International Journal of Innovative Research in Technology and Science

ISSN: 2321-1156 www.ijirts.org Volume 12 Issue 2, March 2024

Advancements in AI-driven Techniques for MIMO-OFDM Systems: A Comparative Analysis

Balajee Sharma, Akant Kumar Raghuwanshi
Department of Electronics and Communication Engineering
Vedica Institute of Technology, RKDF University, Bhopal, India
sharmabalajee@gmail.com, akantthakur7@gmail.com

Selection and peer review of this article are under the responsibility of the scientific committee of the International Conference on Current Trends in Engineering, Science, and Management (ICCSTEM-2024) at SAM Global University, Bhopal.

Abstract- This study systematically reviews and compares various AI-driven approaches employed in MIMO-OFDM systems, including machine learning algorithms, neural networks, and optimization techniques. It delves into each method's strengths, limitations, and unique contributions, offering insights into their effectiveness in addressing specific challenges such as channel estimation, interference mitigation, and spectral efficiency improvement. Furthermore, the paper discusses the impact of AI on system adaptability and robustness in dynamic communication environments. Through a comparative lens, the research aims to identify trends, best practices, and areas of improvement in AI applications for MIMO-OFDM systems. The findings contribute to a deeper understanding of the evolving landscape of AI-driven enhancements in communication systems, offering valuable insights for researchers, engineers, and practitioners in the field.

Keywords- MIMO-OFDM, Artificial Intelligence, Comparative Analysis, Communication Systems, Neural Networks

INTRODUCTION

Many wireless communications technologies, such as IEEE 802.16, WiMAX, and LTE, rely on orthogonal frequency-division multiplexing (OFDM), which has also been utilized for up-linking and down-linking of 5G New Radio. OFDM's ability to convert frequency-selective channels to flat fade by dividing the bandwidth into smaller sub-bands is one of the main reasons for its growth. Another important technology that plays a vital role in 4G (LTE) networks is multi-input, multi-output transmission (MIMO). MIMO and OFDM are deployed in an LTE system to boost the data rate. However, This data rate does not seem adequate for next-generation systems. Space modulation (SM) transmits bits using active antenna indices in combination with standard modulations to provide higher data speeds and high scalability. Traditional MIMO transmission systems can be replaced with SM as a low-complexity option. A couple of antennas on both the broadcast and reception sides (multiple-input multiple-output (MIMO)) can significantly enhance capacity. This is due to two consequences: (i) diversification, which refers to the durability of the channel between a send and receive antenna against fading, and (ii) space-time coding, which refers to the simultaneous transfer of data over numerous transmit antennas. Therefore, the increase in capacity relied on a fundamental assumption: that the characteristics of all channels between transmitting and receiving antennas are accurately known. However, measuring all such channels proves to be exceedingly complex. These channels are specific to both frequency and time.

Additionally, spatial selectivity becomes crucial with multiple antennas. This involves multipath transmission schemes, considering factors such as angular positions at both the receiver and transmitting arrays, transmission delays, and complex amplitudes for each signal path. Utilizing probabilistic estimates regarding the dispersion of these parameters can be instrumental in enhancing the system's performance. Multiple Antenna Techniques: SISO stands for Single-Input Single-Output. The most popular antenna arrangement in wireless communication is single-input-single-output, which utilizes one antenna at the transmitter and one at the receiver. It's utilized in radio and TV stations and technologies such as WiFi and Bluetooth. SIMO stands for Single-Input Numerous-Output, a system in which one antenna is utilized at the transmission side, and numerous antennas are utilized at the reception side. It enables receiver diversification, allowing the strongest signal from many transmit antennas to be received.

In most cases, it's employed in an uplink environment. Two or more antennas are utilized on the transmission side, and one is utilized on the receiving side for multiple inputs with a single output. A couple of antennas on the transmission end enable transmission variety. WLAN, MAN, and digital television utilize the MISO technique (DTV). It's most commonly employed in downlink settings. MIMO stands for Multiple-Input Multiple-Output. Numerous-output technology employs antennas on both ends to create broadcast and receiving variety. It can be utilized in various networks, including PANs, LANs, WLANs, and MANs. MIMO systems can be utilized to increase signal diversification storage or counteract fading signals. A network developer's typical goals are high information rate, low bit error rate, low energy consumption, cheap cost, and ease of implementation. The MIMO system provides extremely high data speeds, exceeding 1Gbps, while minimizing bit error rates. The rate of transmission is always less than or equivalent to the capacities, according to Shannon's theorem. It's, in fact, less than the ability. The throughput of a channel is determined by its bandwidth and signal-noise ratio. The channel's bandwidth and signal-to-noise ratio are both properties.

