the OFDM degradation is proportional to the frequency offset and the SNR simultaneously. Figure 7 illustrates the degradation of the Signal-to-Interference-Noise ratio SINR (in decibels) [36,37] as a function of the frequency offset. According to this figure, without effects of normalized frequency, not being subcarriers interferences. SINR represented 13, 17, 23, and 29 dB. Also, SINR was reduced by increasing the value of the normalized frequency offset, while SINR increased by growing the SNR. Figure 8 compares the BER performance of a 64QAM and QPSK OFDM system with over AWGN in the presence of CFO due to transmitter-side devices and signal processing at values of ε= 0, 0.05, and 0.1. This comparison shows that the 64 QAM OFDM system's BER performance was low because the CFO influenced the high modulation index OFDM system. However, the result was acceptable at 10^{-3} and a normalized frequency of (0.05) compared with the benefits of using high modulation systems. Meanwhile, the BER for an OFDM system with 64QAM and QPSK in the case of 23 dB S/N is shown in Fig. 9. In the event of ε = 0.05 and BER of 10^{-4}, S/N varied between 27dB and 40 dB for 64QAM and QPSK, respectively.

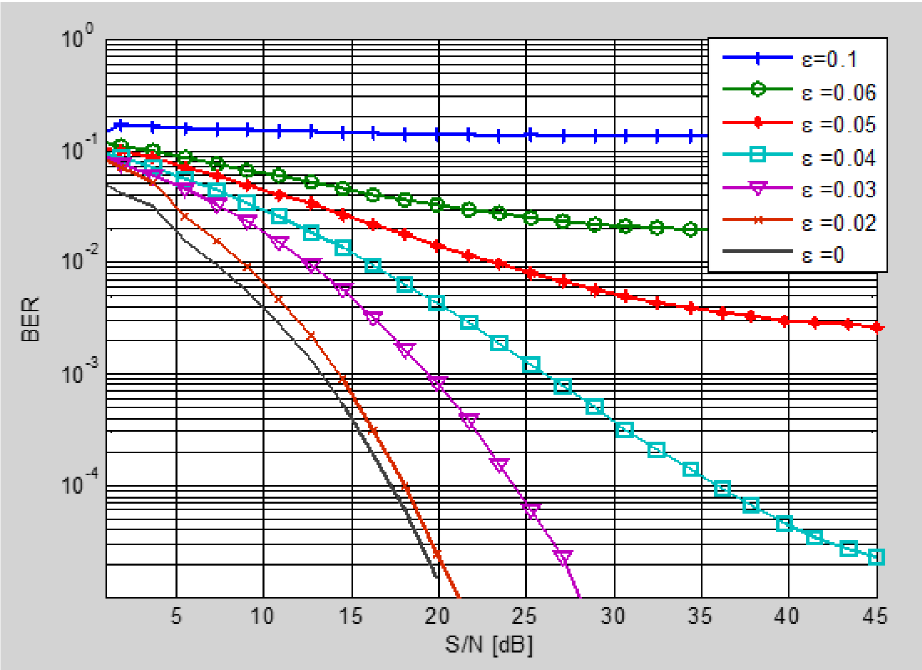


Fig. 6 BER Performances for Different Values of the Normalized CFO.

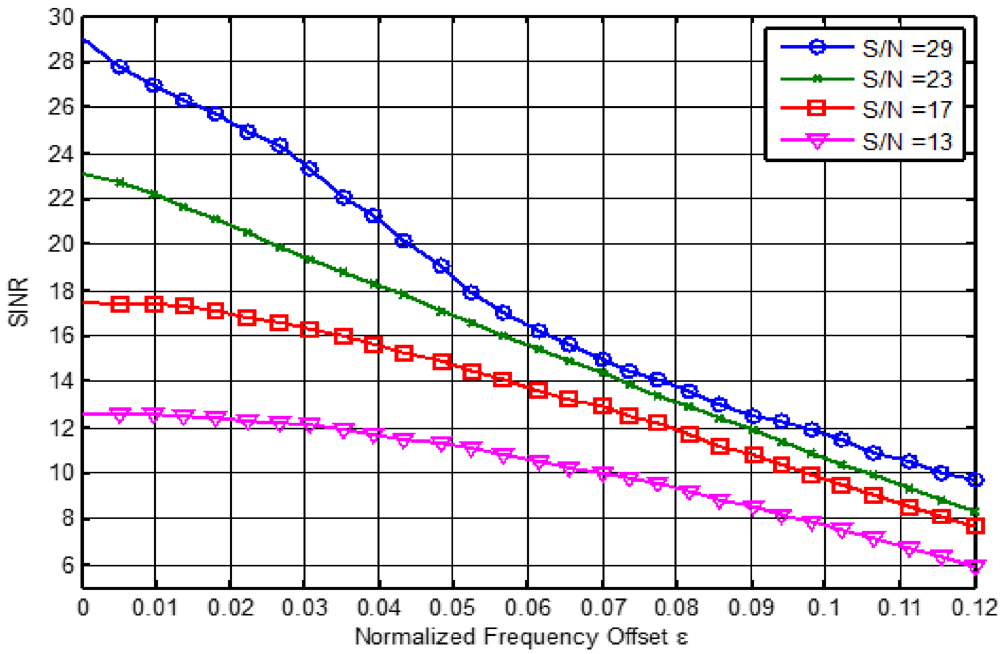


Fig. 7 Signal-to-Interference-Plus-Noise-Ratio (SINR) Performances Over CFO.

