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A New Approach to Improve Transmitting and Receiving Timing in Orthogonal Frequency Division Multiplexing (OFDM) Systems

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ABSTRACT: Nowadays, most wireless communications employ OFDM technology to reduce signal interference. Its sensitivity to timing faults, however, can cause a severe performance reduction. This study suggests a new approach to enhance communication systems' transmitting and receiving time. Although OFDM is a widely used modulation strategy in communication systems, it is vulnerable to timing faults, which can seriously affect performance. A frequency interference processing method is created that uses OFDM technology and goes through numerous steps, such as correcting CFO, adding a periodic prefix to prevent frequency distortion, calculating the time delay between transmission and reception, and spotting timing mistakes. It is clear that the lack of synchronization between the transmitter and channel interference has caused the Signal-to-Noise Ratio (SNR) to decline correspondingly. The initial approach had a piece of code that computed the transmission and reception times while recording their differences. As a result, it handles signal interference and frequency and temporal synchronization, two key aspects of OFDM. Timing precision varies from 0 to 1, and the time gap between transmission and reception is only a fraction of a second. When the SNR was available, timing errors and the lag between transmission and reception timing were seen, which suggests that there is a small probability of having too many locks or losing codes while utilizing OFDM. Simulation exercises show that the suggested method considerably enhances the system's Bit Error Rate (BER) performance in a variety of time offset conditions. The outcomes imply that the suggested strategy could be a workable remedy for OFDM systems with timing issues.

Keywords: Wireless communication, OFDM, Time synchronization, Frequency Synchronization

1. INTRODUCTION

The Orthogonal Frequency Division Multiplexing (OFDM) [1][2][3] technique was developed by Bell Labs' Robert W. Chang. Based on quick Fourier transform techniques, multiple orthogonal convergent sub-carriers are conveyed with overlapping spectra in the OFDM technology [4]. Weinstein and Ebert improved OFDM's orthogonality in transmission channels affected by multipath propagation by adding a guard interval to it in 1971 [6]. Each subcarrier (signal) is altered using a conventional modulation approach at a low symbol rate (such as phase shift switch or amplitude square modulation). For a single load in the same bandwidth, this keeps total data rates comparable to those of classic modulation techniques [7].

Weinstein and Ebert improved OFDM's orthogonality in transmission channels affected by multipath propagation by adding a guard interval to it in 1971 [6]. Each subcarrier (signal) is altered using a conventional modulation approach at a low symbol rate (such as phase shift switch or amplitude square modulation). Due to the low symbol rate, it is feasible to use protection intervals between symbols, which eliminates inter-symbol interference (ISI) and allows for the use of echo and time diffusion (which appear as shadows and noise, respectively, in analog visual television), respectively, for a variety of gains, including an improved signal-to-noise ratio. This mechanism also makes it simpler to design Single Frequency Networks (SFNs), in which several neighboring transmitters simultaneously transmit the same signal on the same frequency. By constructively reconnecting signals from the farther away multiple transmitters, this mechanism avoids interference from a conventional single bus system.

The broadcast signal is subjected to forward error correction (convolutional coding) and time/frequency interleaving in COFDM. This is done to combat multipath propagation and Doppler effects-related problems in mobile communication networks. Alard developed COFDM in 1986 [8][9][10] for the Eureka Project 147. The acronyms

COFDM and OFDM are sometimes used interchangeably for similar purposes in practice since OFDM has been used in conjunction with this coding and interleaving [11][12].

2. Related Work

Many researchers have worked on networks that operate on the OFDM technology, whether it is single or multi-band. In this part, we will review the most important works that dealt with this technology.

The threshold criteria were examined and its theoretical performance was determined by S. Rosati et al. in 2009. Better characterization of the OFDM synchronization algorithms as a consequence of this work brought design expectations and actual performance closer together. The computer simulation revealed that the theoretical hypotheses and the numerical outcomes were in excellent accord [12].

A. Ejaz et al. introduced a low-complexity OFDM systems in frequency-selective fading channels SNR estimation technique. The estimate was based on a traditional hypothesis with two identical components. The signal power was calculated using the correlation of the received signal samples, whereas the noise power was calculated using the variance of the received samples. The proposed estimator has good channel frequency selectivity, according to simulation findings, and its attained accuracy and simplicity make it a desirable alternative for current wireless OFDM systems [13].

Due to the inherent averaging over several subcarriers, Timothy M. Schmidl and Donald C. developed techniques for frequency shift estimation that operate close to the Cram'er-Rao minimum of variance [14].

Utilizing all available data, Cong Luong Nguyen et al. proposed a combined frequency and Maximum a Posteriori Probability MAP frequency synchronization algorithm. Using this approach, we may fine-tune the time synchronization by a certain scale in the frequency domain, lowering the expectation of the transmission error function over all channel estimation errors. Simulation results compatible with the IEEE 802.11a standard in both indoor and outdoor situations showed that the recommended method significantly improved the performance in terms of synchronization. Bit error rate and failure probability are measured in comparison to the most recent techniques [15].

José Luis Hinostroza Ninahuanca et al. presented methods to improve the estimation of symbol timing shift (STO) and carrier frequency shift for dual-polarization orthogonal frequency division multiplexing systems (CFO). For very spectral-efficient communication systems, multiple-input and quad-output OFDM has recently been proposed. This technique can flexible investigate various types of diversity, including spatial, temporal, frequency, and polarization diversity. Their study concentrated on periodic prefix synchronization strategies for DP-OFDM systems, where the use of quadratic algebra results in new, better estimators. When compared to their monopolarized (SP) counterparts, simulations of the DP system methods for the STO estimator and CFO estimate showed a faster decline in variance with a double slope in the log variance line against the SNR plot for quadrupole-valued or complex-valued signals, respectively. The reported benefits for DP systems using SP OFDM were used to estimate the Cramer-Rao limits for STO and CFO for the synchronization techniques [16].

A new technique for temporal synchronization of a direct visible-light optical frequency-division multiplexing (DCO-OFDM) system was reported by Jianli Jin et al. This enhanced technique integrated pseudo-noise (PN) sequencing with a modified Park synchronization technique. The suggested method's synchronization performance in the DCO-OFDM system was carefully examined and compared to the performance of three other standard approaches. It is shown that the enhanced technique can only acquire a single precise and constrained time point, which boosts the DCO-OFDM VLC system's synchronization capabilities. Additionally, the simulated results showed that the novel technique outperformed other traditional methods in terms of time and accuracy for various signal noise ratios (SNR) and fast Fourier transform (FFT) block sizes. An experiment was utilized to further evaluate the time scale performance, and the findings demonstrated that the suggested approach is better to previous methods [17].