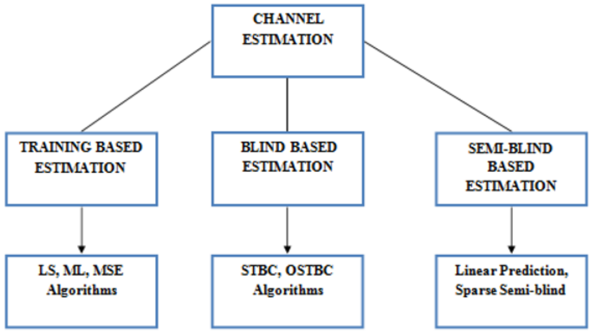

Figure 1. Classification of Channel Estimation

Additionally, whether block-type or comb-type pilot configurations can be utilized for pilot insertion, the block-type pilot channel estimate is favoured for slow-fading channels. Still, comb-type channel estimation is employed whenever the channel varies, even in a single OFDM block. Furthermore, there are two types of channel estimation processing methods: 1) "block-oriented computation," in which the symbols (pilots or subcarriers) must be known in advance so that the channel may be calculated from the signals detected in the sub-bands. 2) "Block-adaptive computation" utilizes symbol judgments to predict the channel from the signals detected in the sub-bands.

LITERATURE REVIEW

Ahmad Hasan et al. [1] used the Least Squares (LS) algorithm and Minimum Mean Square Error (MMSE) algorithms in cellular communication for channel estimation. LS estimation is simple to adopt and resource-friendly. LS performance is the same as MMSE, which requires channel statistics. It's not practical for the industry. In this work, an efficient LS estimation approach is suggested by minimizing relative error or difference among each estimated channel coefficient from its actual value, and it's often left out although considering overall error. This approach reduces the error per bit and gives rapid data processing. Suggested algorithms are demonstrated via bit error rate and mean square error comparison. Amr Elnakeeb et al. [2] researched to investigate the impact of finite bandwidth and realistic pulse shapes on the sparse MIMO-OFDM channel, where the non-sparse effect is called leakage. Their study demonstrated that the leaked MIMO-OFDM channel could be effectively separated within the delay and Doppler domains. The suggested method improves 4 dB mean squared error over methods that ignore leakage. 1.3 dB gain over a method that does consider leakage.

The leaked channel parameters are derived by Cramér Rao bound (CRB). It also presents decoupling in delay and Doppler parameters. These parameters are determined by solving key fixed-point equations. The suggested channel estimation algorithm obtains the CRB that provides an average performance gain of 3 dB concerning the probability of error compared to a conventional sparse channel estimation scheme. Srivastava et al. [3] investigated the utilization of millimetre-wave (mmWave) technology in conjunction with multiple-input multiple-output (MIMO) and orthogonal frequency division multiplexing (OFDM) techniques for the purpose of channel estimation. Their study explored the efficacy of these methods in scenarios involving sparse, collectively sparse, and internet-based channel environments. The mmWave channel impulse response (CIR) utilizes angular sparsity to achieve prediction results. They utilized a Sparse Bayesian learning (SBL) algorithm to evaluate the quasi-static channel of each independent subcarrier. This approach improved the efficiency compared to existing channel estimation techniques, balancing efficiency and interconnectivity trade-offs. Subsequently, they developed a novel group-sparse Bayesian learning (G-SBL) strategy to reduce the mean square error (MSE) in channel estimation. G-SBL establishes a frequency-domain (FD) connection of the channel's frequency response (CFR), thereby reducing pilot overhead during transmission. They also introduced a low-complexity (LC) G-SBL to decrease the computational burden notably.

Furthermore, an internet-based G-SBL (O-SBL) was employed to predict doubly-selective mmWave MIMO OFDM channels. This was exemplified by designing a hybrid transmit prior coder and achieving a combination that can operate on the predicted beam space domain CFRs with a limited channel state information (CSI) closed-loop system. Simulation results validate the accuracy of their analysis. Yan Chen et al. [4] investigated uplink huge multi-input multi-output orthogonal frequency division multiplexing (MIMO-OFDM) systems, considering in-phase and quadrature-phase disparities (II), channel estimation, and robust sensing. They characterized the effective medium as a combination of the IqI and the wireless medium/channel. Channel estimation was performed using the minimum mean square error (MMSE) criterion within a genuine framework. Customizable phase shift pilots (CPSPs) were employed to mitigate pilot operating costs.

