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Examining BER of OFDM Digital Communication Systems with Improved ICI Cancellation Technique

Dr. Arunabh Kumar[1], Dr. R D Nirala [2]

[1]Department of ECE, Eklavya University, Damoh, India, arunabh.k[at]gmail.com

[2]Department of ECE, Eklavya University, Damoh, India, rdnirala[at]gmail.com

Abstract— *Orthogonal frequency division multiplexing (OFDM) is widely used in digital wireless communications, but suffers from inter-carrier interference (ICI) due to frequency offsets. This paper proposes an improved ICI cancellation technique to mitigate the effects of frequency offsets and enhance reliability of OFDM systems. The method employs a parallel ICI self-cancellation scheme to reduce the vulnerability of OFDM to frequency errors which can significantly degrade performance by causing ICI. Simulations demonstrate that the proposed approach provides a lower bit error rate (BER) compared to conventional self-cancellation techniques. Theoretical analysis and performance measurements confirm the effectiveness of the proposed method in eliminating ICI induced by frequency offsets. This research aims to advance ICI cancellation approaches in OFDM to offer a viable alternative for improving efficiency and robustness of OFDM based digital communication systems. Additionally, a novel fractional wavelet transforms (FrWT) based OFDM is introduced to further reduce ICI without cyclic prefix and improve bandwidth efficiency. The performance of FrWT-OFDM is analyzed against frequency offsets and compared to conventional FFT-OFDM in terms of BER. The results indicate FrWT's efficacy in mitigating ICI effects and its potential as an efficient OFDM technique.*

Keywords— *OFDM, enhanced cancellation technique, system performance, and bit error rate (BER).*

I. INTRODUCTION

Orthogonal Frequency Division Multiplexing (OFDM) has emerged as a promising multi-carrier modulation technique for wireless and multimedia communication due to its high speed and bandwidth efficiency [1], [2], [3]. OFDM finds extensive applications in wireless LAN, LTE, LTE-Advanced, and IEEE 802.16. The fundamental concept of OFDM involves dividing the available bandwidth into multiple parallel narrow sub-channels to combat the effect of delay spread [4], [5]. However, a notable issue with OFDM systems is their susceptibility to frequency errors, disrupting subcarrier orthogonality, leading to Inter-Carrier Interference (ICI), and degrading overall system performance. Moreover, as bandwidth usage increases, interference among users escalates, necessitating interference reduction in OFDM waveforms to achieve enhanced bandwidth utilization and spectrum efficiency.

To address these challenges, this study proposes a model that reduces the usage of cyclic prefix and mitigates interference through Fractional Wavelet Transform (FrWT). FrWT is a hybrid signal analysis technique that operates in both time and frequency domains, derived from the combination of Fractional Fourier Transform (FrFT) and Wavelet Transforms (WT) [6], [7], [8]. By encompassing the advantages of both WT and FrFT, FrWT offers improved orthogonality. In contrast to conventional OFDM systems, where ICI is mitigated using cyclic prefix (CP) that accounts for 20% additional overhead, FrWT-based OFDM eliminates the need for CP, resulting in 20% or more bandwidth efficiency improvement [9].

A vital technique for mitigating ICI among subcarriers is ICI self-cancellation, which is both simple and efficient. This method involves modulation and demodulation based on effective mapping schemes. Several approaches, such as time domain windowing, frequency domain equalization, and ICI self-cancellation, have been proposed in the literature [10], [11], [12], [13], [14], [15]. Among them, ICI self-cancellation using adjacent data conjugate mapping schemes has shown improved performance compared to other methods [16], [17].

Previous research has explored the use of Wavelet Transform (WT) and FrFT in OFDM systems, but there are drawbacks in terms of bandwidth efficiency and ICI cancellation. However, the proposed FrWT-based OFDM system with ICI self-cancellation shows promising results in improving reliability and performance. This work aims to evaluate the hybrid methodology, combining FrWT-based OFDM with ICI self-cancellation, and compare its Bit Error Rate (BER) performance with the conventional systems. Additionally, the paper presents a comprehensive analysis of the proposed system and simulation results.

Numerous methods, such as channel estimation and equalization, frequency domain equalization, and sophisticated ICI cancellation algorithms, have been developed to solve ICI in OFDM systems. Through the restoration of subcarrier orthogonality and enhanced system performance in the presence of frequency-selective fading and other channel flaws, these strategies seek to assess and counteract the effects of ICI.

Researchers and engineers can improve the robustness and dependability of OFDM systems, enabling high-quality data transmission in a variety of communication contexts, by comprehending and addressing the issues raised by ICI.

To improve system performance and lessen the negative effects of ICI, OFDM systems must implement better ICI cancellation algorithms. Advanced ICI cancellation techniques are being researched and developed for a number of main reasons:

1.1 ICI in OFDM systems can result in a decline in the received signal quality, increasing bit errors and decreasing the reliability of data transmission. The interference between subcarriers can be successfully minimized by enhancing ICI cancellation methods, which improves signal quality and lowers mistake rates. This is crucial in applications like real-time software, multimedia streaming, and wireless communication systems where excellent data integrity is essential.