In this paper, we have developed an algorithm that works with OFDM technology, to address interference in frequencies through several stages, the most important of which are CFO correction, Cyclic Prefix to avoid distortion in frequencies, specifying the difference between the transmitting and receiving times, and determining the timing error.

3. OFDM technology Reasons

It is known that the received signal through wireless channels, in which the transmitted (original) signal is multiplied by the channel matrix, as the original signal may be subjected to attenuation and the result is that which is received at the other end [1]. This operation is calculated according to the following formula:

$$y[n] = Hx[n] \tag{1}$$

Where y[n] represents the received signal, while H represents the channel matrix, and H x[n] represents the transmitted signal [2]. This technique works only for narrow-band channels, where the band is small, but not for wide-band channels, where the band is large [3][4].

In the normal situation, either you send the signal all in one band and this is called a wideband channel, or we divide the signal and send it in batches so that we send each batch in a separate band, and this is better to ensure that data is not lost in one go [5][6].

We notice in the figure 1, that the signal was divided into orthogonal signals to ensure that it was sent in batches and not lost at once, as the bandwidth was divided into sub-frequencies, each part of us called orthogonal sub-channels [5][6].

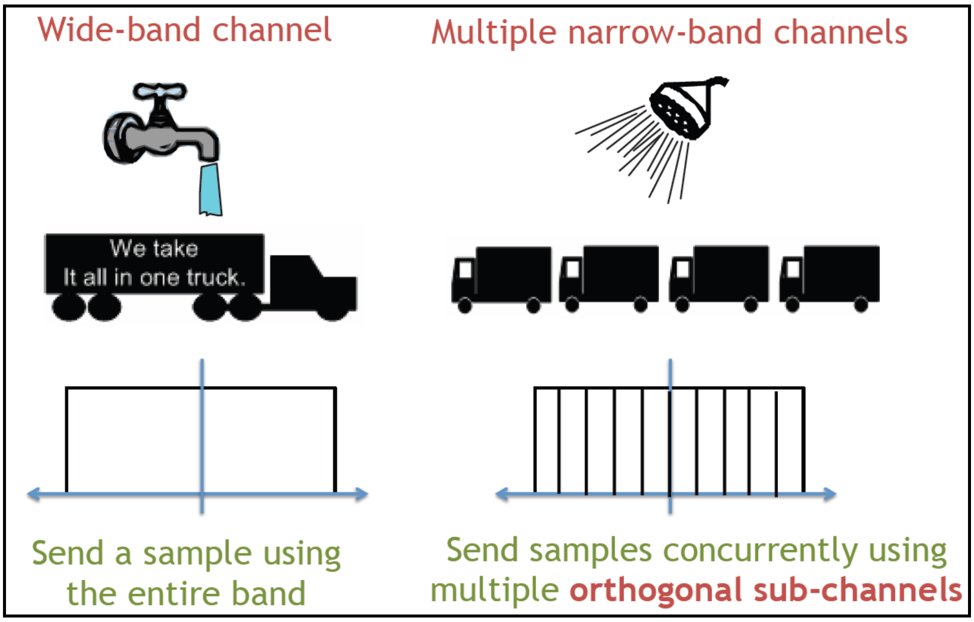


FIGURE 1. - Wide-band vs. multiple narrow-band channels

When using FDM technology, the individual sub-channel interferes with each other, causing interference in the received signal. To solve this problem, Need guard bands between adjacent frequency bands to ensure no interference, which causes some of the bandwidth to be neglected and not exploited [6][7].

The best solution to ensure no interference is to use OFDM where the channels are perpendicular to the different frequencies. The following figure shows the difference between FDM and OFDM [7][8].

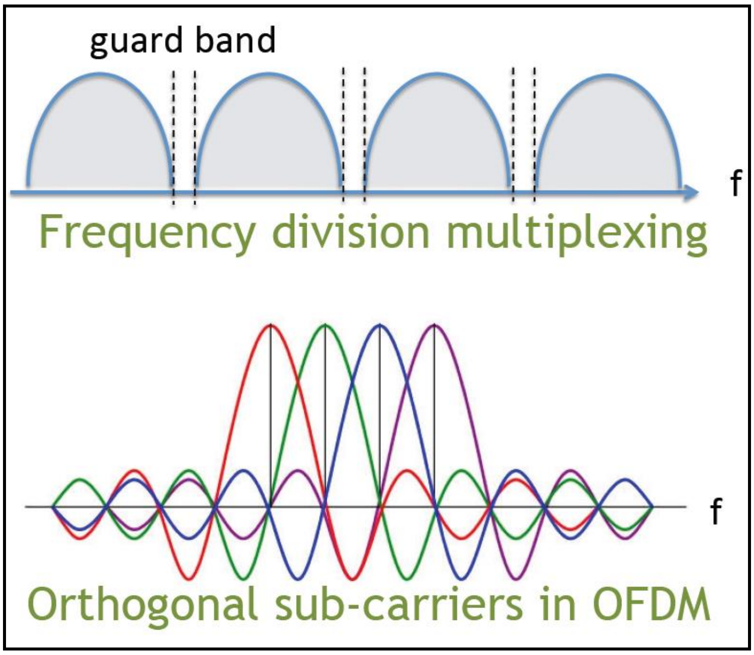


FIGURE 2. - FDM vs. OFDM

4. Background of OFDM

As mentioned earlier, OFDM splits the bandwidth into how it does OFDM work to ensure that the signals do not interfere with each other. In this part of the paper we will discuss the mechanism of OFDM working, as shown in the following figure:

