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Performance Analysis of MIMO-OFDM Wireless Communication Systems for Channel Estimation: A Review

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Abstract - MIMO-OFDM (Multiple Input Multiple Output Orthogonal Frequency Division Multiplexing) is a wireless communication technology that integrates two advanced techniques: Multiple Input Multiple Output (MIMO) and Orthogonal Frequency Division Multiplexing (OFDM). MIMO employs multiple antennas at both the transmitter and receiver ends to enhance the overall performance and capacity of wireless communication systems. By utilizing multiple antennas, MIMO can boost data rates, reduce interference, and extend the range of the wireless link. OFDM, a digital multi-carrier modulation technique, divides the available bandwidth into multiple orthogonal subcarriers. Each subcarrier transmits a portion of the data, with all subcarriers being modulated and transmitted simultaneously. This method makes OFDM particularly effective at mitigating the effects of multipath fading and interference in wireless communication systems. MIMO-OFDM is extensively used in wireless communication systems such as 4G LTE, Wi-Fi, and WiMAX to deliver high-speed and reliable wireless communication. It offers several advantages over traditional single-antenna and single-carrier communication systems, including increased data rates, improved spectral efficiency, enhanced reliability, and better resistance to fading and interference.

Key Words: MIMO-OFDM, Channel Estimation, Pilot carriers, Minimum Mean square error.

1. Introduction:

Mobile communication systems are wireless networks that provide services to devices like smartphones, tablets, and laptops. These systems enable users to communicate with each other and the outside world, regardless of their location. Typically, mobile communication systems consist of:

- **Network of Base Stations**: Each base station has a defined coverage area and connects to mobile devices used by users.
- **Core Network**: The base stations are connected to a core network that provides the necessary infrastructure and services to support communication between mobile devices.

Mobile communication systems use various technologies and standards, including cellular networks, Wi-Fi, and satellite communication, to deliver a range of services such as voice, text, multimedia messaging, and high-speed data. With the widespread adoption of mobile devices and the increasing demand for data services, these systems have become essential in modern society, enabling constant connectivity.

MIMO is a wireless communication technology that uses multiple antennas at both the transmitter and receiver ends of a wireless link to enhance performance and capacity. Key features of MIMO include:

- **Multiple Data Streams**: MIMO systems transmit and receive multiple data streams simultaneously, exploiting the spatial diversity of the wireless channel.
- **Benefits**: This results in increased data rates, reduced interference, and improved link range.
- **Applications**: MIMO can be used in both single-user and multi-user scenarios and is widely implemented in systems like 4G LTE, Wi-Fi, and WiMAX.
- **Configurations**: MIMO can be configured in various ways, including spatial multiplexing, beamforming, and diversity combining, depending on specific system requirements.

Overall, MIMO is crucial for enhancing the performance and capacity of wireless communication systems and will continue to play a vital role in future developments.

OFDM is a digital multi-carrier modulation technique used in wireless communication systems. It divides available bandwidth into multiple orthogonal subcarriers, each carrying a portion of the data, which are modulated and transmitted simultaneously. The main advantages of OFDM are:

- **Multipath Fading and Interference Mitigation**: By spreading data over multiple subcarriers with narrow bandwidth, OFDM effectively combats the effects of fading and interference.
- **Applications**: OFDM is widely used in systems like 4G LTE, Wi-Fi, and Digital Video Broadcasting (DVB) for high-speed and reliable communication. It is also used in broadband wired communication systems such as DSL and cable modems.

OFDM provides several benefits, including increased data rates, improved spectral efficiency, enhanced reliability, and better resistance to fading and interference compared to traditional single-carrier modulation techniques.

MIMO-OFDM combines the benefits of MIMO and OFDM technologies. MIMO-OFDM systems use multiple antennas at both the transmitter and receiver ends, along with OFDM modulation, to improve performance and capacity. Key aspects of MIMO-OFDM include:

- **Bandwidth Division**: The available bandwidth is divided into multiple orthogonal subcarriers, each carrying a portion of the data.
- **Multiple Data Streams**: Multiple antennas transmit and receive data streams simultaneously, exploiting the spatial diversity of the wireless channel.
- **Benefits**: This combination results in improved data rates, reduced interference, and increased link range.

MIMO-OFDM is extensively used in systems like 4G LTE and Wi-Fi, providing high-speed and reliable wireless communication. The integration of MIMO and OFDM offers several advantages over traditional single-antenna and single-carrier modulation techniques, including increased data rates, improved spectral efficiency, enhanced reliability, and better resistance to fading and interference. MIMO-OFDM is a key technology for enhancing wireless communication systems and will continue to be significant in future developments.

