

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

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ABSTRACT

The combination of Multiple-Input Multiple-Output (MIMO) and Orthogonal Frequency Division Multiplexing (OFDM) has become a key technology in modern wireless communication systems due to its ability to improve data rate, coverage, and energy efficiency. Conventional modulation schemes such as QPSK, 16-QAM, and 64-QAM are widely used; however, they offer limited spectral efficiency, especially under the high Signal-to-Noise Ratio (SNR) conditions commonly found in 5G networks. To overcome these limitations, this study investigates higher-order modulation schemes, including 256-QAM, 1024-QAM, and 4096-QAM. The performance of these schemes is evaluated using metrics such as Bit Error Rate (BER), throughput, and spectral efficiency through MATLAB-based simulations. The results show that higher-order modulation techniques significantly improve throughput and spectral efficiency at high SNR levels, making them suitable for high-data-rate 5G MIMO-OFDM systems. In contrast, lower-order modulation schemes like QPSK demonstrate better robustness in noisy environments, where reliability is more important than data rate. These findings indicate that different modulation schemes are suitable for different network conditions. Future work should focus on hybrid modulation strategies that adaptively combine low- and high-order schemes to achieve optimal performance across diverse 5G scenarios.

KEYWORDS: MIMO-OFDM, 5G, modulation schemes, QAM, spectral efficiency, Signal-to-Noise Ratio.

1. INTRODUCTION

Modern wireless communication systems are designed to support high data rates, low latency, and reliable connectivity for a wide range of users and applications. Fifth-generation (5G) networks aim to meet these requirements by enabling faster data transmission, improved network capacity, and better quality of service compared to previous generations. To achieve these goals, advanced transmission techniques are required to efficiently use the available radio spectrum and handle challenging channel conditions. Multiple-Input Multiple-Output (MIMO) and Orthogonal Frequency Division Multiplexing (OFDM) are two core technologies widely adopted in 5G wireless systems. MIMO improves system performance by using multiple antennas at both the transmitter and receiver. This allows the system to transmit several data streams at the same time, making better use of spatial diversity and multipath

propagation. As a result, MIMO enhances data throughput, reliability, and spectral efficiency. OFDM complements this approach by dividing the available bandwidth into many closely spaced subcarriers. This structure helps reduce the effects of inter-symbol interference and frequency-selective fading, making OFDM well suited for high-speed data transmission in complex wireless environments.

The joint implementation of MIMO and OFDM combines the advantages of both techniques, leading to significant improvements in overall system performance. MIMO-OFDM systems are capable of delivering higher data rates, wider coverage, and improved energy efficiency, especially in dense urban areas where signal propagation is highly variable. These characteristics make MIMO-OFDM a key enabling technology for important 5G services such

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as enhanced mobile broadband and large-scale device connectivity. An important factor influencing the performance of MIMO-OFDM systems is the choice of modulation scheme. Lower-order modulation techniques, including QPSK and 16-QAM, are known for their robustness in noisy channel conditions but offer limited spectral efficiency. In contrast, higher-order modulation schemes can transmit more bits per symbol, resulting in higher data rates and improved spectral efficiency. However, these schemes typically require higher Signal-to-Noise Ratios (SNRs) to maintain acceptable error performance. Most existing research has primarily focused on lower-order modulation schemes. With the increasing demand for high-capacity wireless communication in 5G networks, it is necessary to investigate the performance of higher-order modulation techniques such as 256-QAM, 1024-QAM, and 4096-QAM. These schemes have the potential to significantly enhance network throughput in favorable channel conditions, making them attractive for next-generation wireless systems. This paper presents a detailed performance evaluation of various modulation schemes in a MIMO-OFDM-based 5G system. Key performance indicators such as Bit Error Rate (BER), throughput, and spectral efficiency are analyzed using MATLAB simulations. The study provides a clear comparison of low- and high-order modulation techniques and highlights their advantages and limitations under different operating conditions. The results offer valuable insights into selecting appropriate modulation strategies to balance reliability and efficiency in 5G MIMO-OFDM networks.

2. IOT OVERVIEW OF MIMO-OFDM SYSTEMS

This section presents a detailed overview of MIMO-OFDM systems by explaining the basic concepts of MIMO and OFDM technologies, their combined operation, and the advantages and limitations associated with their integration. In addition, a concise review of existing performance analysis studies related to MIMO-OFDM in 5G networks is provided.