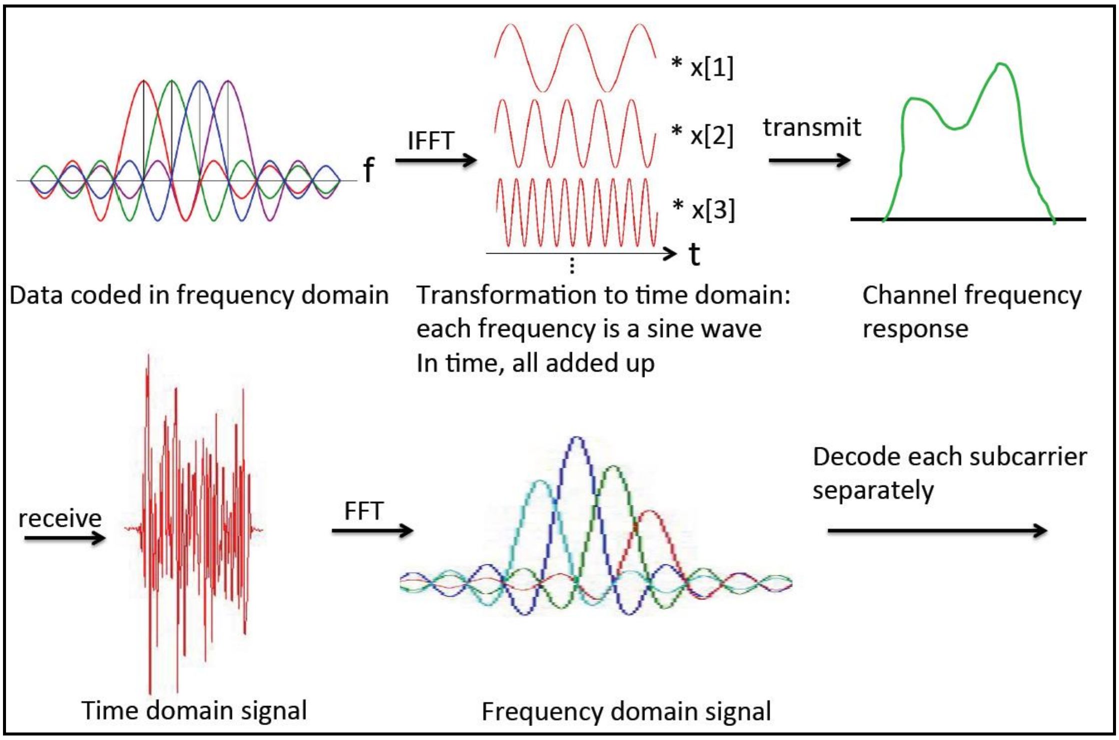


FIGURE 3. - OFDM transmission and receiving

Since each signal is a wave signal and is combined to be sent across the medium transporter, the transmitted data is encoded into the frequency domain to split the bandwidth into orthogonal parts before entering the Inverse Fast Fourier Transform (IFFT) to convert the signal to the time domain [9][10].

The signal is decoded and the distortions are eliminated at the receiving end before it undergoes the IFFT, which converts the signal's time domain to its frequency domain [11].

By using the following equation [13], the signal in IFFT is transformed from the frequency domain to the time domain:

$$X(t)=\sum_{k=N/2}^{\frac{N}{2}-1} x(k)e^{-j2\pi kt/N} \tag{2}$$

Where X(t) represents the data in the time domain, and k represents the frequency.

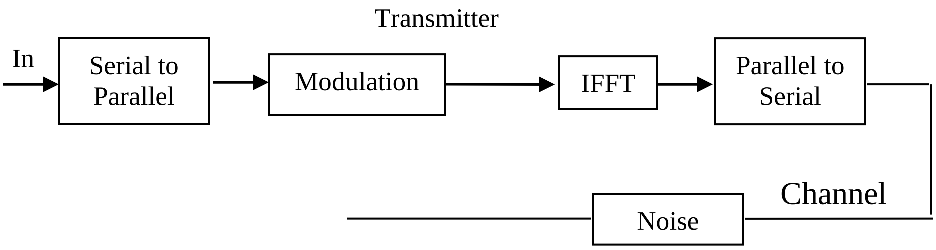
In FFT, the data is transferred from the frequency domain to the time domain according to the following equation [10]:

$$X(k)=\sum_{k=N/2}^{\frac{N}{2}-1} x(t)e^{-j2\pi kt/N} \tag{3}$$

Orthogonally of any two bins (orthogonal sub-channels) must have their beats 0 to ensure that the interference between them is neglected, and as shown by the following equation [11]:

$$X(p)=\sum_{k=N/2}^{\frac{N}{2}-1} e^{-j2\pi kt/N}e^{-j2\pi pt/N}=0, \forall \neq k \tag{4}$$

To illustrate the architecture of OFDM, we include the following figure:



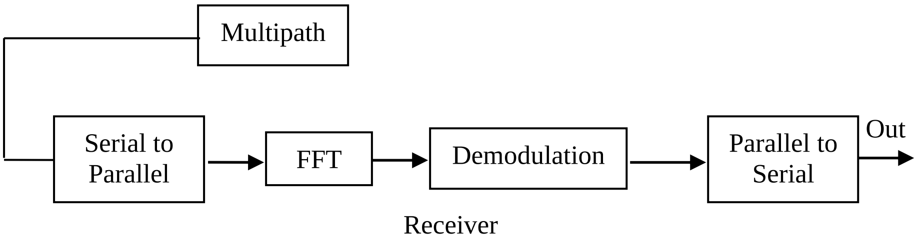


FIGURE 4. - OFDM architecture diagram

The OFDM architecture above, is a good but not perfect architecture, as these data transmitters will face two main problems: noise and multi-paths. As for the noise, it can be deleted when the data reaches the receiver by discovering the data frame. The main problem lies in the multiple paths and their effects [9].

Usually when sending data from the sender to the receiver, most of the time there is a line of site signal, which is the signal that is directly from the sender to the receiver without any obstacle, but there are also signals called fade path, in which the signal is subjected to collision with obstacles such as buildings or Trees, and thus those signals may be reflected or broken and then reach the receiver. Each of the paths crossed by the signal will be exposed to path gain and path delay, which differ from one path to another [8,9].