Additionally, it was demonstrated that appropriately planning the pilot phase shifts can reduce the mean squared error (MSE) of the ideal transmission assessment. They proposed a pilot phase for a shift scheduling algorithm based on the covariance matrices of the effective channels approach. The utilization of APSPs may degrade channel prediction results. Hence, they utilized an MMSE to fulfil the objective criteria of the data detection method to address this issue. Xiaofeng Liu et al. [5] addressed the sparse channel estimation problem in broadband massive multiple-input-multiple-output orthogonal frequency division multiplexing (MIMO-OFDM) systems. They proposed using a Hidden Markov model to capture the structured sparsity and temporal dependency characteristic of massive MIMO-OFDM channels in the angle-delay domain. The Hidden Markov model demonstrated significant adaptability to various realistic propagation scenarios. To address the channel estimation problem, they employed Bethe free energy (BFE) minimization within a novel optimization framework applicable to a generic statistical model.

Furthermore, they introduced a hierarchical hybrid message passing (HHMP) algorithm to dynamically estimate channel parameters recursively. This approach enables learning multiuser channels' sparse structure and temporal correlation without necessitating the knowledge of hidden Markov channel parameters. Numerical simulations verified that the suggested HHMP algorithm accurately estimates angle-delay domain channels with reduced iteration times and pilot overhead. Furkan Batuhan Okumuş et al. [6] proposed the use of generalized LED index modulation (GLIM-OFDM) for VLC systems, which relies on orthogonal frequency division multiplexing (OFDM) with multiple inputs and multiple outputs (MIMO). They analytically derived the mean error (MSE), bit error rate (BER), and lower Cramer-Rao limit (CR) of the channel estimation algorithm. Computational modelling was employed to assess the performance of the SNR algorithm. Through this analysis, they derived MSE, BER, and CR curves, demonstrating the significant effectiveness of the envisaged channel estimation algorithm.

Moreover, they observed that the BER performance of the system obtained using data from the approximated channel closely matches that of the system with perfect channel knowledge. Deergha Rao Korrai et al. [7] utilized the OFDM MIMO approach to enhance link reliability, increase spectral efficiency, and boost data rates. They employed the orthogonal matching pursuit (OMP) algorithm, a type of compressive sensing (CS) recovery algorithm, for channel estimation in MIMO-OFDM systems. Recognizing the high computational complexity of the OMP algorithm, they designed VLSI architecture for MIMO channel estimation to simulate its speed. The simulation was conducted using the Xilinx Vivado HLS simulator. K P Anjana et al. [8] investigated the utilization of MIMO-OFDM and MIMO systems as part of 5G technologies. They noted the vulnerability to eavesdropping inherent in conventional methods due to security protocols. They proposed employing Secret Key Capacity (SKC) in MIMO and MIMO-OFDM systems with multiple receiver antennas for the eavesdropper. Their method analyzed the impact of channel estimation errors on SKC performance and derived closed-form expressions for SKC for both MIMO and MIMO-OFDM channels.

Additionally, they examined the effect of channel estimation errors at the authorized receiver end across various MIMO-OFDM configurations. It was observed that MIMO-OFDM channels can achieve positive SKC when the eavesdropper possesses a higher number of receiver antennas than the authorized receiver. The study also highlighted how increasing channel estimation errors can enhance the SKC system. Furthermore, they discussed SKC results with different numbers of transmit and receive antennas for both eavesdropper and authorized receiver scenarios. Myeung Suk Oh et al. [9] implemented multiple-input multiple-output (MIMO) orthogonal frequency division multiplexing (OFDM), which necessitates accurate channel estimation at the receiver during communication. Using a channel curvature magnitude threshold, they introduced a denoising process based on channel curvature computation to identify unreliable channel estimates. They formulated a Markov decision process for the denoising mechanism, where actions are guided by a geometry-based channel estimation update and a reward function based on a policy that minimizes mean squared error (MSE). By employing q-learning to update channel estimates, they demonstrated that the denoising algorithm successfully mitigates noise in channel estimates, offering improvement over the practical least squares (LS) estimation method. Feng Jiang et al. [10] explored how channel smoothing enhances the channel estimation of orthogonal frequency division multiplexing (OFDM) systems by leveraging the smoothness among frequency-domain channel responses. They utilized beamforming vectors to enable the transmitter to generate smooth beamforming vectors from the disruptive ones provided by the receiver. Leveraging a beamformed channel, they applied powerful smoothing to achieve more than a 2 dB gain. They formulated an objective function for smoothing in beamforming and derived an optimization problem to obtain an optimal solution.

