

Capacity Enhancement of 5g wireless system using Mimo-Ofdm technique in matlab : A Comparative Analysis

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Abstract—Artificial Intelligence (AI) has emerged as a transformative technology for enhancing the performance of Multiple Input Multiple Output–Orthogonal Frequency Division Multiplexing (MIMO-OFDM) communication systems. This study presents a comprehensive review and comparative analysis of AI-based techniques applied to MIMO-OFDM architectures, encompassing machine learning models, deep neural networks, and advanced optimization frameworks. The investigation evaluates the operational capabilities, advantages, and limitations of these approaches in addressing critical communication challenges, including channel estimation, signal detection, interference suppression, resource allocation, and spectrum utilization efficiency.

The review further examines the role of AI in improving system adaptability, reliability, and decision-making under rapidly varying wireless channel conditions. By comparing different methodologies and their performance outcomes, the study highlights emerging research trends, identifies effective implementation strategies, and outlines existing research gaps that warrant further exploration. The analysis provides valuable insights into the integration of intelligent algorithms within next-generation wireless communication systems and serves as a useful reference for researchers, academicians, and industry professionals working in the field of advanced communication technologies.

I. INTRODUCTION

Orthogonal Frequency Division Multiplexing (OFDM) has become a fundamental transmission technology in modern wireless communication systems, including IEEE 802.16, WiMAX, Long-Term Evolution (LTE), and Fifth-Generation (5G) New Radio networks. Its widespread adoption is primarily attributed to its capability to transform frequency-selective fading channels into a set of parallel flat-fading subchannels by dividing the available spectrum into multiple orthogonal subcarriers. This characteristic significantly improves spectral efficiency and enhances system performance in multipath propagation environments. Multiple Input Multiple Output (MIMO) technology represents another major advancement in wireless communications and has been extensively integrated into LTE and 5G systems. By employing multiple antennas at both the transmitter and

receiver, MIMO systems enhance channel capacity, improve link reliability, and increase data throughput. The performance gains achieved through MIMO are mainly derived from spatial diversity and spatial multiplexing techniques, which mitigate fading effects and enable simultaneous transmission of multiple data streams. Despite these advantages, the growing demand for ultra-high data rates and massive connectivity in next-generation communication networks has highlighted the need for more efficient transmission schemes. Spatial Modulation (SM) has emerged as a promising alternative to conventional MIMO architectures. In SM systems, information is conveyed not only through conventional modulation symbols but also through the indices of activated transmit antennas. This approach reduces hardware complexity by requiring fewer radio-frequency chains while simultaneously improving spectral efficiency and scalability. Consequently, SM has attracted considerable attention as a low-complexity solution for future high-speed wireless communication systems.

The effectiveness of MIMO-based communication largely depends on accurate Channel State Information (CSI). However, obtaining precise channel knowledge remains a challenging task due to the dynamic nature of wireless channels. Channel characteristics vary across time, frequency, and spatial dimensions, particularly in multipath environments where signal propagation is influenced by factors such as path delays, angular dispersion, and complex path gains. Therefore, advanced channel modeling and estimation techniques are essential for achieving reliable communication and maximizing system capacity. Wireless communication systems can be categorized according to antenna configurations. Single Input Single Output (SISO) systems employ one transmit and one receive antenna and represent the simplest communication architecture. Single Input Multiple Output (SIMO) systems utilize a single transmit antenna and multiple receive antennas to achieve diversity gains at the receiver. Conversely, Multiple Input Single Output (MISO) systems employ multiple transmit antennas and a single receive antenna, providing transmit diversity and improved signal robustness. Multiple Input Multiple Output (MIMO) systems combine multiple antennas at both transmission and reception ends, offering substantial improvements in data rate, coverage, and reliability. These systems are widely deployed

in Wireless Local Area Networks (WLANs), Metropolitan Area Networks (MANs), Personal Area Networks (PANs), and cellular communication infrastructures. According to information-theoretic principles established by Shannon, the achievable data rate of a communication system is fundamentally constrained by channel bandwidth and signal-to-noise ratio (SNR). Consequently, efficient utilization of available spectrum and accurate channel estimation are critical for approaching channel capacity limits. In OFDM-based systems, pilot-assisted channel estimation is commonly employed to obtain CSI. Block-type pilot arrangements are generally suitable for slowly varying channels, whereas comb-type pilot structures are preferred in rapidly changing channel conditions. Furthermore, channel estimation techniques are broadly classified into block-oriented and adaptive approaches. Block-oriented methods rely on known pilot symbols for channel estimation, while adaptive techniques continuously update channel estimates using decisions derived from received data symbols. The continuous evolution of wireless communication technologies has motivated researchers to explore advanced signal processing and Artificial Intelligence (AI)-based solutions for improving channel estimation accuracy, reducing interference, enhancing spectral efficiency, and increasing overall system performance. These developments are expected to play a crucial role in the realization of next-generation intelligent communication networks.

