

Capacity Enhancement of 5G Wireless System Using MIMO-OFDM Technique in MATLAB

Ms. Bugade P. S.

ME Student (VLSI & Embed.)
SPCOE,Otur,Maharashtra, india

Prof. Bansode R.S.

Asst. Professor
SPCOE,Otur,Maharashtra, india

Prof. Nighojkar P.K.

Asst. Professor
SPCOE,Otur,Maharashtra, india

1. INTRODUCTION

Abstract— This document Modern wireless networks such as 5G and upcoming 6G rely heavily on advanced technologies like rate-less digital fountain codes and Multiple-Input Multiple-Output (MIMO) systems. This study focuses on improving the performance of a MIMO system combined with Orthogonal Frequency Division Multiplexing (OFDM) by using rate-less fountain codes. Unlike traditional channel coding methods that use a fixed coding rate, rate-less codes—such as Tornado codes and Raptor codes—offer flexibility by adapting the coding rate based on channel conditions. In this work, the Raptor code is selected to analyze how rate-less coding affects the performance of MIMO systems under different wireless channel environments. The proposed system, which integrates MIMO with fountain coding, is tested under various channel conditions, especially considering changes in Doppler frequency. To further enhance system performance, different interleaving methods and equalization techniques are applied. Simulation-based experiments are carried out to evaluate the system under multiple data transmission scenarios. The results show that the proposed rate-less communication system performs better than conventional fixed-rate systems, particularly in terms of lower Bit Error Rate (BER) and higher data throughput.

In today's digital world, there is a rapidly growing demand for wireless systems that can support very high data rates. This demand is mainly driven by modern applications such as virtual reality (VR), 3D video streaming, and the Internet of Things (IoT). These applications require fast, reliable, and efficient data transmission, which pushes the need to improve existing communication technologies. One of the key technologies used to achieve high data rates is Orthogonal Frequency Division Multiplexing (OFDM). OFDM is a multi-carrier modulation technique in which a high-speed data stream is divided into several smaller, lower-rate data streams. Each of these smaller streams is transmitted over separate subcarriers. Since each subcarrier occupies a smaller bandwidth than the channel's coherence bandwidth, OFDM becomes highly resistant to frequency-selective fading. In addition, OFDM has relatively low computational complexity, making it widely suitable for modern communication systems. Because of these advantages, OFDM has been widely adopted in many communication standards such as Wireless Local Area Networks (WLAN), Digital Audio Broadcasting (DAB), Digital Video Broadcasting (DVB), Wireless Wide Area Networks (WWAN), and Long-Term Evolution (LTE). In particular, LTE-based 4G systems use OFDM to provide high-speed data services, efficient scheduling, and balanced Quality of Service (QoS) for different types of traffic. To further improve performance beyond 5G and towards 6G, advanced technologies like Massive MIMO (mMIMO) have been introduced. In mMIMO systems, the base station is equipped with a very large number of antennas, often much higher than the number of users being

served. This allows the system to transmit multiple data streams simultaneously, increasing both network capacity and overall data throughput. Massive MIMO is an advanced form of Multi-User MIMO (MU-MIMO). While MU-MIMO was used in earlier wireless generations, mMIMO offers better spectral efficiency and simpler signal processing. It achieves this by directing narrow beams toward individual users, which becomes more precise as the number of antennas increases. This technique not only improves signal strength but also reduces interference. Another important advantage of mMIMO is a phenomenon known as channel hardening. When a large number of antennas are used, the wireless channel becomes more stable and predictable. As a result, the effects of noise and fading are reduced, and the channel behaves almost like a constant gain channel with minimal variations. This simplifies signal processing and channel estimation for both the base station and user devices. Due to these benefits, combining mMIMO with OFDM has become a promising solution for future wireless networks such as beyond 5G (B5G) and 6G. Many studies have explored this combination for improving data transmission performance. However, very limited research has been conducted on evaluating image transmission performance over mMIMO-OFDM systems. The quality of image transmission in such systems depends on several factors, including signal-to-noise ratio (SNR), modulation techniques, and channel conditions. In this work, the performance of mMIMO-OFDM systems is analyzed using different transforms such as Fast Fourier Transform (FFT), Discrete Wavelet Transform (DWT), and Fractional Fourier Transform (FrFT). A standard reference image (baboon image) is transmitted and evaluated under varying conditions like SNR levels, modulation orders, and number of users. The quality of the received image is measured using Peak Signal-to-Noise Ratio (PSNR) and Structural Similarity Index (SSIM).

2. CHANNEL CODING TECHNIQUES OVERVIEW

This section explains different types of error control methods used in wireless communication systems. It also compares the computational complexity of traditional Forward Error Correction (FEC) techniques, which use fixed coding rates, with modern rate-less FEC methods that can adapt their coding rates. These techniques play an important role in improving data reliability during transmission.