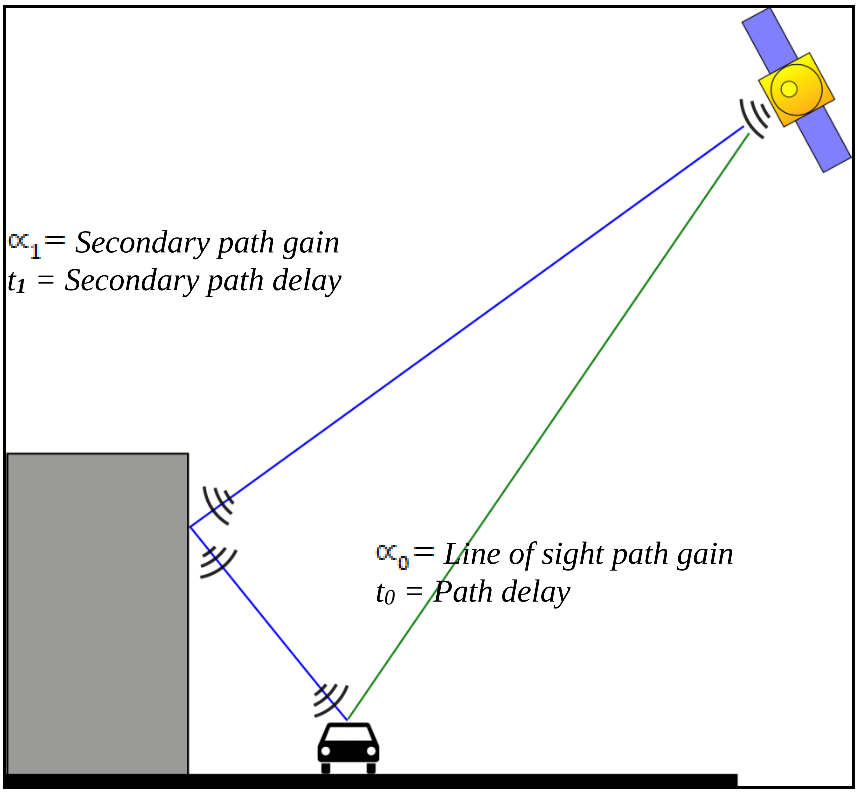


FIGURE 5. - Multi-path effects

We notice in the figure above that the signal sent from the satellite (the transmitter) to the vehicle (the receiver) passed two paths, the first is a direct path without any obstacle, and the second path collided with an obstacle which is the building, so the signal in the first path will arrive faster from the second with a lower attenuation rate, and then the signal from the second path arrives late, and therefore the received signal will be calculated by summing the signals through the two paths, taking into account the path gain and path delay[11,14], and as in the following equation:

$$y(t) = h(0)\times x(t) + h(1)\times x(t-1) + \ldots + h(k)\times x(t-k) \quad (5)$$

$$y(t) = \sum_{\Delta} h(\Delta)x(t-\Delta) \quad (6)$$

In this case, the recipient will receive the current copy with multiple delayed copies, so the signals will coalesce destructively, destroying the signals arriving at the other end. Only some sub-carriers are impacted in what is known as frequency selective fading [13][14].

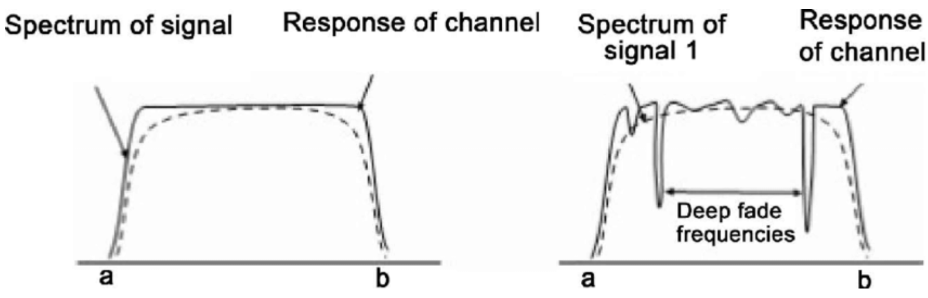


FIGURE 6. - Frequency selective fading

frequency selective fading will cause inter symbol interference, as the late version will overlap the adjacent symbols. As shown in the accompanying image, we will utilize a cyclic prefix to overcome this issue by lengthening the symbol period by duplicating the tail and adhering it to the front:

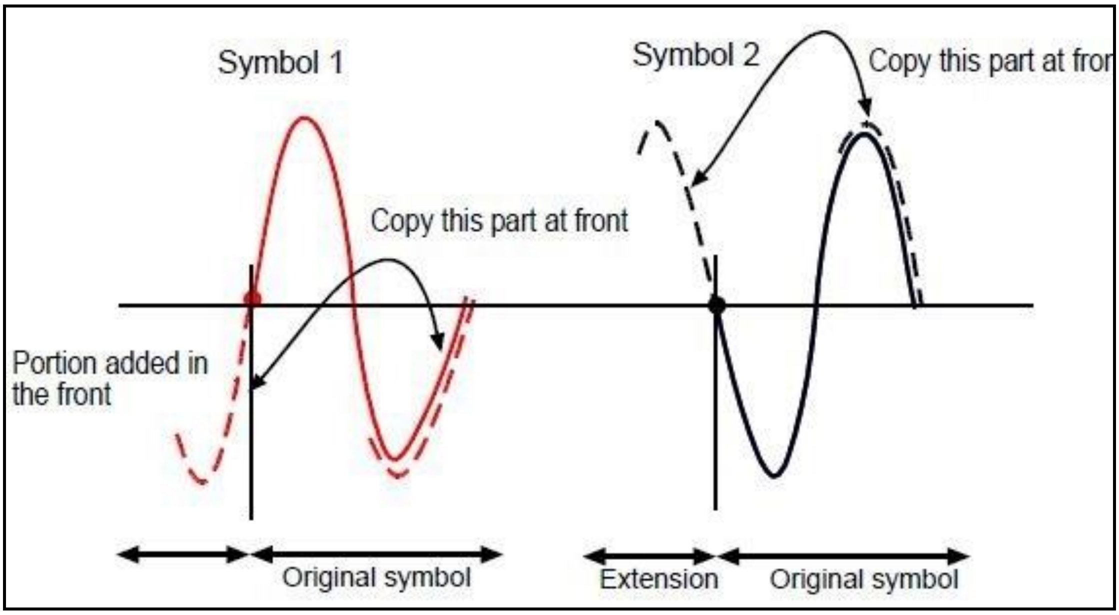


FIGURE 7. - Cyclic Prefix

It is still feasible to retrieve the proper signal in the frequency domain by correcting for this rotation since the delay in the time domain that results from CP corresponds to the rotation in the frequency domain [12][13][14].