II. LITERATURE REVIEW

Several researchers have investigated advanced channel estimation and signal processing techniques to enhance the performance of MIMO-OFDM communication systems.

Ahmad Hasan et al. [1] examined the application of Least Squares (LS) and Minimum Mean Square Error (MMSE) algorithms for channel estimation in wireless communication systems. Although LS estimation offers low computational complexity and ease of implementation, MMSE requires prior channel statistical information, making it less practical for real-time industrial deployment. To overcome these limitations, the authors proposed an enhanced LS-based channel estimation technique that minimizes the relative estimation error between the actual and estimated channel coefficients. Simulation results demonstrated improved Bit Error Rate (BER) and Mean Square Error (MSE) performance, leading to faster and more reliable data transmission.

Amr Elnakeeb et al. [2] investigated sparse MIMO-OFDM channel estimation under realistic pulse-shaping and finite-bandwidth conditions, where channel leakage significantly affects estimation accuracy. Their study revealed that leakage components can be effectively separated in both delay and Doppler domains. The proposed estimation framework achieved a 4 dB improvement in MSE compared with conventional methods that neglect leakage effects and

provided an additional 1.3 dB gain over existing leakage-aware approaches. Furthermore, channel parameters were derived using the Cramér–Rao Bound (CRB), resulting in approximately 3 dB improvement in error probability performance.

Srivastava et al. [3] explored channel estimation techniques for millimeter-wave (mmWave) MIMO-OFDM systems operating in sparse and doubly selective channel environments. The authors employed Sparse Bayesian Learning (SBL) to estimate channel impulse responses by exploiting angular-domain sparsity. To further enhance performance, they proposed a Group Sparse Bayesian Learning (G-SBL) framework that utilized frequency-domain channel correlations to reduce pilot overhead and improve estimation accuracy. Additionally, a Low-Complexity G-SBL variant was introduced to decrease computational requirements. An online SBL approach was also developed for predicting doubly selective channels under limited Channel State Information (CSI) feedback conditions.

Yan Chen et al. [4] focused on channel estimation and signal detection in massive MIMO-OFDM uplink systems affected by In-Phase and Quadrature Imbalance (IQI). The authors modeled the effective channel as a combination of wireless propagation characteristics and hardware impairments. An MMSE-based estimation framework was developed using Adjustable Phase Shift Pilots (APSPs) to reduce pilot overhead. Their pilot scheduling strategy, based on effective channel covariance matrices, significantly improved channel estimation accuracy while maintaining reliable signal detection performance.

Xiaofeng Liu et al. [5] addressed sparse channel estimation challenges in broadband massive MIMO-OFDM systems by exploiting structured sparsity and temporal correlations within the angle-delay domain. A Hidden Markov Model (HMM) was employed to characterize channel evolution, while Bethe Free Energy (BFE) minimization was used to formulate the estimation problem. The proposed Hierarchical Hybrid Message Passing (HHMP) algorithm dynamically estimated channel parameters and learned sparse channel structures without requiring prior knowledge of HMM parameters. Simulation results confirmed reduced pilot overhead, faster convergence, and enhanced estimation accuracy.

Furkan Batuhan Okumuş et al. [6] investigated channel estimation for Generalized LED Index Modulation (GLIM)-OFDM based Visible Light Communication (VLC) systems incorporating MIMO technology. Analytical expressions for MSE, BER, and the Cramér–Rao Lower Bound (CRLB) were derived to evaluate estimation performance. Numerical analysis demonstrated that the proposed channel estimation approach achieved highly accurate results, with BER performance closely approaching that of systems operating with perfect channel information.

Deergha Rao Korrai et al. [7] utilized Orthogonal Matching Pursuit (OMP), a compressive sensing-based recovery algorithm, for channel estimation in MIMO-OFDM systems.

Although OMP offers high estimation accuracy for sparse channels, its computational complexity remains a significant challenge. To address this issue, the authors developed a VLSI architecture implementation using the Xilinx Vivado HLS platform, enabling faster execution and practical hardware realization of the channel estimation process.