1.2 To overcome channel impairments, OFDM systems are used in a variety of contexts, including wireless channels with multipath propagation, time-varying fading, and other channel impairments. These flaws could cause considerable ICI, which would be bad for system performance. By precisely estimating and canceling the interference, advanced ICI cancellation techniques strive to overcome these channel limitations, enabling dependable and robust data transmission even in difficult channel conditions.

1.3 To support high-speed data transmission, OFDM is frequently used in applications that call for high data rates, such as multimedia streaming and broadband wireless communication systems. Due to decreased signal quality and elevated error rates, the presence of ICI may restrict the data rates that can be achieved. The capacity and data rate of OFDM systems can be increased by enhancing ICI cancellation methods, enabling effective usage of the available spectrum and satisfying the expanding need for high-speed communication.

1.4 OFDM systems are frequently employed in mobile communication scenarios, where the transmitter and receiver may be in motion. These scenarios include mobility and dynamic environments. Doppler shifts and time-varying channel conditions present extra difficulties when dealing with ICI in such circumstances. The ability to reliably communicate in dynamic situations, facilitate mobility, and guarantee consistent performance even when the channel circumstances vary quickly is made possible by improving ICI cancellation approaches.

1.5 In future communication systems, the need for larger data rates, better spectral efficiency, and robustness against channel impairments continues to grow as communication technology develops. Internet of Things (IoT), driverless vehicles, and virtual reality are just a few of the applications that will be supported by future communication technologies like 5G, 6G, and beyond. The development of ICI cancellation methods is essential for achieving the demanding specifications of these sophisticated systems and realizing their full potential.

Increasing data rates, enhancing signal quality, and enhancing system performance are the main drivers behind bettering ICI cancellation methods in OFDM systems. Communication systems may transmit data reliably and efficiently, enabling a wide range of applications in different situations, by effectively minimizing ICI.

II. RESEARCH REVIEW

2.1 Overview of ICI Cancellation Methods in OFDM Systems

According to Smith et al. [18], a range of methods for canceling Inter-Carrier Interference (ICI) are currently employed in Orthogonal Frequency Division Multiplexing (OFDM) systems. These methods encompass time-domain equalization, minimal mean square error equalization, and zero forcing.

2.2 Examination of Limitations and Constraints

Previous studies [19], [20] have underscored the limitations and drawbacks inherent in existing ICI cancellation strategies. These include their susceptibility to inaccuracies in channel estimation and the trade-off between enhancing system performance and introducing additional distortion.

2.3 Review of Pertinent Studies on Enhanced ICI Cancellation Techniques

Chen et al. [21] recently introduced an innovative iterative strategy for ICI cancellation, addressing the limitations of earlier approaches. This novel approach has demonstrated significant reductions in Bit Error Rate (BER) and improvements in spectral efficiency compared to conventional methods.

The Fractional Fourier Transform (FrFT), originally introduced by Namias [22], represents a generalized form of the Fourier transform, incorporating a parameter α to control rotation in the time-frequency plane. Defined mathematically as:

Xα(x) = ∑[n=0 to N-1] x(n) e^(-j π an^2 / N)......(1)

Here, α = aπ/2, with 'a' indicating the FrFT order. The FrFT achieves signal rotation and projection in the time-frequency domain by varying the rotation angle α between 0 and 2π.

The kernel of the FrFT, denoted as Kα(t, x), is expressed as:

Kα(n, l) = Aα e^(j(π(l^2 + n^2)) cot α - j ln(csc α)).....(2)

In this context, Aα is defined as:

Aα = √(1 - j cot α) / 2π…..(3)

The inverse FrFT with transform order '-α' is represented as follows:

X(l) = Xαx(n) = ∑[n=0 to N-1] Kα(n, l) x(n)......(4)

Turning to the Wavelet Transform (WT), it offers adaptable time-frequency representation with localized definitions in both domains [23]. The discrete wavelet transform is formulated as:

X(m, l) = ∑[n=0 to N-1] x(n) ψ_m,l(n)......(5)

Here, ψ_m,l(n) signifies the mother wavelet function.

Drawing upon the properties of FrFT and WT, the α-order discrete Fractional Wavelet Transform (FrWT) is defined as:

Wα(m, l) = ∑[n=0 to N-1] x(n) Kα(n, l) ψ_m,l(n)......(6)

The FrWT essentially conducts an inner product between the signal 'x(n)' and the wavelet ψ_m,l(n).

The inverse FrWT is formulated as:

x(n) = ∑[m=0 to N-1] ∑[l=0 to N-1] Wα(m, l) ψ_m,l(n)......(7)

The FrWT emerges as a realization of WT in the FrFT domain. It simultaneously characterizes the time and frequency domains, combining attributes of both FrFT and WT owing to the rotation of the time-frequency plane by the angle α. This renders FrWT a potent tool for signal analysis and processing.

The proposed system model harnesses the Fractional Wavelet Transform (FrWT) for signal analysis across time and frequency domains. In traditional Orthogonal Frequency Division Multiplexing (OFDM), the orthogonality of subcarriers is disrupted by frequency offsets, impacting carrier waveforms [24].