By adding the CP process to the OFDM structure, we obtain the following diagram [11]:

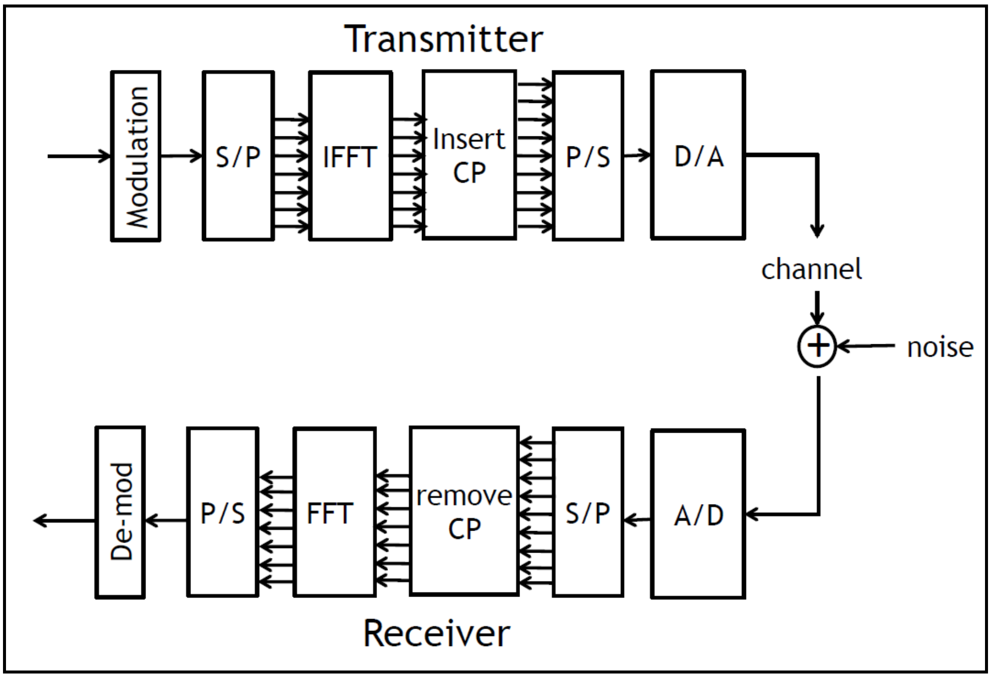


FIGURE 8. - OFDM diagram with cyclic prefix

5. Synchronization problem in OFDM

In both wired and wireless networks, there is frequently a difference between the transmission and reception times during the data transmission process. DAC (at Tx) and ADC (at Rx) never have exactly the same sampling period, and this results in what is known as a "slow shift of the symbol timing point," which rotates the carriers. Subcarriers that induce inter-carrier interference (ICI), which results in the loss of the subcarriers' orthogonality, will interfere with those channels and lose their orthogonality, which is their most crucial characteristic [12][14].

Slow shift can be manipulated by CFO, by which we mean control shift, where we scuff the carrier frequency by a certain amount [9][10], which we calculate mathematically through the following equations:

- Up-convert base-band signal S_n to pass-band signal

$$y_n = s_n * e^{j2\pi\, ftxnTs} \tag{7}$$

- Down-convert pass-band signal y_n back to

$$r_n = s_n * e^{j2\pi\, ftxnTs} * e^{-j2\pi\, frxnTs} = s_n * e^{j2\pi \mathbf{f\Delta n}Ts} \tag{8}$$

Sampling Frequency Offset (SFO), in which the transmitter and receiver may sample a signal at a slightly different displacement, is a further technique that is required in addition to Carrier Frequency Offset (CFO). Although each sub-carrier has a distinct frequency from the others, they all have the same sampling latency [7][9].

To get rid of all these synchronization problems, we will use Phase Tracking, which is a set of operations whose primary function is the frequency shifting operations with a small difference in time that does not affect the overall transmission and reception process [9,12].

After optimizing of synchronization in OFDM, and adding optimizations to the master scheme [12][13], the OFDM scheme becomes as follows:

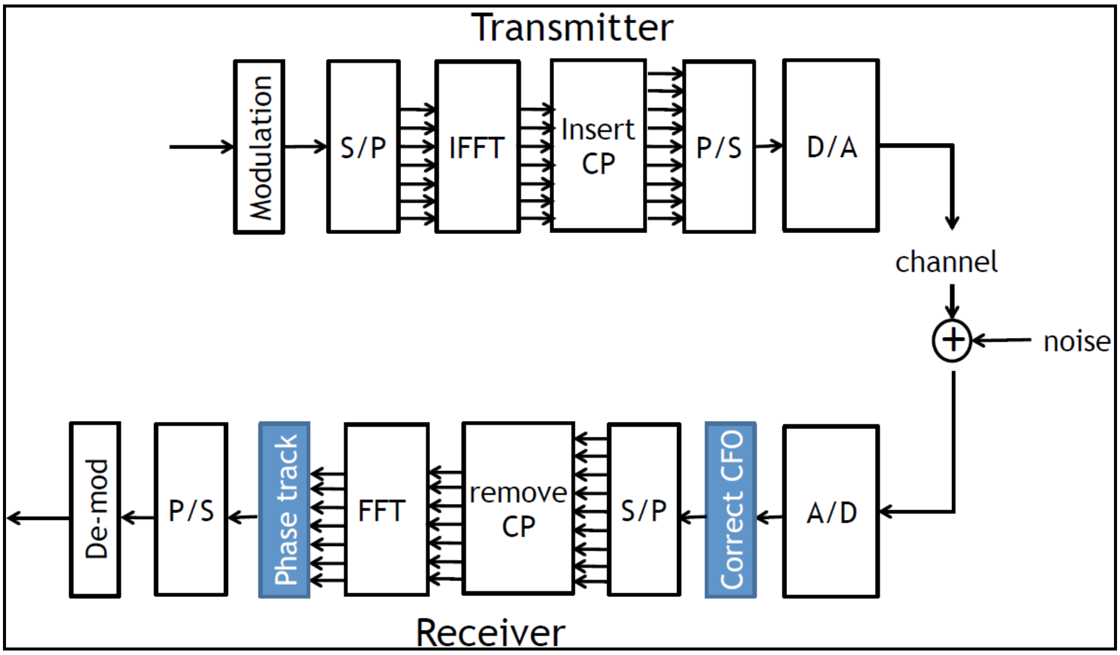


FIGURE 9. - OFDM diagram after synchronization optimizing

We note in the above chart the addition of two blocks, the first is the Correct Carrier Frequency Offset, and the second is Phase Tracking, which we talked about previously [12][14].

6. The Proposed Algorithm and system simulation

In light of the OFDM diagram in Figure 9, an algorithm was developed using MATLAB. This algorithm simulates the transmission and reception processes in wireless networks based on OFDM technology.

The transmitted data has gone through all the stages of OFDM scheme, from the beginning of the modeling, where the digital data has been converted to analog for the purpose of sending it through the medium, including converting the data from serial to parallel to ensure that it is sent simultaneously. Here is an example of this conversion process.