2.1. MIMO Technology

Multiple-Input Multiple-Output (MIMO) technology improves wireless communication performance by employing multiple antennas at both the transmitter and receiver sides, as illustrated in Fig. 1. The main idea behind MIMO is to use multiple signal paths to transmit and receive data at the same time. This approach enhances system capacity and reliability through the use of spatial diversity and spatial multiplexing. Spatial diversity is used to improve

signal robustness by transmitting identical information through different antennas. Since each signal experiences independent channel conditions, the probability that all signal copies are simultaneously degraded by fading or interference is reduced. This results in more reliable signal reception. The diversity gain, denoted as G_d depends on the number of transmit and receive antennas and is given by:

$$G_d = \min(N_t, N_r)$$

Where N_t and N_r represent the number of transmit and receive antennas, respectively.

In addition to diversity, MIMO systems employ spatial multiplexing to increase data rates. Spatial multiplexing allows different data streams to be transmitted simultaneously from multiple antennas. This technique effectively increases system capacity without requiring additional bandwidth. The capacity CCC of a MIMO system operating in the presence of noise can be expressed as:

$$C = \log_2(\det(I N_r + \rho / N_t * HH))$$

where $I N_r$ is the identity matrix of size ρ / N_t denotes the average Signal-to-Noise Ratio (SNR), and HH represents the channel matrix.

By combining spatial diversity and spatial multiplexing, MIMO technology significantly improves both reliability and throughput, making it a fundamental component of modern wireless communication systems, including 5G networks.

2.2. OFDM Technology

Orthogonal Frequency Division Multiplexing (OFDM) is a multicarrier transmission technique that divides the available bandwidth into a large number of orthogonal subcarriers. Each subcarrier carries a low-rate data stream, which makes OFDM highly resistant to frequency-selective fading and inter-symbol interference (ISI). A defining feature of OFDM is the orthogonality among its subcarriers, as shown in Fig. 2. Although the subcarriers overlap in the frequency domain, orthogonality ensures that inter-carrier interference (ICI) does not occur. The subcarrier spacing is equal to $1/T_1/T_1/T$, where TTT is the OFDM symbol duration. The orthogonality condition is given by:

$$\int_0^T e^{(j2\pi f_i t)} e^{(-j2\pi f_j t)} dt = 0 \text{ for } i \neq j$$

where f_i and f_j represent the frequencies of the i -th and j -th subcarriers.

To further mitigate ISI, a cyclic prefix (CP) is added to each OFDM symbol. The CP is a repetition of the end portion of the OFDM symbol appended to its beginning. If the CP duration T_{cp} is longer than the

channel delay spread τ , ISI can be effectively eliminated, ensuring accurate symbol detection at the receiver.

2.3. MIMO-OFDM System

The integration of MIMO and OFDM results in a communication system that is both efficient and resilient, making it highly suitable for 5G applications. In a MIMO-OFDM system, the input data stream is divided into multiple parallel streams, which are then mapped onto OFDM symbols and transmitted simultaneously through multiple antennas.

For each subcarrier, the received signal can be modeled as:

$$y_k = H_k x_k + n_k$$

where y_k is the received signal vector for the k -th subcarrier, H_k is the channel matrix, x_k represents the transmitted signal vector, and n_k denotes the noise vector.

Accurate channel estimation is essential for reliable data detection in MIMO-OFDM systems. Pilot symbols are commonly used to estimate channel characteristics, and equalization techniques such as Zero-Forcing (ZF) and Minimum Mean Square Error (MMSE) are applied to compensate for channel distortion.

MIMO-OFDM plays a critical role in 5G and beyond networks, particularly in densely populated urban environments. Its ability to support multiple users simultaneously makes it well suited for high-bandwidth applications such as video streaming, online gaming, and real-time video conferencing, even during periods of heavy network traffic.