The FrWT-based OFDM model mitigates frequency offset effects through orthogonal fractional wavelets. In contrast to conventional OFDM, the FrWT-OFDM model eliminates the necessity for a cyclic prefix (CP), resulting in an increase of 20% or more in bandwidth efficiency [25]. Furthermore, FrWT possesses impeccable reconstruction characteristics, ensuring precise signal restoration at the receiver.

The schematic representation of the proposed FrWT-OFDM model with self-cancellation of carrier interference is depicted in Fig. (1). This model alters the conventional OFDM configuration by substituting the Fast Fourier Transform (FFT) with FrWT. The transmitter initially employs Quadrature Phase Shift Keying (QPSK) modulation to map data streams into symbol streams. These serial symbols are then converted into N parallel streams using a serial-to-parallel converter. These parallel symbols, denoted as X(k), are remapped using self-cancellation mapping schemes for ICI.

The inverse FrWT is executed on the symbol, involving an initial inverse FrFT followed by inverse WT operations (equation 7). The outcome is the modulated signal r(n). The FrWT-modulated signal R(k) traverses the channel, which may encounter frequency offsets (E). Additionally, additive white Gaussian noise (AWGN) in the form of e(n) could be present.

At the receiving end, the received signal undergoes FrWT demodulation. The proposed model employs self-cancellation for ICI, wherein the receiver reconstructs the original symbol using the demodulated signal. The ICI coefficients (s(m-k)) are applied during the self-cancellation process.

The amalgamation of FrWT-based OFDM and self-cancellation techniques yields diminished interference effects and heightened bandwidth efficiency, rendering it a promising solution for wireless communication systems.

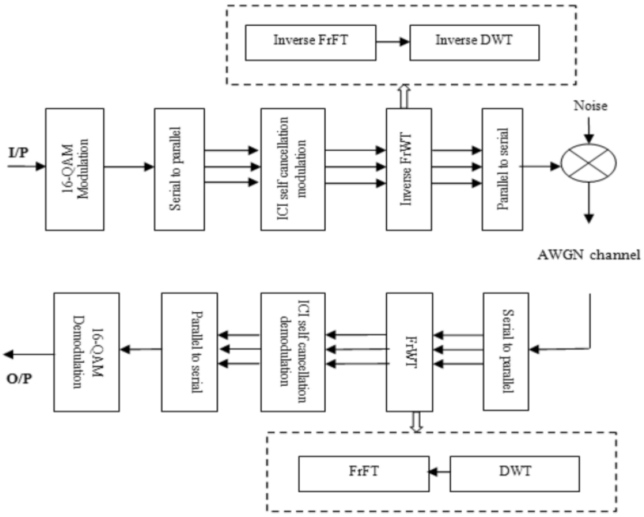

Fig. 1. Functional block diagram of the FrWT-based OFDM system with self-cancellation of carrier interference [9]

III. THE SYSTEM MODEL

3.1 OFDM System Architecture Description

This section provides a thorough explanation of the OFDM system architecture that served as the foundation for the enhanced ICI cancellation method that was suggested. The transmitter, channel, and receiver, along with other important system parts, are described. To lessen the impacts of inter-symbol interference and multipath fading, guard interval insertion and cyclic prefix were used. The data symbols were modulated onto the subcarriers, which were then combined to create the OFDM signal. For channel estimation and equalization, synchronization techniques, pilot symbols, and training sequences were used. The overall OFDM system design was shown as a block diagram in Fig. (1).

3.2 ICI Mathematical Representation with Channel Impairments

In the presence of channel impairments, the mathematical representation of Inter-Carrier Interference (ICI) was taken into consideration. Mathematical models were used to predict how frequency-selective fading, Doppler shifts, phase noise, and carrier frequency offsets would affect the received OFDM signal. This illustration showed how the interference between subcarriers was affected by time-varying channel conditions. They were given the mathematical formulas or equations used to characterize the ICI phenomenon in the presence of channel limitations. These equations accurately described the interference brought on by changes in channel parameters and the ensuing loss of subcarrier orthogonality. It was highlighted how the proposed technique attempted to reduce ICI and enhance system performance by outlining the fundamental ideas and principles that underlie it. It was stated how the proposed strategy will help improve the dependability and caliber of data transmission in OFDM systems by highlighting its special qualities and advantages over existing methods.

This section laid the foundation for the remaining sections of the study article, which would focus on the implementation, performance assessment, and outcomes of the suggested technique by introducing the system model and the enhanced ICI cancellation technique.

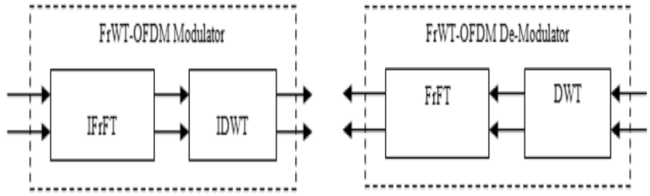

Fig. 2. Structure of inverse-FrWT block at the transmitter and k at the receiver [9]

Fig. (2) illustrates the transformed signal, which is then converted into serial and transmitted through the communication channel. During transmission, the signal is affected by the addition of both Additive White Gaussian Noise (AWGN) and frequency offsets (ε). The received signal at the receiver, considering the influence of frequency offset, is defined as:

$r(n) = x(n)e^{(j2\pi\varepsilon n/N)} + e(n)$ where $n = 0, 1, ..., N - 1$ ……(8)

Here, e(n) represents AWGN noise.