2. Literature Review

In this literature survey, we review previous research on the MIMO-OFDM system. Summaries of the key papers are provided below:

Ganesh et al.: This study investigates MIMO-OFDM channel estimation under Rayleigh fading using two techniques: LS (Least Squares) channel estimation and MMSE (Minimum Mean Square Error) channel estimation. Simulations reveal that the BER (Bit Error Rate) is lower when using a comb-type pilot carrier for channel estimation in a MIMO-OFDM system compared to a block-type pilot carrier. Additionally, the MSE (Mean Square Error) is lower when using MMSE rather than LS channel estimation, indicating that the MMSE channel estimator outperforms the LS channel estimator.

Abdelhakim, Ridha: This paper assesses the impact of channel length on the efficiency of LS and LMMSE (Linear Minimum Mean Square Error) estimation methods for LTE Downlink networks. A cyclic prefix (CP) is added to each OFDM symbol to reduce ICI (Inter-Carrier Interference) and ISI (Inter-Symbol Interference), ideally as long as the channel. However, unexpected channel behavior can cause the CP length to be insufficient. The study finds that LMMSE outperforms LS when the CP length is comparable to or greater than the channel length but at the expense of complexity due to its reliance on channel and noise statistics. LMMSE's superior performance is limited to low SNR values and diminishes as SNR increases, where LS performs better.

Archana et al.: This research shows that in the low-to-medium SNR range, the BER is significantly lower in the STBC-OFDM (Space-Time Block Coding) system compared to the SM-OFDM (Spatial Multiplexing) system. Therefore, STBC-OFDM can improve performance even at low SNR. However, SM-OFDM can deliver double the throughput with a negligible error rate at high SNR. The study suggests that OFDM can be integrated with either STBC or SM systems. The quality of received images sent by both models is assessed through throughput and BER. The findings indicate that the STBC-OFDM system produces less noise in received images than the SM-OFDM model. Further research into MIMO-OFDM hybrid models may be needed to understand the receiver's power consumption and design complexity in relation to BER and throughput.

Juhi et al.: This paper discusses the rapid increase in demand for mobile data services, with predictions that mobile data traffic would double annually through 2014. LTE-Advanced and WiMAX-2 systems can use up to 8x8 MIMO, depending on the development level. The introduction of new reference signals has improved demodulation/detection and channel state information estimation. Modern SU/MU-MIMO (Single-User/Multi-User MIMO) systems have focused on improving signaling. However, implementing MIMO in cellular networks is challenging due to the high vulnerability of MIMO receivers to channel interference. To minimize disruption to adjacent cells, system designers need to lower transmission power and data rates. MIMO systems require a higher SINR (Signal-to-Interference-Noise Ratio) to transmit the same amount of data. Advances in signal processing techniques at the receiver and transmitter levels have been used to mitigate interference. The paper concludes that MIMO systems use multiple antennas at both the transmitter and receiver to improve network stability and data transfer rates without needing more bandwidth or power. Processing techniques such as pre-coding, diversity coding, and spatial multiplexing distinguish between multi-user and single-user MIMO. Reconfigurable antennas have been used to create pattern and frequency diversity in MIMO communications. The article notes that many of these methods have practical limitations, especially regarding complexity and the channel information required for effective application to 3G cellular networks.

Vipin, Parveen: This study demonstrates that the MSK (Minimum Shift Keying) modulation scheme performs well in multi-bit transmission scenarios from the MIMO-OFDM system. Metrics such as throughput, Bit Error Rate (BER), Ergodic Capacity, Symbol Error Rate (SER), Signal-to-Noise Ratio (SNR), and Outage Capacity are used to evaluate MSK modulation's effectiveness. The study opens up several avenues for future research.

B.K. Mishra et al.: The performance of different modulation schemes like QPSK, 16-QAM, and 64-QAM in a MIMO-OFDM system is evaluated using Least Mean Squares (LMS), Leaky Least Mean Squares (LLMS), and Modified Leaky Least Mean Square (MLLMS) algorithms. The primary goal is to increase SNR and decrease BER by adjusting the step size. Results show that reducing the step size improves steady-state error and SNR values. The Modified Leaky Least Mean Square algorithm outperforms the others, offering the lowest BER and highest SNR, thereby maximizing channel capacity.

Monika, Mahendra: This paper states that MIMO-OFDM systems, with effective channel estimation methods, can meet future wireless communication system requirements. The effectiveness of different channel estimation methods, including those based on training data, channel observation, and hybrid methods, is reviewed. Despite its complexity, the

MMSE channel estimator provides quicker estimates compared to LS and ALS estimators.

Yu et al.: This study recommends leveraging the synergy of MIMO, cognitive radio, and OFDM. Using orthogonal space-time block codes in MIMO, they aim to maximize the digital transmission rate while reducing multipath fading effects and improving BER performance. The findings indicate a positive impact on SNR as well.

