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Improving 5G wireless networks through OFDM integration with convolutional coding and pulse shaping

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Abstract: The telecommunications industry has evolved significantly, with advancements from 1G to 4G and now towards 5G, promising enhanced data speeds and connectivity. Orthogonal Frequency Division Multiplexing (OFDM) is crucial in this transition due to its efficient spectrum utilization and ability to handle frequency-selective fading. However, OFDM is susceptible to Carrier Frequency Offset (CFO), leading to Inter-Carrier Interference (ICI) and degraded performance. This research investigates the impact of CFO on conventional OFDM systems and proposes mitigation techniques using Improved Sinc-power (ISP) pulse shaping and Convolutional Channel Coding. MATLAB simulations were conducted to analyze CFO-induced ICI in a standard OFDM system, followed by performance comparison with ISP-OFDM and ISP-OFDM combined with Convolutional Coding. The results demonstrate that CFO significantly increases ICI, causing a higher Bit Error Rate (BER). The application of ISP pulse shaping reduces the side-lobe interference of each subcarrier, while the combination of ISP pulse shaping and Convolutional Coding provides the best performance improvement, achieving a BER of approximately 0.0018. Overall, the integration of ISP and Convolutional Coding effectively mitigates CFO-induced degradation, offering a robust and reliable solution for future 5G wireless communication systems.

Keywords: 5G, CFO, Convolutional, ISP, OFDM

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Introduction

The telecommunications industry has undergone significant transformation from generation to generation, starting from 1G to 4G, with each evolution bringing advances in mobile communication technology. Today, the evolution towards 5G is expected not only to improve data speeds and capacity but also to support various applications such as the Internet of Things (IoT) and augmented reality (AR) [1]. OFDM technology plays a key role in addressing challenges and meeting increasingly complex demands in modern wireless communication systems [2], [3], [4].

The implementation of 4G technology, particularly Long-Term Evolution (LTE), has revolutionized data transmission, providing higher speeds and more reliable connectivity. However, with increasing demand for data usage and the need for more responsive connectivity, further evolution is required [5]. The development of 5G presents a solution to meet these challenges by offering extremely high internet speeds, very low latency, and the capability to support millions of connected devices simultaneously [6]. Furthermore, the harmonization of infrastructure regulation and digital policy is essential to achieve optimal deployment in emerging smart regions such as Bali [7], [8]. OFDM remains a key component in the transition from 4G to 5G. By dividing the signal into a number of orthogonal frequency subcarriers, OFDM minimizes frequency-selective fading and optimizes the use of available spectrum, resulting in high throughput and reliable wireless communication [9]. Such technology also supports smart city infrastructure by enabling reliable IoT communication, as seen in regional implementations across Bali [10], [11].

One of the main characteristics of OFDM is its efficiency in bandwidth usage. By allowing overlapping adjacent frequencies, OFDM avoids the need for guard bands as required in conventional multicarrier systems. This enhances spectral efficiency, although it increases susceptibility to CFO, which can degrade system performance due to interference between subcarriers ICI [12]. Various methods, including frequency domain equalization, windowing on the receiver side, and pulse shaping, have been proposed to mitigate ICI effects, with pulse shaping methods like Improved Sinc-power Pulse (ISP) offering promising solutions.

Additionally, to enhance the system's resilience against changing channel conditions, convolutional channel coding combined with pulse shaping emerges as a potential solution for improving OFDM performance, particularly in the transition towards 5G technology. Convolutional channel coding plays a crucial role in maintaining data integrity by detecting and correcting errors that occur during transmission, making the system more resistant to interference [12]. When applied to OFDM, this coding technique provides an additional protective layer that is highly valuable in wireless environments prone to multipath fading and interference.