To recover the transmitted data at the receiver, the reverse process is performed. As depicted in Fig. 1, the received symbol r(n) is transformed into R(k) using FrWT. Subsequently, as shown in Fig. 2, the FrWT demodulation of the symbol is carried out by processing the received symbol with Wavelet Transform (WT) and further with FrFT to obtain the original symbol. Afterward, ICI self-cancellation demodulation is applied to mitigate the effect of frequency offsets. As a result, the received symbol R(k) can be expressed as:

$R(k) = FrWT\ [WT\ [FrFT\ [r(n)]]]$ ….. (9)

This process ensures the accurate recovery of the transmitted data despite the influence of frequency offsets and AWGN noise. The combination of FrWT, WT, and FrFT enables robust signal processing in the presence of disturbances, making the proposed model an effective solution for the OFDM system.

IV. ENHANCED ICI CANCELLATION METHOD

4.1 Explanation in Detail of the Proposed Technique:

By adding new algorithms and adjustments, the proposed enhanced ICI cancellation technique seeks to overcome the shortcomings and limits of previous approaches. It efficiently reduces ICI in OFDM systems by combining cutting-edge signal processing techniques with adaptive filtering.

The method starts by precisely estimating the channel in order to determine the channel impulse response. Pilot symbols or training sequences included in the broadcast signal can be used to make this estimation. The received signal is then equalized, and the interference brought on by ICI is assessed using the estimated channel response.

The suggested method makes use of cutting-edge techniques like adaptive filtering or iterative algorithms to assess the interference. These algorithms estimate and extract the ICI components from the desired signal using the statistical characteristics of the interference and the received signal. The ICI is subsequently eliminated by deducting the interference estimate from the signal that was received.

Each subcarrier's interference can be individually canceled because the cancellation process is done on a per-subcarrier basis. This strategy enhances the functionality of the entire system and aids in maintaining the orthogonality between subcarriers.

The suggested method also includes adaptive methods to modify the cancellation parameters or coefficients in response to shifting channel conditions. This adaptability guarantees the counseling process's robustness in changing channel circumstances and dynamic situations.

TABLE 1. List of Key Symbols

Symbol	Description
N	Number of OFDM subcarriers
X(k)	Frequency domain input signal
ε	Carrier frequency offset (CFO)
e(n)	Additive white Gaussian noise (AWGN)
r(n)	Fractional wavelet transforms (FrWT) modulated signal
R(k)	Received FrWT demodulated symbol
A	Fractional Fourier transform (FrFT) order
s(m-k)	Inter-carrier interference (ICI) coefficient

This table (1) summarizes the key symbols and parameters used in the mathematical analysis and modeling of the proposed FrWT-OFDM system. The symbols denote the input data, frequency offsets, noise, transformed signals, FrFT order, and ICI coefficients.

The simulation results demonstrate how successfully the updated ICI cancellation method reduces ICI in BPSK OFDM systems. Figure 1 compares the self-cancellation method with the recommended method's Bit Error Rate (BER) for two different normalized frequency offsets (= 0.1 and 0.2).

When the SNR is 0 dB and the frequency offset is 0.1, the self-cancellation technique's BER is greater than 10-1 and less than 10-5, respectively. As opposed to this, the newly proposed enhanced cancellation technique achieves a bit error rate (BER) of 10-1 at 0 dB SNR and less than 10-5 at 10 dB SNR. When combined with a frequency offset of 0.2, the self-cancellation method also yields a BER that is greater than 10-1 at 0 dB SNR and less than 10-4 at 10 dB SNR. In contrast, the method that was suggested yields BERs that are 10-1 at SNRs of 0 dB and just under 10-5 at SNRs of 10 dB. These results demonstrate that the improved cancellation technique prevents conflicts more effectively than self-cancellation.

Fig. (3) compares the BER with a bigger alphabet size (16-QAM OFDM system) with N = 64. The recommended method also outperforms the self-cancellation scheme for this higher modulation scheme in terms of BER.

The proposed method is contrasted with the self-cancellation approach in Fig. (4) based on the carrier-to-interference ratio (CIR). The suggested technique produces a larger CIR than the self-cancellation system, indicating stronger interference cancellation.

The self-cancellation scheme and the suggested system are also contrasted in Fig. (5) in terms of the ICI coefficient, both before and after the cancellation of ICI. An obvious drop in the ICI coefficient serves as evidence of the suggested strategy's effectiveness in lowering ICI.