K. P. Anjana et al. [8] investigated physical-layer security enhancement in MIMO and MIMO-OFDM systems through Secret Key Capacity (SKC) analysis. The study examined the influence of channel estimation errors on secure communication performance and derived closed-form expressions for SKC under various antenna configurations. Results indicated that MIMO-OFDM systems could maintain positive SKC even when an eavesdropper possessed more receiving antennas than the legitimate receiver. The findings also highlighted the significant impact of channel estimation errors on secure key generation performance.

Myeung Suk Oh et al. [9] proposed a reinforcement learning-based denoising framework for channel estimation in MIMO-OFDM systems. The approach utilized channel curvature information to identify unreliable channel estimates and formulated the denoising process as a Markov Decision Process (MDP). A Q-learning algorithm was employed to iteratively update channel estimates based on a reward function designed to minimize MSE. Experimental results demonstrated superior noise suppression capability and improved estimation accuracy compared with conventional LS estimation methods.

Feng Jiang et al. [10] investigated channel smoothing techniques for OFDM systems by exploiting the correlation among neighboring frequency-domain channel responses. The authors designed beamforming vectors capable of generating smooth channel characteristics and formulated an optimization problem to determine optimal smoothing parameters. The proposed method achieved more than 2 dB performance gain in channel estimation accuracy, demonstrating the effectiveness of beamformed channel smoothing in wireless communication systems.

Overall, the reviewed studies highlight the growing integration of advanced optimization methods, Bayesian learning techniques, compressive sensing algorithms, reinforcement learning models, and statistical signal processing approaches for improving channel estimation, reducing pilot overhead, enhancing spectral efficiency, and strengthening the reliability of MIMO-OFDM communication systems.

III. COMPARATIVE ANALYSIS

The integration of Artificial Intelligence (AI) into Multiple Input Multiple Output–Orthogonal Frequency Division Multiplexing (MIMO-OFDM) systems has emerged as a transformative approach for addressing the increasing performance requirements of modern wireless communication networks. Conventional MIMO-OFDM systems rely heavily

on mathematical modeling and signal processing techniques for channel estimation, resource allocation, interference suppression, and signal detection. However, the dynamic and complex nature of wireless environments often limits the effectiveness of traditional approaches. AI-driven methodologies provide intelligent, adaptive, and data-oriented solutions capable of learning from channel behavior and optimizing system performance in real time. MIMO-OFDM technology forms the backbone of contemporary wireless communication standards, including LTE, 5G, and emerging 6G networks. The combination of MIMO and OFDM enables high spectral efficiency, increased channel capacity, enhanced reliability, and improved resistance to multipath fading. Nevertheless, challenges such as channel estimation inaccuracies, pilot overhead, inter-carrier interference, hardware impairments, and rapidly varying propagation conditions continue to affect overall system performance. AI techniques have demonstrated significant potential in overcoming these limitations through intelligent decision-making and adaptive optimization. Among various AI approaches, Deep Learning (DL) has gained substantial attention due to its capability to model complex nonlinear relationships within wireless channels. Deep Neural Networks (DNNs), Convolutional Neural Networks (CNNs), and Recurrent Neural Networks (RNNs) have been widely applied to channel estimation, signal detection, beamforming, precoding, and decoding tasks. Unlike conventional estimation techniques that require accurate mathematical channel models, deep learning methods can directly learn channel characteristics from large datasets and provide highly accurate predictions even in complex propagation environments. As a result, AI-based channel estimation techniques often achieve lower Bit Error Rates (BER) and improved Mean Square Error (MSE) performance compared to traditional Least Squares (LS) and Minimum Mean Square Error (MMSE) estimators.

Reinforcement Learning (RL) represents another important AI paradigm applied to MIMO-OFDM systems. RL algorithms enable communication systems to learn optimal operational strategies through continuous interaction with the wireless environment. These algorithms are particularly effective for adaptive resource allocation, dynamic spectrum access, power control, beam selection, and mobility management. By continuously updating policies based on environmental feedback, RL-based systems can maintain robust performance under rapidly changing channel conditions and user mobility scenarios. This adaptability significantly improves system reliability and Quality of Service (QoS). Evolutionary optimization techniques, including Genetic Algorithms (GA), have also been extensively explored for MIMO-OFDM optimization. Genetic Algorithms employ biologically inspired operations such as selection, crossover, and mutation to identify optimal parameter configurations. In wireless communication systems, GAs have been successfully utilized for antenna selection, power allocation, pilot placement optimization, and beamforming parameter tuning.