2.1 Fixed Code Rate: Classical FEC Techniques

Traditional FEC methods are widely used to maintain Quality of Service (QoS) in wireless systems. These techniques use a fixed coding rate, meaning the amount of redundancy added to the data remains constant regardless of channel conditions. Classical FEC schemes are mainly divided into two types:

Block codes: These process data in fixed-size blocks and add redundancy for error detection and correction.

Convolutional codes: These work on continuous data streams and provide error correction based on previous input bits.

Although these methods are reliable, their fixed nature limits flexibility in changing channel environments.

2.2 Rate-less Fountain Codes

Rate-less fountain codes are advanced FEC techniques designed to improve data transmission over unreliable wireless channels. Unlike classical methods, they do not use a fixed coding rate. Instead, they generate an unlimited number of encoded symbols until the receiver successfully recovers the original data. These codes can be seen as a combination of FEC and adaptive packet transmission methods. Because of their flexibility, they are highly suitable for real-time communication where channel conditions may vary frequently.

2.3 Automatic Repeat Request (ARQ)

ARQ is a simple error control technique based on error detection rather than correction. At the receiver side, data is checked using methods such as parity bits or Cyclic Redundancy Check (CRC). If an error is detected, the receiver asks the sender to retransmit the corrupted data. While ARQ is easy to implement, it is not ideal for real-time applications because retransmissions cause delays. However, some advanced coding techniques, such as fountain codes, incorporate ARQ-like concepts to improve reliability without excessive delay.

2.4 Pseudo Coding Techniques

Pseudo coding methods are low-complexity techniques that work by randomizing the input data before transmission. These methods are particularly useful for transmitting multimedia content like images and audio over channels affected by correlated fading. By introducing randomness, they help reduce the impact of channel errors and improve overall signal quality.

2.5 Hybrid Techniques

Hybrid error control methods are developed by combining two or more existing techniques. The goal of these approaches is to take advantage of the strengths of different methods while reducing their individual limitations. For example, hybrid schemes may combine Forward Error Correction (FEC) with Automatic Repeat Request (ARQ) to achieve both error correction and error detection with retransmission support. These mixed strategies provide better performance compared to using a single technique, especially in challenging wireless channel conditions.

2.6 Adaptive Techniques

Adaptive techniques are designed to adjust system parameters based on current wireless channel conditions. These include adaptive FEC and adaptive packet transmission methods.

In adaptive FEC, the system selects the most suitable coding scheme depending on the quality of the communication channel. Similarly, adaptive packet techniques modify the packet size or structure to improve transmission efficiency.

3. RELATED WORK OVERVIEW

Rate-less error control techniques have gained significant attention as an effective solution for reducing transmission errors and improving communication performance in modern wireless networks such as 5G and beyond. This section reviews previous research that focuses on digital fountain codes, particularly their use in MIMO systems and next-generation wireless technologies. Several studies have explored the use of rate-less fountain codes to enhance OFDM-based systems. In one study, Raptor codes were applied along with different modulation techniques to improve the error performance of OFDM systems. The research also discussed various types of fountain codes and compared their computational complexity with traditional fixed-rate channel coding methods. The findings highlighted that rate-less codes provide better flexibility and performance under varying channel conditions. Another important research area focuses on security challenges in 5G networks, especially the risk of eavesdropping. Traditional cryptographic techniques can address these threats, but they often introduce high computational overhead. To overcome this limitation, Physical Layer Security (PLS) techniques have been proposed. In this context, fountain codes combined with massive MIMO systems have been used to improve both security and reliability. For example, Raptor codes help ensure that legitimate users can recover transmitted data faster than potential attackers, thereby reducing the risk of interception. In addition, Raptor coding has been applied to multimedia transmission, such as video signals, to reduce interference and improve data protection over complex wireless channels. These implementations often combine Raptor codes with Low-Density Parity-Check (LDPC) and Luby Transform (LT) codes to achieve better

performance. Some studies have also introduced multi-link communication strategies using rate-less coding to enhance link reliability and optimize network resource usage. Rate-less coding techniques have also been used in specialized networks such as Wireless Body Area Networks (WBANs), which are commonly used in medical applications. In such systems, energy efficiency is critical due to limited battery power. Research shows that using Raptor codes can extend network lifetime while maintaining reliable communication.