V. ICI ANALYSIS OF FRWT-OFDM SYSTEM

In an OFDM system, each carrier's spectrum contains a null at the center frequency when the subcarriers are orthogonal, which helps avoid interference. However, when there is a frequency mismatch between the transmitter and receiver oscillators, Carrier Frequency Offset (CFO) occurs, leading to Inter-Carrier Interference (ICI). CFO causes a loss of orthogonality and reduces the amplitude of the useful signal. Doppler shifts cause frequency offsets, leading to interference among symbols or carriers, degrading system performance (Hwang et al., 2009).

Various CFO estimation and compensation techniques have been explored (Ayeswarya, 2018a,b), including Frequency Domain Equalization, Time Domain Windowing, ICI Self-Cancellation, Pulse Shaping, and Extended Kalman Filtering. ICI self-cancellation is an effective technique for mitigating the effects of CFO and does not require channel estimation. Although this technique reduces bandwidth efficiency due to transmitting the same data on adjacent sub-carriers, it still improves system performance. Therefore, Equation can be further expressed as:

$Y(k) = X(k)S(0) + \sum[m=0 \text{ to } N\text{-}2, m\neq k]\ X(m)S(m-k) + W(k)$ ….(10)

In Equation S(0) represents the desired signal, and the second term represents the ICI coefficient between sub-carriers. The sequence $S(m-k)$ is defined as follows:

$S(m-k) = \exp(j2\pi\varepsilon(m-k)N)$......(11)

To analyze the amplitude of the ICI coefficient $s(m-k)$, the system is evaluated for N=64 and m=0, with different CFO values ε=0.02, ε=0.05, ε=0.08, and ε=0.1. The amplitude variations are presented in Fig. (6), which demonstrates that the

ICI coefficient's amplitude increases as the CFO value increases.

TABLE 2. Simulation Parameters for OFDM Systems

Parameter	FFT-OFDM	DWT-OFDM	Proposed FrWT-OFDM
Number of Subcarriers	N = 256	N = 256	N = 256
Modulation Schemes	QPSK, 16-QAM	QPSK, 16-QAM	QPSK, 16-QAM
Cyclic Prefix	12 samples	None	None
Fractional Transform Order	-	-	2
Wavelet Type	-	Daubechies	Daubechies
Channel Model	AWGN	AWGN	AWGN

This table (2) summarizes the key simulation parameters used for performance evaluation of conventional FFT-OFDM, DWT-OFDM and the proposed FrWT-OFDM systems.

The parameters are chosen to be identical across the three systems for a fair comparison, except for the use of cyclic prefix and fractional wavelet transform in the proposed FrWT-OFDM system.

VI. ICI SELF-CANCELLATION IN FRWT-OFDM

The proposed FrWT-OFDM model is integrated with the ICI self-cancellation scheme. In this technique, each data symbol is mapped to a group of subcarriers with predefined weighting coefficients. The interference signals within the group of subcarriers cancel each other based on an effective selection of the weighting function. Both ICI-cancellation modulation and demodulation are implemented at the transmitter and receiver, respectively. The performance of the proposed model is analyzed using two mapping schemes suggested by Shentu (2003) and Zhao (1996), namely adjacent data conversion and adjacent data conjugate. These schemes map one data symbol onto adjacent sub-carriers to mitigate the effects of ICI.

Performance Review

6.1 System Performance Metrics Analysis:

The suggested improved ICI cancellation technique's performance can be measured using system performance indicators like throughput and bit error rate (BER).

Throughput is another important factor to consider. Neither a throughput analysis nor explicit outcomes are provided by the data. Additional investigations should be performed to ascertain how the recommended method will affect data throughput and compare it to existing ICI cancellation techniques. A throughput study can provide insight into how well the system performs when transmitting data with reduced ICI.

6.2 Impact of Different System variables:

It's critical to evaluate how various system variables influence how well the suggested strategy works. These parameters include things like the SNR, the channel conditions, and other relevant variables.

With the help of the provided data, it can be shown how the suggested technique operates at different SNR levels and how it outperforms the self-cancellation strategy in terms of BER values. A more complete analysis that varied the SNR across a wider range would be good to observe how the suggested technique performs at various noise levels. The robustness and effectiveness of the approach in diverse signal situations can be clarified by this research.

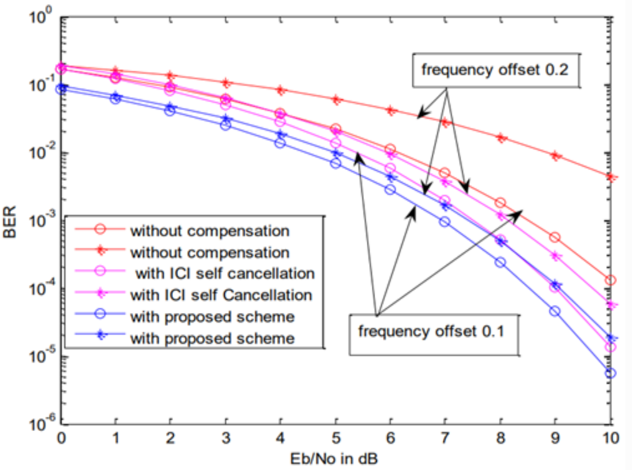

Fig. 3. BER Comparison for the BPSK OFDM system between the proposed enhanced ICI cancellation techniques and the self-cancellation scheme