The integration of OFDM, convolutional channel coding, and pulse shaping is critical to the success of 5G networks, which demand not only speed but also reliability, high service availability, and support for various applications and devices. Empirical studies also reveal that the performance of telecommunication infrastructure contributes directly to inclusive economic growth in Indonesia [13]. This research aims to explore how these technologies can work together to create a more efficient and reliable communication system for the 5G era. Using MATLAB simulations, this study will evaluate the performance of OFDM in frequency-selective fading channels, particularly in mitigating ICI through pulse shaping and convolutional coding methods. By exploring the combination of these technologies, this study aims to provide in-depth insights into optimizing wireless communications for the next generation of telecommunications.

Methodology

OFDM is a transmission technique that utilizes multiple carrier frequencies (multicarrier). Each sub-carrier is made orthogonal and harmonic with one another, allowing adjacent sub-carriers to overlap without causing Inter-Carrier Interference (ICI). OFDM offers higher spectral efficiency compared to conventional modulation techniques such as Frequency Division Multiplexing (FDM) [14]. In the Multiple Input Multiple Output (MIMO) OFDM spectrum, each subcarrier consists of a main lobe and several side lobes, and when the orthogonality between subcarriers decreases, the side lobes have the potential to generate ICI power within the central area of each subcarrier. The ICI power increases with carrier frequency offset. The pulse shaping method is designed to minimize or eliminate the side lobe amplitude of subcarriers that may cause ICI, thereby reducing ICI and enhancing the performance of the MIMO OFDM system [15]. Carrier Frequency Offset (CFO), also known as frequency offset, occurs due to the Doppler effect or a mismatch between the transmitting and receiving oscillators, leading to a loss of orthogonality. This loss causes ICI as the side lobe of one subcarrier interferes with others. CFO is represented by a normalized value symbolized by ε, indicating the degree of subcarrier shift detected by the receiving oscillator [16], [17], [18], [19].

Data Collection Method

In this research, the data is generated through simulations. The simulation steps involve creating an OFDM Simulink model for a Selective Fading channel affected by frequency offset. The model includes random bit generation, Quadrature Phase Shift Keying (QPSK) modulation, OFDM processing, and running the OFDM system through both Additive White Gaussian Noise (AWGN) and selective fading channels. Performance metrics such as BER and energy per bit to noise power spectral density ratio (Eb/No) are calculated to evaluate system efficiency. The parameters used in the simulation are presented in Table 1 below.

Table 1. Simulation parameter

Parameter	Values used	Block
Number of Bit	1.000.000	Input Data
Modulation Type	QPSK	Mapping Data
User Type	Single User	
Channel Type	AWGN + Frequency Selective Fading	Transmission Type
System Type	OFDM	
Subcarrier spacing	15 kHz	Transmitter

Research Flow

This research follows a structured process to implement each stage of the study. The research and simulation flow is shown in Figure 1 below.