2.4. Benefits and Challenges

MIMO-OFDM systems offer several notable advantages. One of the most important benefits is their ability to support very high data rates, which is essential for modern wireless applications. The use of multiple antennas and orthogonal subcarriers enables simultaneous transmission of large volumes of data. Additionally, the combination of spatial diversity and OFDM's resistance to frequency-selective fading improves link reliability and ensures stable performance in challenging propagation environments. Another major advantage of MIMO-OFDM is its high spectral efficiency, which makes it particularly suitable for deployment in spectrum-limited and densely populated areas. Despite these advantages, MIMO-OFDM systems also present certain challenges. The requirement for multiple antennas and advanced signal processing techniques increases system complexity. Reliable channel estimation is especially difficult in fast-varying

channels. Furthermore, effective management of intra-cell and inter-cell interference is necessary to fully exploit the benefits of MIMO-OFDM. Without proper interference mitigation strategies, system performance may degrade.

2.5. Review of Related Works

Several studies have investigated the performance of MIMO-OFDM systems for 5G networks under different configurations. Previous research has primarily focused on Bit Error Rate (BER) performance using various modulation schemes and channel models. Many studies report that lower-order modulation schemes such as BPSK and QPSK achieve better BER performance, particularly when combined with MMSE equalization and under AWGN channel conditions. Other works have compared MIMO-OFDM with alternative multicarrier techniques such as GFDM, UFMC, FBMC, and filtered OFDM. These studies typically evaluate metrics such as power spectral density, peak-to-average power ratio, spectral efficiency, and BER. In several cases, alternative waveforms demonstrate performance advantages over conventional MIMO-OFDM, depending on system configuration and detection methods.

Overall, the literature indicates that while extensive performance evaluations of MIMO-OFDM systems exist, most studies emphasize lower-order modulation schemes and primarily rely on BER as the main performance metric. The impact of higher-order modulation techniques has not been thoroughly explored. To address this limitation, the present work provides a comprehensive performance analysis of MIMO-OFDM systems by considering both low- and high-order modulation schemes. In addition to BER, key performance indicators such as throughput and spectral efficiency are evaluated to offer a more complete understanding of system performance in 5G networks.

3. EXPERIMENTAL SETUP AND PERFORMANCE METRICS

3.1. System Model

The system model used in this study represents a MIMO-OFDM communication framework designed to evaluate performance under realistic 5G conditions. At the transmitter, a stream of random binary data is first generated and encoded using a Low-Density Parity-Check (LDPC) encoder to improve error correction capability. The encoded bits are then modulated using the selected digital modulation schemes. After modulation, the symbols are assigned to OFDM subcarriers and converted from the frequency domain to the time domain using the Inverse Fast Fourier Transform (IFFT). To reduce

the effects of inter-symbol interference (ISI) caused by multipath propagation, a cyclic prefix is added to each OFDM symbol before transmission. The wireless channel is modeled using Rayleigh fading combined with Additive White Gaussian Noise (AWGN) to reflect practical propagation conditions such as multipath fading, signal scattering, and noise. This channel model captures the impact of reflections and signal distortion commonly encountered in real-world wireless environments. At the receiver, the cyclic prefix is removed from the received signal, and the Fast Fourier Transform (FFT) is applied to convert the signal back into the frequency domain. Zero-Forcing (ZF) equalization is then employed to mitigate channel effects and separate the signals transmitted from multiple antennas. The equalized symbols are demodulated and passed through an LDPC decoder to recover the original data bits. These recovered bits are used to evaluate system performance in terms of Bit Error Rate (BER), throughput, and spectral efficiency. All simulations and analyses were carried out using MATLAB 2021a.

3.2. Modulation Schemes in 5G Networks

A modulation scheme defines how digital information is mapped onto a carrier signal for transmission. Different schemes offer trade-offs between data rate, robustness, and spectral efficiency. This study evaluates several modulation techniques commonly considered for MIMO-OFDM-based 5G systems.

Quadrature Phase Shift Keying (QPSK): QPSK transmits 2 bits per symbol and provides strong resistance to noise and interference. Due to its robustness and relatively low receiver complexity, it is widely used in 5G control channels and initial access procedures. Although its data rate is lower than higher-order schemes, its reliability makes it suitable for poor channel conditions.

16-Quadrature Amplitude Modulation (16-QAM): 16-QAM transmits 4 bits per symbol, offering higher data rates and improved spectral efficiency compared to QPSK. It is suitable for applications requiring moderate throughput, such as high-definition multimedia services. However, it is more sensitive to noise, requiring better channel conditions.

64-Quadrature Amplitude Modulation (64-QAM): With 6 bits per symbol, 64-QAM provides increased throughput and is commonly used in 5G systems for data-intensive services. While it improves spectral efficiency, it requires a higher Signal-to-Noise Ratio (SNR) for reliable performance, especially in interference-prone environments.