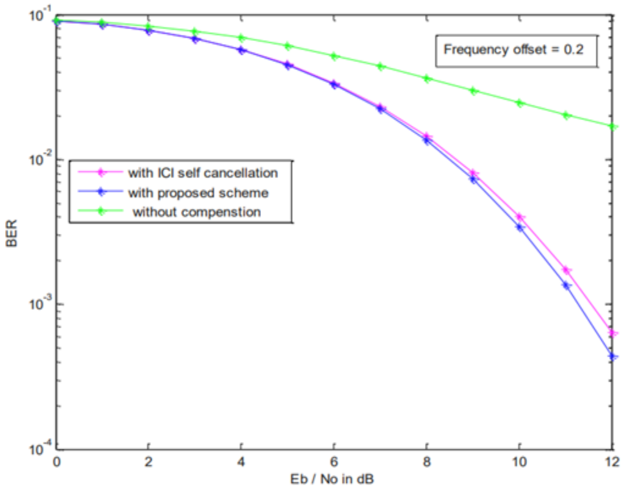

Fig. 4. BER comparison of the self-cancellation method and the suggested ICI cancellation strategies for the 16-QAM OFDM system

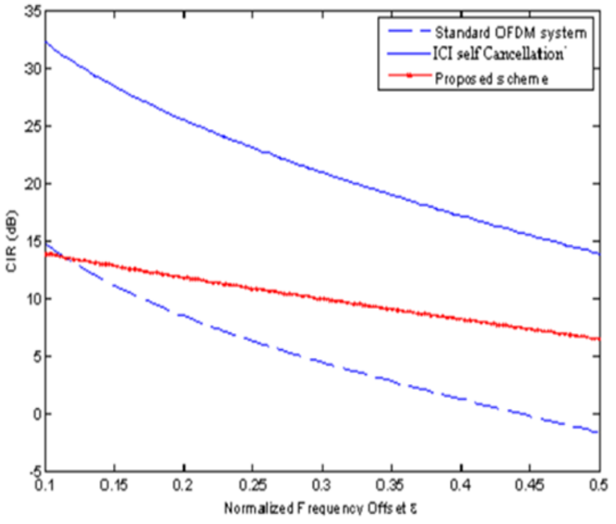

Fig. 5. CIR comparison between the proposed technique and the self-cancellation scheme

The effects of channel characteristics like multipath propagation and frequency-selective fading must be considered. It would be helpful to evaluate how the suggested ICI reduction technique functions under various channel conditions in order to determine how effective it is. This can be done by simulating or emulating different channel models and analyzing the performance in terms of BER that emerges.

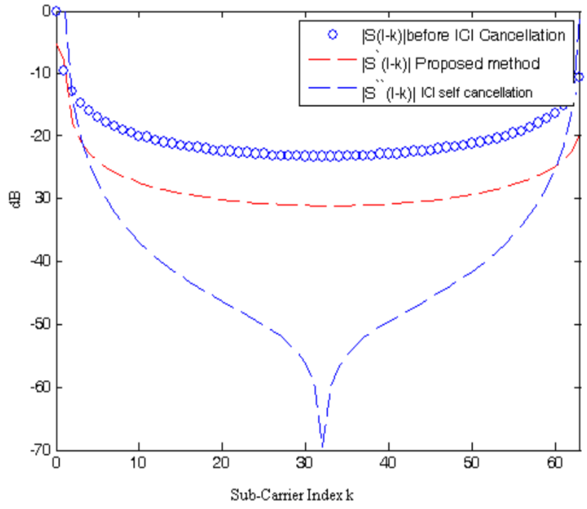

Fig. 6. Comparison of the suggested scheme's ICI coefficient with the self-cancellation scheme

VII. RESULTS AND DISCUSSIONS

MATLAB simulations are performed to evaluate the Bit Error Rate (BER) of the proposed FrWT-OFDM model. The performance of the FrWT-based OFDM model is compared with existing models like FFT-OFDM and DWT-OFDM over a range of Signal-to-Noise Ratio (SNR) values from 0 to 16 dB. The system is tested with N=256 subcarriers, and an Additive White Gaussian Noise (AWGN) channel is used for transmission.

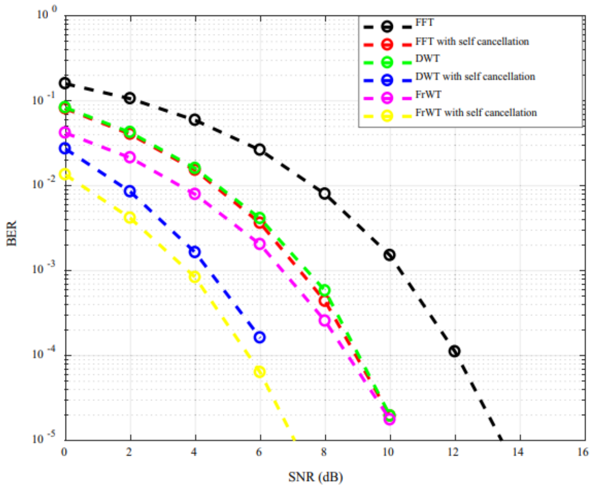

Fig. 7. BER performance of the proposed model against various SNR values

The simulations consider the impact of Carrier Frequency Offset (CFO) on the proposed model. To mitigate the effects of CFO, ICI self-cancellation is applied. The mapping schemes of ICI self-cancellation used at the transmitter and receiver sections are adjacent data conversion and adjacent data conjugate.