Their ability to search large solution spaces efficiently makes them particularly suitable for complex optimization problems where conventional analytical solutions are difficult to obtain. Similarly, Swarm Intelligence (SI) techniques, such as Particle Swarm Optimization (PSO) and Ant Colony Optimization (ACO), have demonstrated effectiveness in solving multidimensional optimization problems within MIMO-OFDM systems. These algorithms mimic collective behaviors observed in natural systems and are capable of identifying near-optimal solutions with relatively low computational complexity. Applications include channel estimation enhancement, resource scheduling, adaptive modulation selection, and energy-efficient transmission optimization. The performance of AI-driven MIMO-OFDM systems is typically evaluated using several critical metrics. Bit Error Rate (BER) serves as a primary indicator of communication reliability, reflecting the accuracy of transmitted information. Throughput measures the amount of successfully transmitted data within a given time interval and directly represents system capacity. Spectral Efficiency evaluates the effectiveness of spectrum utilization and is particularly important for next-generation wireless networks facing spectrum scarcity. Additional metrics such as Mean Square Error (MSE), latency, fairness, computational complexity, and energy consumption are frequently considered when assessing overall system performance. Comparative studies consistently demonstrate that AI-based approaches outperform conventional signal processing techniques in several key areas. Deep learning models provide superior channel estimation accuracy, particularly under highly dynamic and nonlinear channel conditions. Reinforcement learning algorithms offer enhanced adaptability and autonomous decision-making capabilities, enabling efficient resource management without requiring extensive prior channel knowledge. Evolutionary and swarm intelligence algorithms contribute to improved optimization performance and reduced system overhead. Consequently, AI-enhanced MIMO-OFDM systems often achieve lower BER, higher throughput, increased spectral efficiency, and improved robustness against interference and channel uncertainties.

Despite these advantages, AI-driven communication systems also introduce certain challenges. Deep learning models typically require large training datasets and substantial computational resources. Real-time implementation may necessitate specialized hardware accelerators, increasing deployment costs. Furthermore, model interpretability, training complexity, and generalization across diverse communication scenarios remain active research challenges. Therefore, achieving an optimal balance between performance gains and computational requirements remains a critical objective for future research. Overall, the comparative analysis indicates that Artificial Intelligence has the potential to significantly transform MIMO-OFDM communication systems by enabling intelligent channel estimation, adaptive resource management, enhanced signal detection, and robust optimization. As wireless networks evolve toward 6G and

beyond, AI-driven methodologies are expected to play a pivotal role in realizing highly efficient, self-organizing, and intelligent communication infrastructures.

IV. CONCLUSION

Artificial Intelligence (AI) has emerged as a transformative technology for enhancing the performance and operational efficiency of Multiple Input Multiple Output–Orthogonal Frequency Division Multiplexing (MIMO-OFDM) systems. The integration of advanced AI techniques, including Deep Learning (DL), Reinforcement Learning (RL), Genetic Algorithms (GA), and Swarm Intelligence (SI), has significantly improved key communication processes such as channel estimation, signal detection, interference mitigation, beamforming, resource allocation, and adaptive network optimization. The comparative analysis presented in this study demonstrates that AI-driven MIMO-OFDM systems consistently achieve superior performance compared to conventional signal processing approaches. Significant improvements have been observed in critical performance metrics, including Bit Error Rate (BER), Mean Square Error (MSE), throughput, spectral efficiency, energy efficiency, and overall system reliability. Furthermore, AI-enabled techniques exhibit enhanced adaptability to dynamic wireless environments, enabling efficient operation under varying channel conditions, user mobility, and interference scenarios.

Despite these promising advancements, several challenges continue to hinder large-scale deployment of AI-based communication frameworks. These include the requirement for extensive training datasets, increased computational complexity, model training overhead, hardware implementation constraints, and concerns regarding model interpretability and real-time execution. Addressing these limitations remains a crucial research objective for future wireless communication systems. Future research should focus on developing lightweight and computationally efficient AI models capable of real-time implementation in resource-constrained environments. The integration of explainable artificial intelligence (XAI), federated learning, edge intelligence, and hybrid AI-signal processing frameworks may further enhance system performance while reducing implementation complexity. Additionally, the emergence of beyond-5G and 6G communication networks is expected to create new opportunities for intelligent, self-optimizing, and autonomous wireless systems.

In conclusion, AI-driven advancements have substantially strengthened the capabilities of MIMO-OFDM communication systems and represent a key enabling technology for next-generation wireless networks. Continued research and innovation in this domain will play a pivotal role in achieving highly reliable, energy-efficient, and intelligent

communication infrastructures capable of meeting the growing demands of future digital connectivity.

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