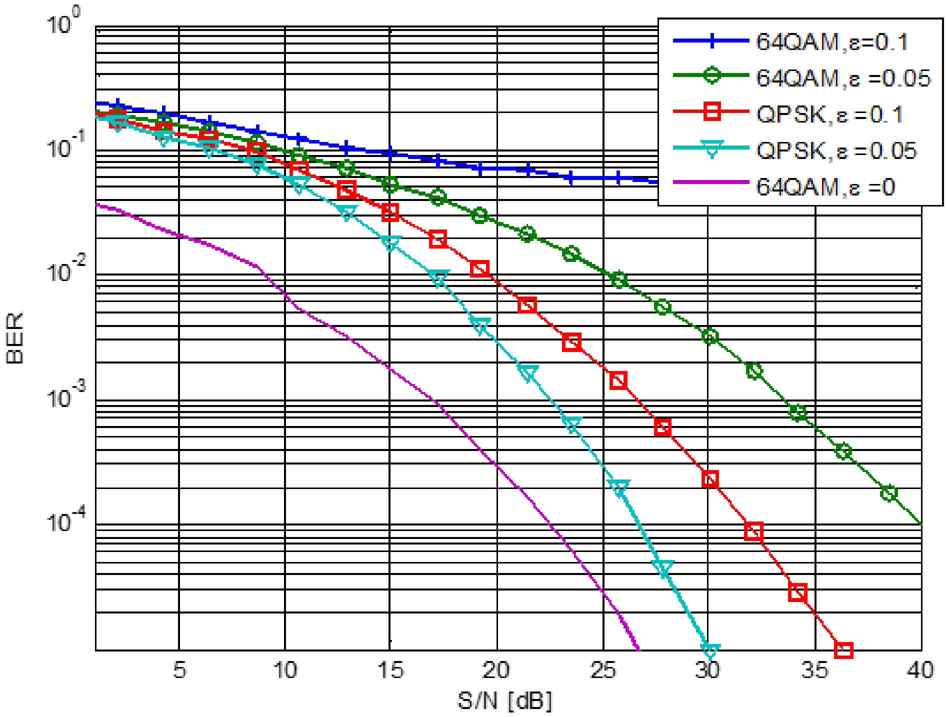


Fig. 8 64QAM and QPSK-OFDM System BER's Performances Over AWGN Channel in Case of ε Equal to 0, 0.05, and 0.1.

Data hiding is part of the system proposed in this paper, so for evaluating the work, steganography also takes a share in these results. Many criteria can evaluate steganography; however, the most important criteria were considered, i.e., Peak-to-Signal Ratio (PSNR) and Mean Square Error (MSE). The following equation is used to determine that:

$$MSE = \frac{1}{mn}\sum_{i=0}^{m-1}\sum_{j=0}^{n-1}[I(i,j) - K(i,j)]^2$$

$$PSNR = 10.log_{10}\left(\frac{MAX_1^2}{MSE}\right)$$

Where Max represents the maximum pixel value of the image, whose dimensions are n and m, and l and k represent the original pixels. When using the proposed method, three different capacities and three types of images from a standard image set in a standard database, USC-SIPI, were proposed to measure better performance. Three volume capacities were used, namely 16394, 32778, and 49252 bytes, with storage rates of 6.25%, 12.5%, and 18.75%, respectively. Here, an image of 1024 × 1024 pixels is used for two types of color images and a grayscale image. The method of addition in the gray image is in the form of one channel. However, in the color image, three channels were used for embedding, namely RGB. The percentage was calculated as 1 pixel = 8 bit, so 1/8 was 12.5%, i.e., the embedding is in one bit, 2 pixels = 16 bits, i.e., 1/16 was 6.25%, i.e., the embedding was in two bits. As shown in Table 1, increasing the payload capacity decreased PSNR because increasing the data in the image raised doubts about the image and made it more vulnerable to hacking. Therefore, it is necessary to balance the load capacity of the image and the quality of the image. Increasing the contrast in the image increased the possibility of increasing the storage capacity. It was noticed that the peppers image contained more contrast in the pixel unit, so filling in the data in this case was feasible.

Table 1 PSNR of Standard Images with 512 ×512 Pixels.

Capacity	%	Lena	Baboon	Peppers
16384	6.25	82.7 dB	86.8 dB	89.5 dB
32768	12.5	80.2 dB	82.9 dB	85.0 dB
65536	18.75	76.9 dB	79,8 dB	80.3 dB

5.CONCLUSION

In the OFDM systems, the CFO problem is due to transmitting the signal between the stages of the transmission device, maximizing the ICI problem with the enlargement of the expansion of the transmitted signal after the amplifier stage. Thus, it causes a significant deterioration of the error rate of bits (BER). Since Many researchers are interested in the issue of the CFO's height, the present study looked at how it affected the various OFDM system standards. When it came to the design of the wireless communication system, the primary objective was to locate a mechanism that strikes a reasonable balance between the system's performance and the various parameters. ICI energy was completely removed when the natural frequency displacement was small (0.03), while higher than (0.03), the ICI power was affected; however, it was not completely removed. While the proposed CFO's compensation in the transmission device completely removed ICI even with the displacement of the high standard frequency 0.12, BER performance was tested with the proposed technology via AWGN, assuming no frequency violation. The simulation results confirmed that the error rate of bits can be improved when comparing the proposed technologies with other methods. Then, the effect of the financial manager on the OFDM system was analyzed using the compensation method. The analysis showed that the non-linearity lands from the CFO through the deterioration of SNR.

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