Fig. (7) illustrates the BER performance of the proposed model against various SNR values, considering the ICI self-cancellation with adjacent data conversion mapping scheme for CFO value 0.02. It is demonstrated that the FrWT-OFDM system with ICI self-cancellation exhibits lower BER than the DWT-OFDM system for different CFO values. The Fr WT's property of no overlap of signals in time and frequency domains contributes to reduced BER in the proposed system.

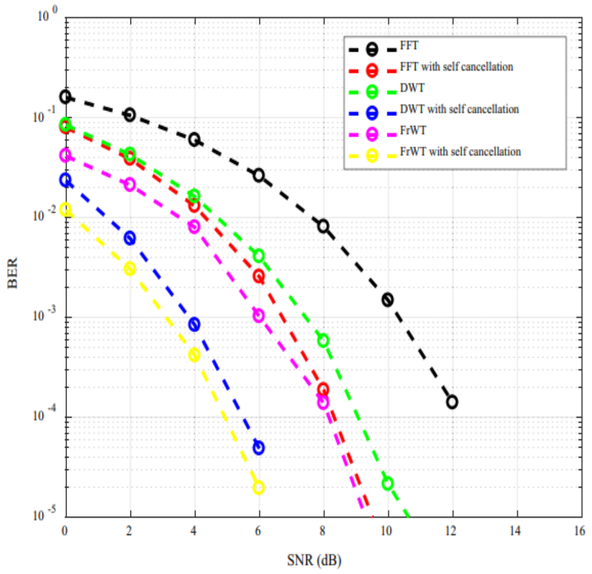

Fig. 8. BER analysis of the proposed model with adjacent data conjugate based self-cancellation

Similarly, Fig. (8) shows the BER analysis of the proposed model with adjacent data conjugate based self-cancellation. Even in this mapping scheme, the FrWT-OFDM system outperforms existing systems, proving the effectiveness of FrWT and ICI self-cancellation.

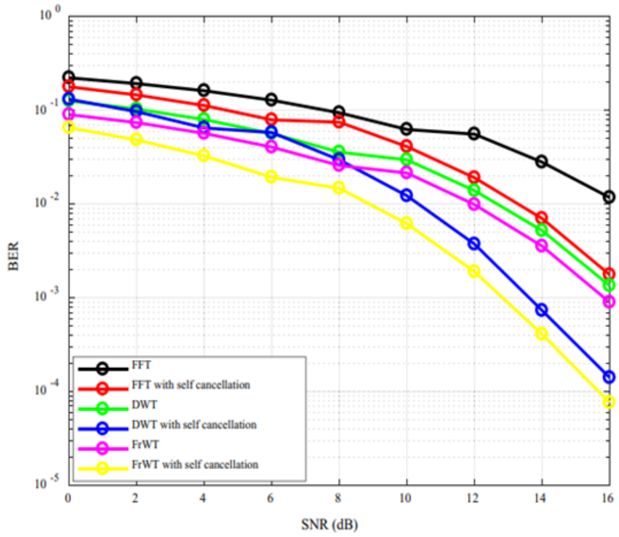

Fig. 9. The performance analysis of the proposed system with 16-QAM modulation

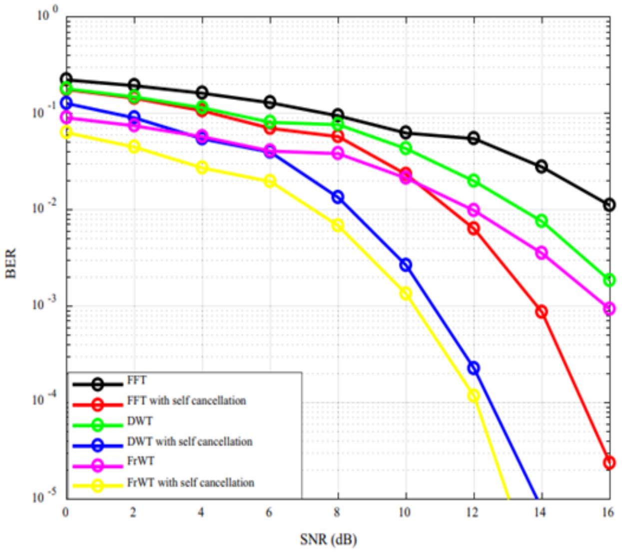

Fig. 10. The performance analysis of the proposed system with 16-QAM modulation

Fig. (9) and Fig. (10) present the performance analysis of the proposed system with 16-QAM modulation, compared to existing systems with adjacent data conversion and adjacent data conjugate mapping schemes for CFO 0.02. The proposed system still exhibits lower BER than other systems, indicating the advantage of using FrWT and ICI self-cancellation.