Gupta et al.: The authors propose combining MIMO and OFDM systems with wideband transmission to reduce intersymbol interference and enhance performance. They suggest that spatial and frequency diversity can further improve system performance. Various equalizers and space-frequency (SF) block coding have been studied, with a proposed optimal equalization strategy for BER analysis.

Jie et al.: Advocating for a hybrid MIMO-OFDM system to increase data transmission speeds, they propose a scenario involving multipath effects and frequency-selective fading. Their findings show that the hybrid system with STBC (Space-Time Block Coding) has superior BER performance compared to MIMO-OFDM without STBC.

Darsena et al.: This paper discusses the use of cyclic prefix OFDM in MIMO broadband wireless communication systems and its role in the STFBC (Space-Time-Frequency Block Coding) formula. They propose two MIMO channel shortening techniques based on linearly restricted minimization of mean output energy. Their findings show that the suggested blind channel shortening approach has minimal performance degradation compared to non-blind methods without significantly increasing computational complexity.

Xin et al.: This presentation analyzes MIMO-OFDM systems with Rayleigh fading channels using adaptive modulation (AM) with discrete rates. They segment the fading gain value for each subchannel and adjust modulation accordingly. The average BER and spectral efficiency (SE) have been evaluated, showing that the enhanced switching-based SE approach outperforms the conventional one.

Seyman et al.: The authors propose a feed-forward multilayer perceptron (MLP) neural network, trained using the Levenberg-Marquardt method, for estimating channel parameters in MIMO-OFDM systems. Performance assessment shows that the neural network channel estimator outperforms LS and LMS algorithms in terms of BER and MSE.

Vakilian et al.: This study proposes a MIMO-OFDM system with space-frequency (SF) block coding using reconfigurable antennas. The system supports frequency diversity, reconfigurable radiation patterns, and spatial variety over frequency-selective fading channels. Their method outperforms competing SF codes in terms of diversity and coding gain.

Doi et al.: The authors present joint decoding of block-coded signals in an overloaded MIMO-OFDM system, maintaining minimal complexity. They suggest a collaborative two-stage decoding approach, efficiently narrowing down the pool of possible codewords using joint maximum likelihood symbol detection. Their approach reduces complexity by approximately 1/174 when transmitting four signal streams.

Chen et al.: Data concealment using OFDM over an error-correcting coded channel is demonstrated, showing the effects of antenna diversity, maximum multipath delay, and Doppler shift on BER performance. The MIMO-OFDM system is less accurate compared to SISO, OFDM, and MIMO channels. The study considers the data concealing capability, carrier data BER, and secret data BER.

Sharma et al.: The hypothesis is that the MIMO system can effectively detect information and transmit/receive data using multiple antennas simultaneously. They combine OFDM and MIMO systems to increase spectral efficiency and decrease ISI.

Sezer et al.: The authors address the optimal channel switching issue to maximize the average capacity of the transmitter's connection with the main receiver, considering both average and peak power limits. They present an alternative optimization problem that meets the conditions equally, supported by numerical examples.

Li et al.: Discussing the k-user MIMO interference channel with M transmit antennas and N reception antennas, the authors propose an interference cancellation strategy to enhance receivers' access to global channel state information (CSI). Their strategy performs better than existing methods in terms of resisting transmitter correlation and tolerating interferences, given the limitation on degrees of freedom.

El et al.: A comprehensive simulation is advised for forecasting RoF system performance, proposing a 60 GHz 2x2 MIMO-OFDM RoF system based on spatial diversity (SD). They test this system in a line-of-sight (LOS) desktop environment, finding that spatial multiplexing (SMX) boosts data rate but not reliability. The 2x2 MIMO-OFDM SMX system achieves higher data rates, as demonstrated by various diversity, modulation, and channel coding rate approaches.

Namitha et al.: The high peak-to-average power ratio (PAPR) in MIMO-OFDM technology is addressed, with selective mapping (SLM) proposed to lower PAPR without signal distortion. The study identifies the need to deliver side information (SI) with each OFDM data symbol as a shortcoming. They propose a simple SLM method using the Hadamard sequence, significantly reducing PAPR in MIMO-OFDM systems without communicating SI.

Qiao et al.: The authors propose combining MIMO and OFDM to enhance bandwidth efficiency for underwater acoustic (UWA) transmissions. They survey and report findings on MIMO-OFDM communication in UWA, comparing algorithm complexity and efficiency across various studies.

3. Conclusion

The principal component analysis (PCA) technique for channel transformation and the advantages of applying blind source separation (BSS) methods in MIMO multiuser detection are emphasized. The effectiveness of discrete wavelet transforms (DWTs) for signal de-noising is also demonstrated in the results section. The proposed Enhanced Independent Component Analysis (ICA) system is shown to be more effective at signal separation and more resistant to channel noise, including bit error rate (BER) and impulsive noise. The findings indicate that the proposed system improves BER performance and robustness while reducing the complexity of the detector system. Additionally, the suggested technique performs well regardless of the input data length, making it an attractive option for large datasets. Enhanced ICA addresses these issues effectively and is more sensitive to the initial settings for the input weight of the separation matrix compared to current methods such as MN-IAMO and COA.