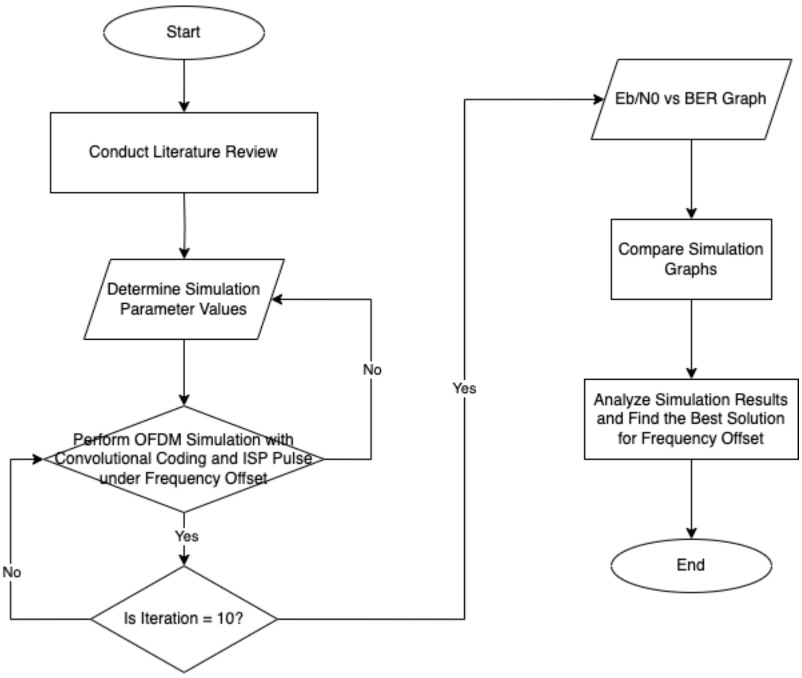

Figure 1. Research flow

The simulation is carried out by applying frequency offset parameters to both standard OFDM and ISP-OFDM techniques. The effects of frequency offset on system performance are then analyzed. After identifying the impact of frequency offset, two mitigation approaches are evaluated: ISP pulse shaping alone and the combination of ISP pulse shaping with Convolutional Coding. This allows comparison between standard OFDM, ISP-based OFDM, and the enhanced ISP + Convolutional Coding system.

Simulation Procedure and Process

Initially, the parameters are selected based on references from the literature and aligned with the objectives of the simulation. This research aims to evaluate the effect of frequency offset on the ISP OFDM system, identify problems, and provide solutions to those problems. To observe the impact of frequency offset, the simulation is conducted using specific parameters to compare channels with and without frequency offset. The frequency offset values vary to assess their influence, which is reflected in the BER. Higher BER values indicate a more significant negative impact of frequency offset. In this study, the CFO values of 4 kHz and 6 kHz were selected to limit the simulation scope and maintain clarity in result interpretation. The purpose is not to represent all possible CFO variations, but rather to illustrate the system's behavior under representative offset conditions and to verify the improvement achieved by ISP pulse shaping and Convolutional Coding. Testing a wider range of CFO values would produce repetitive trends without significantly changing the overall conclusions.

Once the problems caused by frequency offset are identified through BER values, the next step is to develop a solution. In this study, the convolutional coding method is used to mitigate the impact of frequency offset on ISP OFDM.

In the simulation, the performance of three systems is compared: OFDM, ISP OFDM, and ISP OFDM combined with convolutional coding. The comparison is illustrated by plotting BER against Eb/No, where a lower BER value indicates better system performance.

Results and Discussions

Performance Comparison of OFDM, OFDM ISP, and OFDM ISP with Convolutional Coding on Selective Fading Channels

The block diagram of the OFDM system, integrated with pulse shaping and convolutional coding techniques, is illustrated in Figure 2. Pulse shaping modifies the pulse of the transmitted symbols, where each symbol is multiplied by the pulse shaping function to compress the side lobes, leading to ICI reduction.