Other studies have investigated LTE-based systems using fountain codes to improve throughput and data transmission efficiency over different channel models such as Binary Symmetric Channel (BSC) and Additive White Gaussian Noise (AWGN). These approaches demonstrate the effectiveness of combining rate-less coding with modern wireless technologies. In contrast to earlier works that relied on classical error correction methods like convolutional and turbo codes, which often involve high computational complexity, this research focuses on using Raptor codes due to their lower complexity and higher efficiency. Some previous studies did not fully consider the computational cost of their methods, whereas this work includes a detailed analysis of system complexity. Furthermore, earlier research has explored MIMO systems using Space-Time Block Coding (STBC) with smaller antenna configurations. However, the current work introduces additional improvements by applying advanced data randomization techniques, such as chaotic mapping methods, along with Raptor codes. This combination enhances both data security and transmission performance. Overall, this study aims to improve the reliability, energy efficiency, and throughput of MIMO-OFDM systems by integrating rate-less Raptor coding with advanced modulation and data processing techniques. In addition to standard performance metrics like Bit Error Rate (BER) and throughput, this work also evaluates computational complexity to provide a more comprehensive analysis.

4. SIMULATION EXPERIMENTS AND RESULTS

In this section, computer simulations are carried out to evaluate the performance of the proposed Raptor code-based MIMO-OFDM system. The system is tested over Rayleigh fading channels combined with Additive White Gaussian Noise (AWGN). All simulations are implemented using MATLAB 2014. The main performance metrics considered in this study are Bit Error Rate (BER) and system throughput. To analyze system diversity, two types of equalizers are used: Zero Forcing (ZF) and Minimum Mean Square Error (MMSE). The system is tested under both diversity (MIMO) and non-diversity conditions. Additionally, different interleaving techniques are applied, including no interleaving, block interleaving, chaotic interleaving, and zigzag interleaving.

MIMO Simulation Modifications

Two main scenarios are considered in the simulation:

Diversity Scenario: In this case, the transmitted signal is sent through multiple paths. A (2×1) transmission and (1×2) reception configuration is used, allowing the receiver to benefit from spatial diversity. This improves signal reliability.

Non-Diversity Scenario: Here, signals are transmitted through independent paths without correlation. This setup increases throughput due to multiple parallel paths but does not provide diversity gain. Simulation experiments are conducted for all interleaving techniques using the same system parameters.

Simulation Parameters Overview

The system is tested under the following conditions:

Channel models: AWGN and Rayleigh fading

Carrier frequency: 2.4 GHz

Subcarrier spacing: 15 kHz

Doppler frequencies: 0, 50, and 100 Hz

Modulation scheme: QPSK

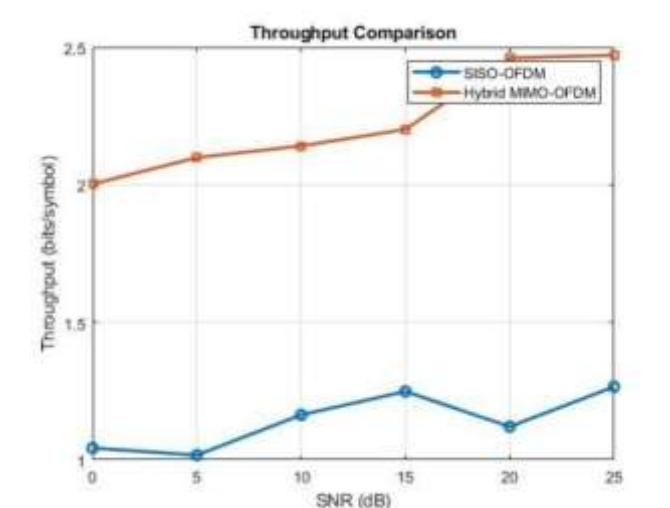
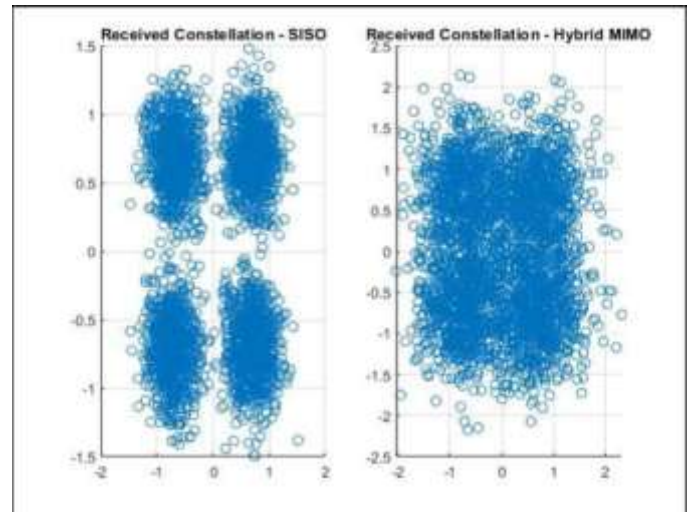
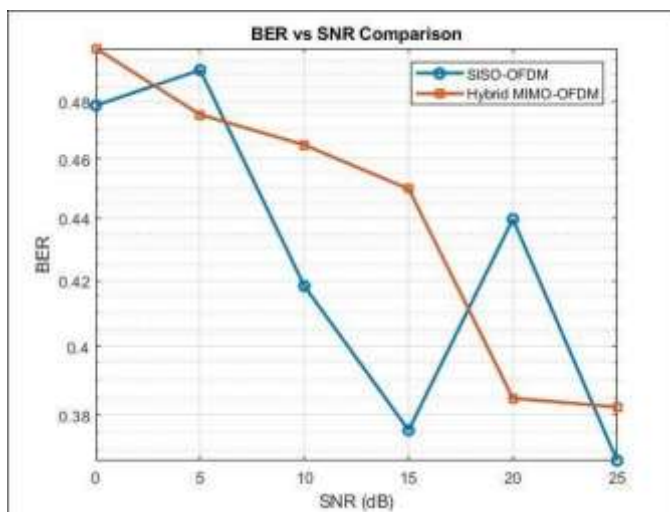
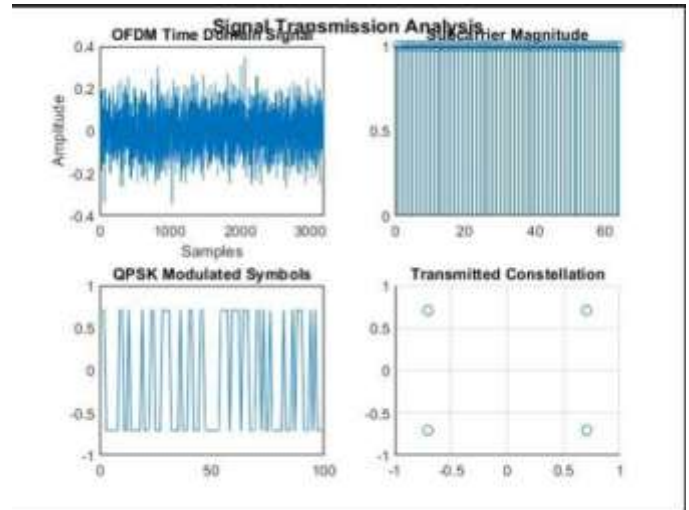
Equalizers: ZF and MMSE