COMPARATIVE ANALYSIS

A comprehensive comparative analysis of AI-driven advancements in Multiple Input Multiple Output Orthogonal Frequency Division Multiplexing (MIMO-OFDM) systems involves evaluating how various artificial intelligence (AI) techniques enhance system performance, efficiency, and robustness. This analysis explores the foundational aspects of MIMO-OFDM systems, including their significance in contemporary wireless communication and fundamental characteristics. It is crucial to provide an overview of integrating AI techniques into wireless communication systems, highlighting their potential benefits, such as adaptive optimization, interference mitigation, and intelligent resource allocation. AI techniques applied to MIMO-OFDM systems, such as deep learning for optimizing tasks like channel estimation, precoding, and decoding, and reinforcement learning for adaptive parameter optimization, are discussed. Genetic algorithms for intelligent parameter tuning and swarm intelligence algorithms for optimization tasks specific to MIMO-OFDM are also examined. Evaluation metrics such as bit error rate (BER), throughput, spectral efficiency, and fairness are utilized to assess MIMO-OFDM systems. The comparative analysis contrasts the performance of AI-driven MIMO-OFDM systems with traditional approaches across various metrics, including BER performance under different channel conditions, throughput and spectral efficiency gains, robustness to channel variations and mobility, complexity, computational requirements, and energy efficiency.

CONCLUSION

Integrating artificial intelligence (AI) techniques into multiple input, multiple output, and orthogonal frequency division multiplexing (MIMO-OFDM) systems has shown tremendous potential in enhancing their performance, efficiency, and robustness. Through techniques such as deep learning, reinforcement learning, genetic algorithms, and swarm intelligence, AI-driven approaches offer adaptive optimization, interference mitigation, and intelligent resource allocation capabilities. Comparative analysis reveals that AI-driven MIMO-OFDM systems often outperform traditional methods regarding bit error rate (BER), throughput, spectral efficiency, and robustness to channel variations and interference. However, challenges such as training data requirements, computational complexity, and real-time implementation constraints remain. Nevertheless, these challenges present opportunities for future research and development to further improve the effectiveness and practicality of AI-driven advances in MIMO-OFDM systems, ultimately contributing to the evolution of wireless communication technologies.

REFERENCES

[1]. Hasan, Ahmad, et al. “A Computationally Efficient Least Squares Channel Estimation Method for MIMO-OFDM Systems.” *Proceedings of the 8th International Conference on Computer and Communication Engineering (ICCCE)*, 2021.

[2]. Elnakeeb, Amr, and Urbashi Mitra. “Bilinear Channel Estimation for MIMO OFDM: Lower Bounds and Training Sequence Optimization.” *IEEE Transactions on Signal Processing*, 2021.

[3]. Srivastava, Suraj, et al. "Sparse, Group-Sparse, and Online Bayesian Learning Aided Channel Estimation for Doubly-Selective mmWave Hybrid MIMO OFDM Systems." *IEEE Transactions on Communications*, 2021.

[4]. Chen, Yan, et al. “Channel Estimation and Robust Detection for Iq Imbalanced Uplink Massive MIMO-OFDM With Adjustable Phase Shift Pilots.” *IEEE Access*, 2021.

[5]. Liu, Xiaofeng, et al. “Sparse Channel Estimation via Hierarchical Hybrid Message Passing for Massive MIMO-OFDM Systems.” *IEEE Transactions on Wireless Communications*, 2021.

[6]. Okumuş, Furkan Batuhan, and Erdal Panayırcı. “Channel Estimation Using Optical MIMO OFDM Based LED Index Modulation.” *Proceedings of the 29th Signal Processing and Communications Applications Conference (SIU)*, 2021.

[7]. Korrai, Deergha Rao, et al. “A VLSI Architecture and its FPGA Implementation for MIMO OFDM Channel Estimation.” *Proceedings of the 2nd International Conference for Emerging Technology (INCET)*, 2021.

[8]. Anjana, K. P., and R. Ramanathan. “Impact of Channel Estimation Errors on Secret Key Capacity in MIMO-OFDM Systems.” Proceedings of the International Conference on Communication Information and Computing Technology (ICCICT), 2021.

[9]. Oh, Myeung Suk, et al. "Channel Estimation via Successive Denoising." IEEE Transactions on Wireless Communications, 2021.

[10]. Jiang, Feng, et al. “Channel Smoothing for 802.11ax Beamformed MIMO-OFDM.” IEEE Communications Letters, 2021.