256-Quadrature Amplitude Modulation (256-QAM):

256-QAM transmits 8 bits per symbol, enabling very high data rates and efficient spectrum usage. It is well suited for high-capacity services such as enhanced mobile broadband (eMBB). Due to its high sensitivity to noise, its operation is typically limited to scenarios with strong signal quality.

1024-Quadrature Amplitude Modulation (1024-QAM):

This modulation scheme conveys 10 bits per symbol and supports extremely high data throughput. It is applied in 5G environments with stable channels and minimal interference. However, the requirement for high SNR restricts its use to favorable transmission conditions.

4096-Quadrature Amplitude Modulation (4096-QAM):

As a very high-order modulation technique, 4096-QAM transmits 12 bits per symbol, providing maximum spectral efficiency and data rate. It is mainly considered for ultra-high-capacity applications such as fixed wireless access and backhaul links. Due to its extreme sensitivity to noise and distortion, it is practical only in carefully controlled environments with exceptionally high SNR.

3.3. Performance Metrics

The performance of the MIMO-OFDM system is evaluated using the following key metrics:

Bit Error Rate (BER): BER measures the accuracy of data transmission and is defined as the ratio of incorrectly received bits to the total transmitted bits:

$$\text{BER} = (\text{Total number of bit errors}) / (\text{Total number of transmitted bits})$$

Throughput: Throughput represents the rate at which data is successfully received over the communication channel and is expressed as:

$$\text{Throughput} = (\text{Number of successfully received bits}) / (\text{Total transmission time})$$

Spectral Efficiency: Spectral efficiency indicates how efficiently the available bandwidth is utilized and is measured in bits per second per Hertz (bps/Hz):

$$\text{Spectral Efficiency} = \text{Throughput} / \text{Bandwidth}$$

Signal-to-Noise Ratio (SNR): SNR quantifies the quality of the received signal and is calculated as:

$$\text{SNR (dB)} = 10 \log_{10}(P_{\text{signal}} / P_{\text{noise}})$$

The simulation parameters used in this study are summarized in below Table

Parameter	Value
SNR range	-10 dB to 20 dB (step size: 2 dB)
Number of subcarriers	64
MIMO configuration	4 × 4 (4 transmit, 4 receive antennas)
Simulation duration	1000 OFDM symbols per SNR value
Modulation schemes	QPSK, 16-QAM, 64-QAM, 256-QAM, 1024-QAM, 4096-QAM
Channel model	Rayleigh fading with AWGN
FFT size	64
Cyclic prefix length	16
Equalization technique	Zero-Forcing
Performance metrics	BER, throughput, spectral efficiency

4. CONCLUSION

This review examined the performance characteristics of MIMO-OFDM systems within 5G networks, with particular emphasis on both traditional and advanced modulation techniques, including QPSK, 64-QAM, 256-QAM, 1024-QAM, and 4096-QAM. The analysis highlights a clear trade-off between spectral efficiency and reliability: higher-order modulation schemes significantly improve throughput and spectral efficiency but tend to exhibit increased Bit Error Rates (BER) at lower Signal-to-Noise Ratios (SNR). These advanced schemes therefore show considerable promise for deployment in high-SNR scenarios, where maximizing network capacity and data rates is critical. Conversely, lower-order modulation schemes such as QPSK offer superior robustness under challenging, low-SNR conditions, underscoring their continued relevance for applications requiring stable, reliable communications even in adverse environments. Looking ahead, there is strong potential in hybrid modulation strategies that synergistically combine low- and high-order modulation benefits to optimize performance across diverse channel conditions. Additionally, adaptive modulation techniques-where the system dynamically selects the most appropriate modulation order based on real-time channel feedback-represent a promising direction for further enhancing network efficiency and reliability.

Ongoing research and development in these areas will be essential to fully realize the capabilities of 5G networks, ensuring they meet growing demands for high data throughput, low latency, and robust connectivity in increasingly complex and dynamic wireless environments.