Coding: Raptor codes with convolutional encoding

FFT size: 2048 with cyclic prefix 512

Antenna configuration: 2 transmit and 2 receive antennas

Performance metrics: BER and throughput (Mbps)



Doppler Frequency Effect

Doppler frequency is used to simulate the effect of user mobility on the wireless channel. It depends on the speed of the user and the signal wavelength. Higher Doppler values represent faster movement, which introduces more channel variation. To ensure accurate comparison across different frequencies, normalized Doppler shift is also considered. This helps in analyzing system performance under varying mobility conditions.

Results and Analysis

The simulation results show several important observations:

Equalizer Performance: The MMSE equalizer consistently performs better than the ZF equalizer in all scenarios. It achieves lower BER at lower Signal-to-Noise Ratio (SNR) values.

Effect of Diversity: Systems using MIMO diversity show better performance compared to non-diversity systems. Diversity reduces error rates and improves communication reliability.

Impact of Doppler Frequency: The proposed system performs well even at higher Doppler frequencies (e.g., 100 Hz), indicating its ability to handle mobility and fading effects effectively.

Interleaving Techniques: Among all interleaving methods, zigzag interleaving provides the best performance improvement. It significantly reduces BER compared to no interleaving and other techniques.

Throughput Performance: The proposed Raptor-coded MIMO-OFDM system achieves higher throughput when diversity is applied. This confirms that spatial diversity enhances both reliability and efficiency.

Adaptability: The system shows strong adaptability to changing channel conditions, maintaining good performance across different SNR and Doppler values.

5. CONCLUSION

In this work, an efficient rate-less MIMO system based on Raptor coding is proposed. The system uses different interleaving techniques, including chaotic interleaving, zigzag interleaving, and traditional methods. These interleaving approaches help improve system performance by rearranging the transmitted data into less correlated sequences, which reduces the impact of channel errors. The proposed method shows better Bit Error Rate (BER) performance compared to conventional block interleaving techniques. By using advanced interleaving strategies, the transmitted signals become more robust against noise and interference

in wireless channels. The performance of the Raptor code-based MIMO-OFDM system is evaluated over a multipath fading channel. At the receiver side, Minimum Mean Square Error (MMSE) equalization is applied to reduce distortion caused by the channel. Simulation results demonstrate that the proposed rate-less system outperforms traditional MIMO systems in terms of both error performance and data throughput. Equalization plays an important role in improving signal quality during transmission over mobile wireless channels. In this work, two different equalization techniques are used to further enhance the overall system performance. For future research, the system performance can be further analyzed under mobile conditions by considering the effect of normalized Doppler shift. This will help evaluate how well the proposed technique performs in real-world dynamic environments.

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