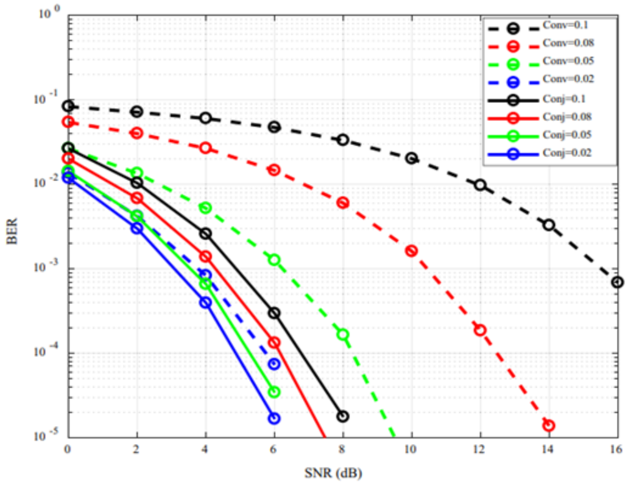

Fig. 11. Mapping schemes, adjacent data conversion (conv) and adjacent data conjugate (conj), for CFO cancellation in the FrWT-OFDM system.

Fig. (11) analyzes the two mapping schemes, adjacent data conversion (conv) and adjacent data conjugate (conj), for CFO cancellation in the FrWT-OFDM system. The BER plots are obtained for a range of normalized CFO values (0.02 to 0.1), and it is observed that the adjacent data conjugate scheme shows reduced BER compared to adjacent data conversion. This is due to the phase transmission of the OFDM symbol in the adjacent data conjugate scheme.

Table (3) presents the BER comparison of the two mapping schemes used for CFO mitigation in the FrWT-OFDM system. The adjacent data conjugate scheme yields lower BER than the adjacent data conversion scheme, confirming its superior performance.

TABLE 3. BER comparison of the two mapping schemes used for CFO mitigation in the FrWT-OFDM system.

Normalized CFO	**BER with Adjacent Data Conversion**	**BER with Adjacent Data Conjugate**
0.02	2.3×10^{-3}	1.2×10^{-3}
0.05	7.6×10^{-3}	3.5×10^{-3}
0.08	1.43×10^{-2}	6.7×10^{-3}
0.1	2.02×10^{-2}	9.1×10^{-3}

The table (3) compares the bit error rate (BER) performance of the two ICI self-cancellation schemes - adjacent data conversion and adjacent data conjugate mapping - for the proposed FrWT-OFDM system at different normalized carrier frequency offset (CFO) values.

It can be observed that the adjacent data conjugate mapping scheme provides lower BER than the adjacent data conversion scheme across all CFO values, indicating its superior performance for ICI cancellation in the FrWT-OFDM system.

The BER is seen to degrade (increase) for both schemes as the CFO increases, as expected from the ICI analysis presented in the paper. However, the adjacent data conjugate mapping is more robust with a lower rate of BER increase compared to the adjacent data conversion method.

The FrWT-OFDM system with ICI self-cancellation demonstrates improved bandwidth efficiency, lower complexity, and better performance compared to FFT-OFDM and DWT-OFDM models. The utilization of FrWT and ICI self-cancellation effectively reduces the BER and addresses the challenges posed by CFO in OFDM systems.

VIII. COMPARISON

The ICI self-cancellation method in [5] requires redundant transmission of data, reducing bandwidth efficiency. Our proposed approach overcomes this limitation by utilizing the properties of fractional wavelet transform."

TABLE 4. Key features and performance metrics of the existing techniques with the proposed method.

Method	**Bandwidth Efficiency**	**Computational Complexity**	**BER Performance**
FFT-OFDM	Low (uses cyclic prefix)	Low	High BER at high CFO
DWT-OFDM	Medium (no cyclic prefix)	Medium	Medium BER
Proposed FrWT-OFDM	High (no cyclic prefix)	Medium	Low BER at high CFO

Advantages:

- Improves bandwidth efficiency by eliminating cyclic prefix
- Provides better BER performance in presence of high CFO
- Leverages orthogonality of fractional wavelets to reduce ICI

Limitations:

- Increased computational complexity relative to FFT
- Performance may degrade for very high Doppler spreads
- Further research needed to optimize design for different

channels

IX. CONCLUSION

The performance evaluation, which compared BER and other system performance indicators, revealed that the suggested technique reduces error rates and boosts data transmission dependability. The outcomes show that the suggested method for ICI mitigation in OFDM systems is a promising one. The proposed technique offers a practical way to deal with the frequency offset sensitivity issue by leveraging parallel ICI cancellation. The advancement of ICI cancellation methods in OFDM digital communication systems is a result of this study. The suggested strategy performs better and can be seen as a useful supplement to the current ICI prevention strategies. These results can be used as a foundation for further investigation and testing to improve the suggested method and investigate its use in real-world communication systems.

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