Let's say we want to send a stream of samples using BPSK and 4 sub-carriers:

1, 1, -1, -1, 1, 1, 1, -1, 1, -1, -1, -1, -1, 1, -1, -1, -1, 1, …

To convert this string into parallel samples (Frequency-domain signal), as follows:

Table 1. - Frequency-domain signal

	c1	c2	c3	c4
symbol1	1	1	-1	-1
Symbol2	1	1	1	-1
Symbol3	1	-1	-1	-1
Symbol4	-1	1	-1	-1
Symbol5	-1	1	1	-1
Symbol6	-1	-1	1	1

The signal is changed from the frequency domain to the time domain by applying Equation No. 2 for IFFT, as shown below:

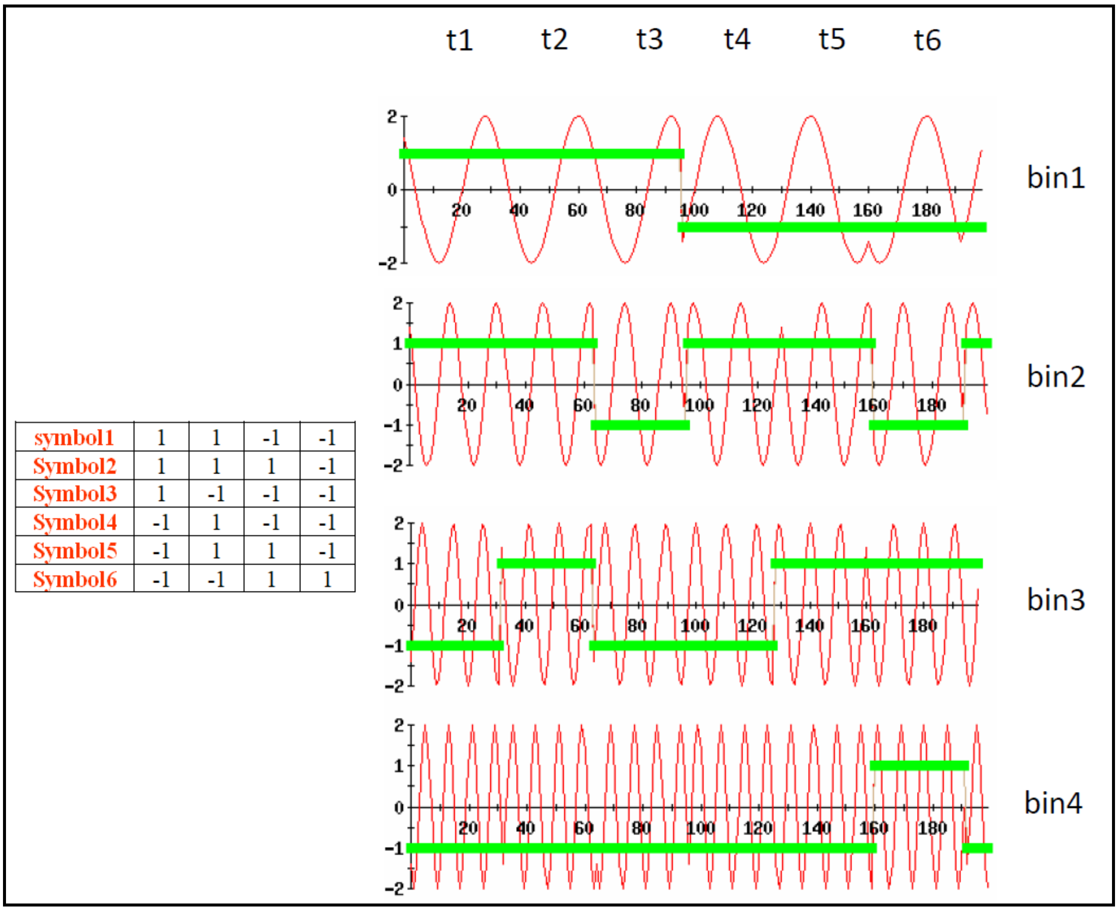
Table 2. - Time-domain signal

	c1	c2	c3	c4
symbol1	0	2-2i	0	2+2i
Symbol2	2	0-2i	2	0+2i
Symbol3	-2	2	2	2
Symbol4	-2	0-2i	-2	0+2i
Symbol5	0	-2+2i	0	-2+2i
Symbol6	0	-2+2i	0	-2-2i

It is then transformed from a parallel chain to a serial chain for the purpose of sending it through the transmission medium.

0, 2-2i, 0, 2-2i, 2, 0-2i, 2, 0+2i, -2, 2, 2, 2, -2, 0-2i, -2, 0+2i, 0, -2+2i, 0, -2+2i, 0, -2+2i, 0, -2-2i

The following figure shows drawing samples in the time domain.



symbol1	1	1	-1	-1
Symbol2	1	1	1	-1
Symbol3	1	-1	-1	-1
Symbol4	-1	1	-1	-1
Symbol5	-1	1	1	-1
Symbol6	-1	-1	1	1

FIGURE 10. - Time-domain signal

Adding noise to an OFDM system is a common method used to simulate the effects of real-world interference and to evaluate the performance of the system under different noise conditions. There are several ways to add noise to an OFDM system:

Additive White Gaussian Noise (AWGN) is a commonly used model for noise in communication systems. It is a type of noise that has a constant power spectral density across all frequencies, and the samples of the noise follow a Gaussian (normal) distribution. In an OFDM system, AWGN can be added to each subcarrier after modulation and before transmission. The power of the AWGN is usually specified as a signal-to-noise ratio (SNR) that determines the strength of the noise relative to the signal.

Multipath fading is another type of interference that can affect an OFDM system. It occurs when the signal reaches the receiver through multiple paths, resulting in constructive and destructive interference. To simulate multipath fading in an OFDM system, one can add a set of delayed and attenuated copies of the transmitted signal to create a realistic channel model. This is often referred to as a channel simulator.

Impulsive noise is a type of noise that occurs in communication systems due to sudden and sharp changes in the signal level. Examples of impulsive noise sources include lightning strikes and power line interference. To simulate impulsive noise in an OFDM system, one can add a series of random spikes or impulses to the signal.

Once the noise is added to the OFDM system, the performance of the system can be evaluated using metrics such as the bit error rate (BER) or the signal-to-noise ratio (SNR). This can help in determining the robustness of the system under different noise conditions and in optimizing system parameters such as the modulation scheme and error-correcting codes.