References

- [1] P. Kamat and R. Sugandhi, "Anomaly detection for predictive maintenance in industry 4.0-A survey," in *E3S web of conferences*, 2020, vol. 170: EDP Sciences, p. 02007.
- [2] Aarab, M. N., Chakkor, O.: MIMO-OFDM for wireless systems: an overview. In: Ezziyyani, M.(eds.) *Advanced Intelligent Systems for Sustainable Development (AI2SD'2019)*, AI2SD 2019, LNNS, vol. 92, pp. 185–196. Springer, Cham (2020). https://doi.org/10.1007/978-3-030-33103-0_19
- [3] Elsanousi, A., Oztürk, S.: Performance analysis of OFDM and OFDM-MIMO systems under fading channels. *Eng. Technol. Appl. Sci. Res.* 8, 3249–3254 (2018). <https://doi.org/10.48084/etasr.2209>
- [4] Nandi, S.; Nandi, A.; Pathak, N.N.: Performance analysis of Alamouti STBC MIMO OFDM for different transceiver system. In: *Proceedings of the 2017 International Conference on Intelligent Sustainable Systems (ICISS)*, pp. 883–887. IEEE, December 2017
- [5] Kamatham, Y., Pollamoni, S.: Performance analysis of FBMC and OFDM with MIMO for Wireless communications. In: Mekhilef, S., Favorskaya, M., Pandey, R.K., Shaw, R.N. (eds.) *Innovations in Electrical and Electronic Engineering, LNEE*, vol. 756, pp. 521–532. Springer, Singapore (2021). https://doi.org/10.1007/978-981-16-0749-3_40
- [6] Gurama, R., Kamatham, Y., Pollamoni, S.: Performance analysis of OFDM and UFMC with MIMO wireless communications. In: Reddy, K. A., Devi, B. R., George, B., Raju, K.S. (eds.) *Data Engineering and Communication Technology, LNDECT*, vol.63, pp.273–283. Springer, Singapore (2021). https://doi.org/10.1007/978-981-16-0081-4_27 Analysis of MIMO-OFDM Systems in 5G Wireless Networks 291
- [7] Shamsul Alam, S. M., Saha, A.: Performance analysis of FBMC over OFDM for high data rate MIMO configurations. *Int. J. Wirel.*

- Microw. Technol. 11, 20–33 (2021). <https://doi.org/10.5815/ijwmt.2021.04.03>
- [8] De Figueiredo, F.A.P.; Aniceto, N.F.T.; Seki, J.; Moerman, I.; Fraidenraich, G.: Comparing F-OFDM and OFDM performance for MIMO systems considering a 5G scenario. In: IEEE 5G World Forum, 5GWF 2019- Conference Proceedings, pp. 532–535 (2019). <https://doi.org/10.1109/5GWF.2019.8911702>
- [9] Trikha, M., Singhal, M., Rajan, R.: BER Performance comparison between QPSK and 4-QA modulation schemes. MIT Int. J. Electr. Instrum. Eng. 3, 62–66 (2013) 21. Xiang, M., Tang, H., Fu, S., Tang, M., Shum, P., Liu, D.: Performance comparison of offset 16QAM and 16QAM for Nyquist WDM superchannel with digital spectral shaping. J. Light. Technol. 33, 3623–3629 (2015). <https://doi.org/10.1109/JLT.2015.2448117>
- [10] Buchali, F., Steiner, F., Böcherer, G., Schmalen, L., Schulte, P., Idler, W.: Rate adaptation and reach increase by probabilistically shaped 64-QAM: an experimental demonstration. J. Light. Technol. 34, 1599–1609 (2016). <https://doi.org/10.1109/JLT.2015.2510034>
- [11] Arunruangsirilert, K., Wongprasert, P., Katto, J.: Performance evaluation of uplink 256QAM on commercial 5G new radio (NR) networks. In: Proceedings of the 2024 IEEE Wireless Communications and Networking Conference (WCNC), pp. 1–6. IEEE (2024)
- [12] Termos, H., Mansour, A.: Concurrent M-QAM transmission performance assessment in a combined Four SOA-MZIs arrangement. Opt. Lasers Eng. 176, 108110 (2024). <https://doi.org/10.1016/j.optlaseng.2024.108110>
- [13] Olsson, S.L.I., Cho, J., Chandrasekhar, S., Chen, X., Winzer, P.J., Makovejs, S.: Probabilistically shaped PDM 4096-QAM transmission over up to 200 Km of fiber using standard intradyne detection. Opt. Express 26, 4522 (2018). <https://doi.org/10.1364/oe.26.004522>