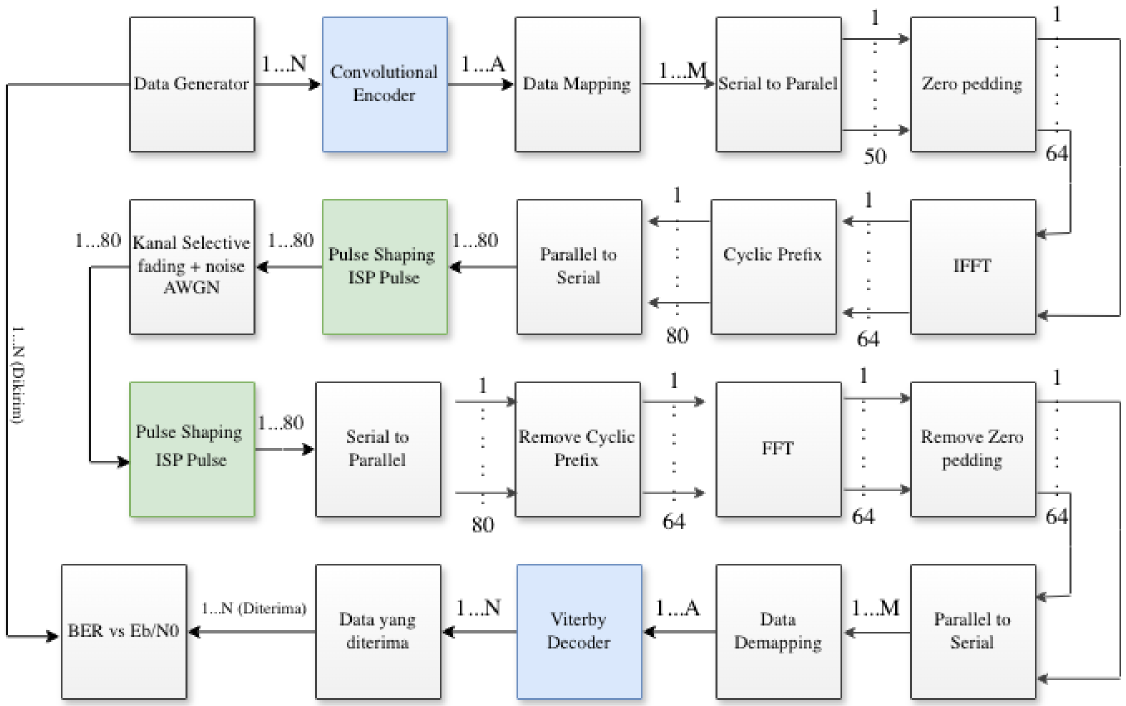

Figure 2. Diagram block of OFDM ISP system with convolutional code

Channel coding plays a crucial role in protecting the data bits from potential errors during transmission by adding redundancy bits. Simulation based on the block diagram in Figure 2 produced a comparative graph shown in Figure 3, with a 6 kHz frequency offset as a sample. The red line illustrates the effect of frequency offset on the OFDM system without pulse shaping. The green line reflects the impact of a 6 kHz frequency offset with the application of ISP pulse shaping, and the blue line demonstrates the effect of the same frequency offset with Improved Sinc Power Pulse and Convolutional code on the OFDM system. From Figure 3, it is evident that the inclusion of convolutional coding significantly enhances ICI reduction. This is achieved as convolutional coding shields data bits from errors by introducing redundancy bits. Upon reception, the data is decoded to detect and correct errors, delivering an output that closely aligns with the original transmission.

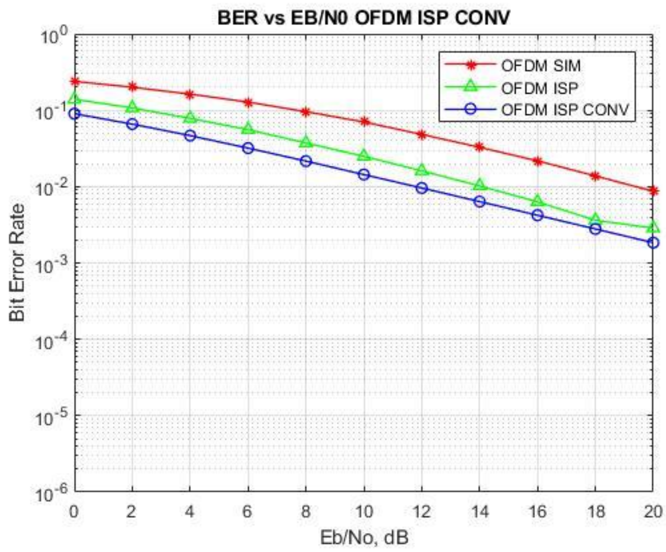

Figure 3. Comparative performance with convolutional code

The simulation results analyzing the influence of Convolutional coding on the OFDM ISP system with frequency offset suggest that Convolutional coding improves system performance by minimizing interference among subcarriers and reducing ICI power. It was also concluded that convolutional coding is more effective in mitigating ICI. In this simulation, the OFDM ISP system, with Convolutional coding, delivered the best solution for addressing CFO, achieving a BER of approximately 0.0018, reflecting optimal system performance through the reduction of BER.