After going through all the stages of the OFDM scheme, the algorithm works fairly well. Below we review the implementation of the algorithm in the MATLAB program, in addition to displaying the results of the work.

When simulating wireless networks in the MATLAB program, this can be done in several ways, the first of which is to write a code without using the tools in the program, or it is possible to write code using the program's tools, and this facilitates programming the simulation in the MATLAB program, or it is possible to build a block using Simulink, and finally we can use Devices related to wireless networks, then linking them to MATLAB through specialized programs, and this is costly in terms of time and money.

In our current work, we will write a code in MATLAB to simulate the process of sending and receiving without using MATLAB tools, and this is a challenge to get the work done at the lowest cost.

7. Results Analysis

After executing the program, the system will request several inputs, which are the basis for the transmission and reception operations and are as we explained previously, size of OFDM symbol assuming fully loaded symbol, constellation order size (Alphabet size), type of modulation (PSK or QAM), constellation phase offset, constellation Symbol Order (Binary or Gray) , size of cyclic prefix samples, and number of OFDM symbols to be simulated.

If we take as an example the number of symbols we want to send 16 symbols, which is the same number of symbols that we want to simulate to send, the number 16 as an option for constellation order size (Alphabet size), the number 1 to choose the modulation type which is PSK, and we hash each bit by entering a value of 2 for Up- sampling factor, and we assume that there is no interference between frequencies by entering the value 0 for the constellation phase offset, and also we will not do cyclic prefix samples by entering the value 0, this implementation will result in data transmission with the calculation of SNR as the ratio of signal power to noise power, where the result is as follows :

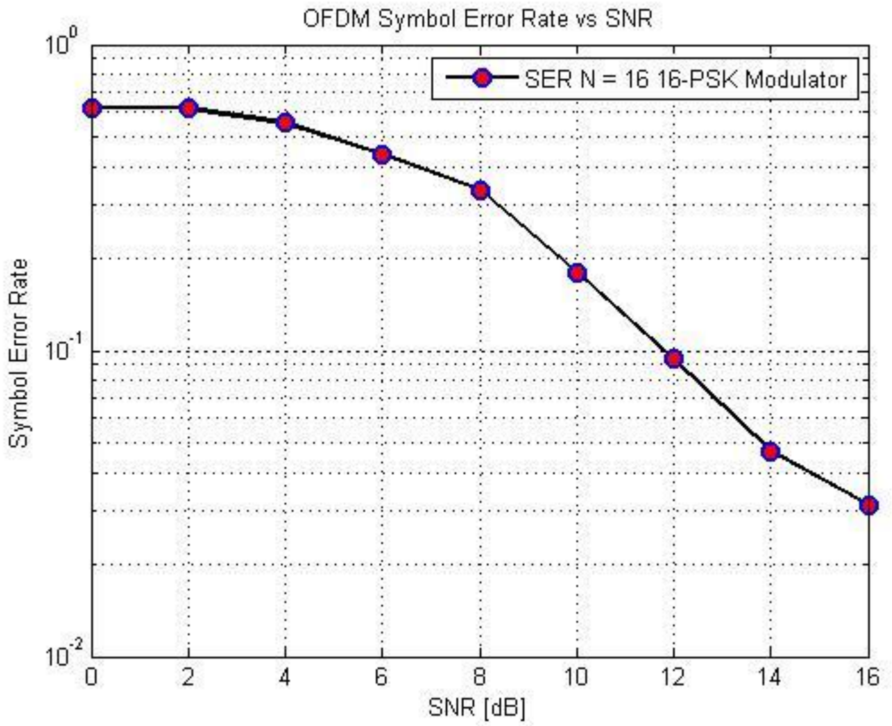


FIGURE 11. - Example1 of result

We note in the above figure, that the SNR ratio is a high percentage resulting from the overlap of the channels with not using the constellation phase offset, as well as not using the cyclic prefix, so we have an interference in the signal frequencies and a difference between the transmitting and receiving time, that time is an unimportant factor in our work because the delay The time in total transmission and reception is very small (milliseconds) compared to the quality of the independent signal. When executing the program, taking into account the constellation phase offset and cyclic prefix operations, with the same previous inputs, in an OFDM system, the symbol error rate (SER) is a measure of the probability that a transmitted symbol is received incorrectly due to noise or other impairments. The SER is a function of the signal-to-noise ratio (SNR), which is the ratio of the power of the signal to the power of the noise.

As the SNR increases, the SER decreased, indicating a better performance of the system. This relationship between SER and SNR can be visualized in a curve called the SER vs. SNR curve or the bit error rate (BER) vs. SNR curve.

The curve shows how the SER or BER varies with the SNR, and it can be used to evaluate the performance of the system under different noise conditions. The curve typically has a characteristic shape that depends on the modulation scheme, coding rate, and other parameters of the system.

In general, at low SNR values, the SER or BER is high, indicating a high probability of errors. As the SNR increases, the SER or BER decreases, and eventually reaches a minimum value, which is the lowest achievable error rate for the given system configuration. This minimum value is known as the error floor, and it represents the irreducible error rate due to various factors such as noise and interference.

At high SNR values, the SER or BER may start to increase again due to other factors such as non-linear distortion or interference from other signals. This region is called the error ceiling and represents the upper limit of the achievable performance, we get the result in the following figure:

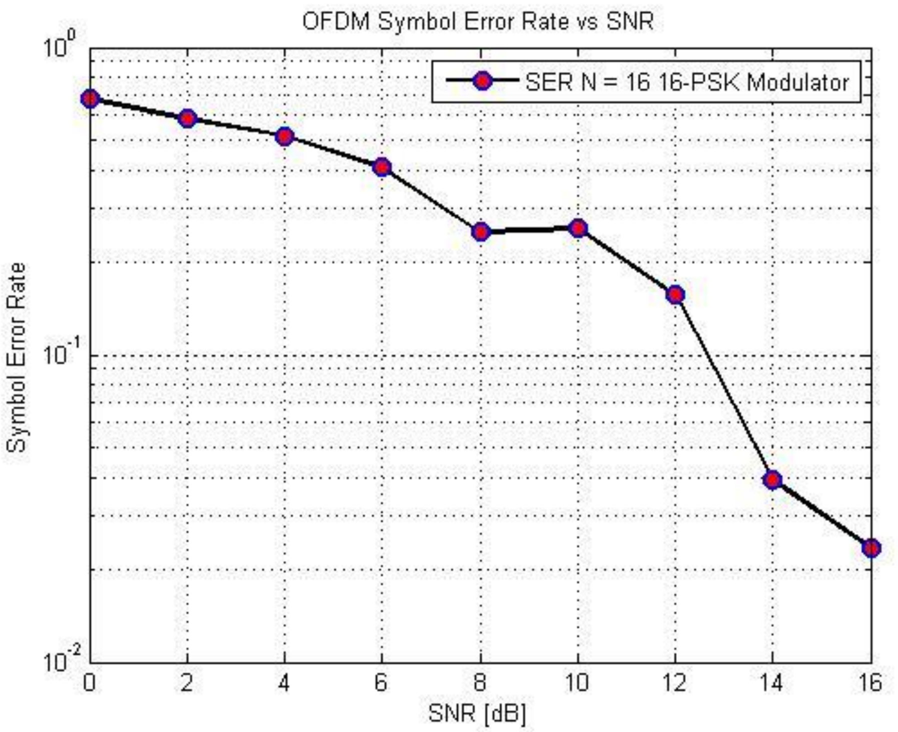


FIGURE 12. - Example2 of result

In the above figure, we can see that the SNR has decreased in good proportion, and this is due to the non-interference of the transmitter and band channels.

For the purpose of determining the time of sending and receiving, and noting the difference between them, a code was written at the end of the original algorithm, where the result of determining the time appears as the following figure:

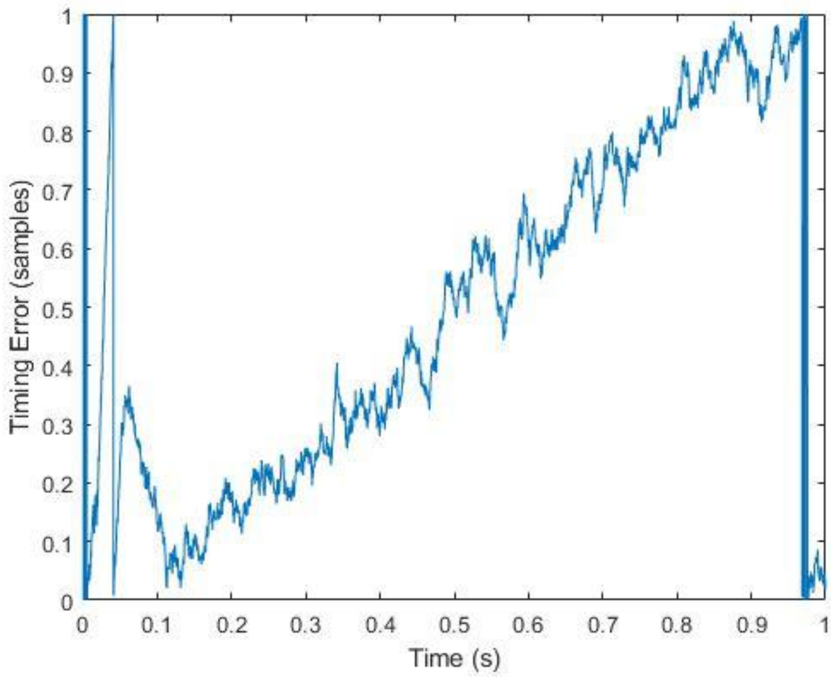


FIGURE 13. - Time detection

We note above, that the difference between the transmitting and receiving time is very small, not exceeding one second, as well as the timing error, its ratio lies between 0 and 1, so the OFDM factor has dealt with two important issues, namely, the interference of signals and the synchronization of frequencies and time.

The OFDM modulation technique is used in many modern communication systems, including Wi-Fi, digital television, and 4G/5G cellular networks. One of the advantages of OFDM is its ability to handle two important issues in wireless communication, namely the interference of signals and the synchronization of frequencies and time.

The OFDM system divides the available frequency band into many narrow subcarriers, each carrying a small piece of the data. This allows the system to be more resilient to interference and noise in the frequency domain. Additionally, OFDM uses error-correcting codes to detect and correct errors introduced by noise.

Furthermore, OFDM also deals with the issue of synchronization by using a technique called cyclic prefix. The cyclic prefix is a guard interval inserted at the beginning of each OFDM symbol, which is a copy of the end of the symbol. This allows the receiver to detect the beginning of each symbol and to synchronize its timing with the transmitter. The difference between the transmitting and receiving time is very small, not exceeding one second, and the timing error ratio lies between 0 and 1.

In summary, the OFDM system is a robust modulation technique that can handle interference and noise effectively, and also deals with the issue of synchronization of frequencies and time through the use of cyclic prefix.

To determine how the proposed research work is different from existing ones, a review of related literature is necessary. However, without access to the specific literature that the proposed research is based on, I can provide a general overview of the existing research on timing synchronization in OFDM systems.

Timing synchronization is a critical issue in OFDM systems, and many research works have proposed different approaches to address this issue. Some of the common methods used for timing synchronization include correlation-based techniques, maximum-likelihood estimation, and pilot-symbol assisted techniques.

Correlation-based techniques use a correlation operation between the received signal and a known synchronization signal to estimate the timing offset. Maximum-likelihood estimation uses statistical models to estimate the timing offset based on the received signal. Pilot-symbol assisted techniques use known symbols inserted into the transmitted signal to estimate the timing offset.

The proposed research work aims to improve the timing synchronization in OFDM systems by using a combination of frequency-domain and time-domain methods. Specifically, the proposed approach utilizes a reference signal that is transmitted at a different frequency band than the data signal. The reference signal is then used to estimate the timing offset in the time domain, and the estimated offset is applied to the frequency-domain signal to correct the timing error.

Therefore, the proposed approach differs from existing methods in terms of the specific technique used for timing synchronization. By utilizing a combination of frequency-domain and time-domain methods, the proposed approach may be able to achieve better timing synchronization performance compared to existing techniques.

8. Conclusion

A method was presented in this paper to simulate the transmission and reception of data in wireless networks using OFDM technology, through which the frequencies and timing were synchronized, and the results were very good to some extent. Where SNR was provided, the possibility of excessive locks or missing codes was few serious using OFDM, timing errors and the difference between the transmit and receive timings were also identified. It is possible that the current work may improve in the future, through the use of other techniques, due to the absence of time errors and the difference between the transmitting and receiving times.

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CONFLICTS OF INTEREST

The author declares no conflict of interest.

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