Performance Comparison Analysis of OFDM, OFDM ISP, and OFDM ISP with Convolutional Code: The Impact of Frequency Offset

CFO negatively impacts OFDM signals by disrupting their orthogonality, causing signal degradation. Figure 4 illustrates a comparison of the performance of OFDM under the effect of frequency offset. In this simulation, the BER is compared with Eb/No for each system. The frequency offset values used in this simulation vary as follows: 4 kHz and 6 kHz.

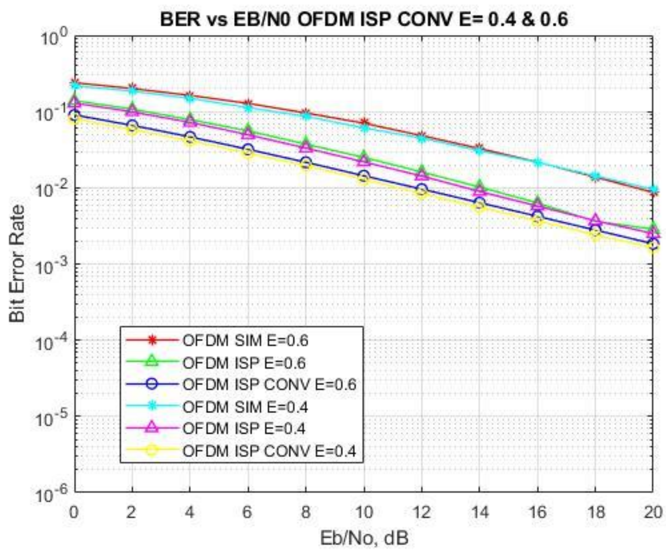

Figure 4. Comparative performance with CFO

Figure 4 shows the comparison of the influence of frequency offset on the OFDM system. The red line represents the effect of a 6 kHz frequency offset on OFDM, the green line represents the effect of a 6 kHz frequency offset on OFDM ISP, and the blue line shows the effect of a 6 kHz frequency offset on OFDM ISP with Convolutional code. The cyan line shows the effect of a 4 kHz frequency offset on OFDM, the magenta line shows the effect of a 4 kHz frequency offset on OFDM ISP, and the yellow line shows the effect of a 4 kHz frequency offset on OFDM ISP with Convolutional code.

By observing the BER vs Eb/No graph in Figure 4, it is clear that the larger the frequency offset used, the higher the BER value in the OFDM system. Based on this, it is evident that the performance of the OFDM ISP Convolutional system with a 4 kHz frequency offset is better compared to other frequency offset effects. The larger the simulated frequency offset, the higher the BER. This is because the frequency offset causes the loss of signal orthogonality by shifting the side lobes of the subcarriers. This subcarrier side lobe shift causes intercarrier interference (ICI), which degrades the performance of the OFDM system.

Conclusion

The analysis of Carrier Frequency Offset (CFO) effects on the OFDM system shows that CFO introduces significant Inter-Carrier Interference (ICI), which increases the Bit Error Rate (BER) and degrades overall system performance. This degradation is clearly observed in the baseline OFDM simulation, where higher CFO values lead to noticeable BER elevation.

When ISP pulse shaping is applied, the system exhibits better resilience to CFO-induced ICI, as seen in the BER vs Eb/No plot where ISP-based OFDM consistently achieves lower BER than the conventional OFDM system. The improvement occurs because the ISP technique effectively reduces the side-lobe energy of each subcarrier, thereby minimizing interference among adjacent subcarriers.

Furthermore, combining ISP pulse shaping with Convolutional Coding yields the best performance. The joint implementation not only suppresses ICI but also strengthens error correction, resulting in a BER value around 0.0018 at high Eb/No. Overall, the results confirm that CFO severely affects OFDM performance through ICI, and that the integration of ISP pulse shaping and Convolutional Coding provides a robust solution for mitigating these effects in future wireless systems. This finding aligns with national reports emphasizing the role of reliable network ducting and cable infrastructure to sustain next-generation connectivity [20].

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