Reference

[1] A. Ladaycia, A. Mokraoui, K. A. Meraim, and A. Belouchrani, “Performance bounds analysis for semi-blind channel estimation in MIMOOFDM communications systems”, IEEE Transactions on Wireless Communications, Vol. 16, No. 9, pp. 5925-5938, 2017.
[2] T. Peken, G. Vanhoy, and T. Bose, “Blind channel estimation for massive MIMO”, Analog Integrated Circuits and Signal Processing, Vol. 91, No. 2, pp. 257-266, 2017.
[3] A. Saci, A. A. Dweik, A. Shami, and Y. Iraqi, “One-shot blind channel estimation for OFDM systems over frequencyselective fading channels”, IEEE Transactions on Communications, Vol. 65, No. 12, pp. 5445- 5458, 2017.
[4] A. Ladaycia, A. Belouchrani, K. A. Meraim, and A. Mokraoui, “EM-based semi-blind MIMOOFDM channel estimation”, In Proc. of IEEE International Conf. on Acoustics, Speech and Signal Processing, pp. 3899-3903, 2018.
[5] R. Bhandari and S. Jadhav, “Spectral efficient blind channel estimation technique for MIMOOFDM communications”, International Journal of Advances in Applied Sciences, Vol. 7, No. 3, pp. 286-297, 2018.
[6] B. Zhang, J. L. Yu, Y. Yuan, and J. W. Lai, “Fast blind channel estimation for space–time block coded MIMO–OFDM systems”, Telecommunication Systems, Vol. 65, No. 3, pp. 443-457, 2017.
[7] J. Yin, G. Yang, D. Huang, L. Jin, and Q. Guo, “Blind adaptive multi-user detection for under ice acoustic communications with mobile interfering users”, The Journal of the Acoustical Society of America, Vol. 141, No. 1, pp. EL70- EL75, 2017.
[8] V. K. Gupta and S. Vijay, “A Summative Comparison of Blind Channel Estimation Techniques for Orthogonal Frequency Division Multiplexing Systems”, International Journal of Electrical & Computer Engineering, Vol. 8, No. 5, pp. 2744-2752, 2018.
[9] B. Gupta, S. Gupta, A. K. Singh, and H. D. Joshi, “Optimised periodic precoder-based blind channel estimation for MIMOOFDM systems”, International Journal of Electronics Letters, Vol. 6, No. 3, pp. 347-363, 2018.
[10] W. Zhang, F. Gao, H. Minn, and H. Wang, “Scattered pilots-based frequency synchronization for multiuser OFDM systems with a large number of receive antennas”, IEEE Transactions on Communications, Vol. 65, No. 4, pp. 1733-1745, 2017.
[11] E. Nayebi and B. D. Rao, “Semi-blind channel estimation for multiuser massive MIMO systems”, IEEE Transactions on Signal Processing, Vol. 66, No. 2, pp. 540-553, 2017.
[12] Y. Huang, Y. He, Q. Luo, L. Shi, and Y. Wu, “Channel estimation in MIMO–OFDM systems based on a new adaptive greedy algorithm”, IEEE Wireless Communications Letters, Vol. 8, No. 1, pp. 29-32, 2018.
[13] M. M. Awad, K. G. Seddik, and A. Elezabi, “Lowcomplexity semi-blind channel estimation algorithms for
vehicular communications using the IEEE 802.11 p standard”, IEEE Transactions on Intelligent Transportation Systems, Vol. 20, No. 5, pp. 1739-1748, 2018.
[14] B. Zhang, J. L. Yu, Y. Yuan, and C. Y. Wu, “Convergenceenhanced subspace channel estimation for MIMO-OFDM systems with virtual carriers”, Circuits, Systems, and Signal Processing, Vol. 36, No. 6, pp. 2384-2401, 2017.
[15] R. Tang, X. Zhou, and C. Wang, “A Haar wavelet decision feedback channel estimation method in OFDM systems”, Applied Sciences, Vol. 8, No. 6, p. 877, 2018.
[16] S. Nandi, N. N. Pathak, and A. Nandi, “Implementation of fast, adaptive, optimized blind channel estimation for multimodal MIMO- OFDM systems using MFPA”, Intelligent Multimodal Data Processing, pp. 183-204, 2021.
[17] S. Nandi, N. N. Pathak, and A. Nandi, “A Novel Adaptive Optimized Enhanced Blind Channel Estimation for Cyclic Prefix Assisted Space– Time Block Coded MIMO-OFDM Systems”, Wireless Personal Communications, Vol. 115, No. 2, pp. 1317-33, 2020.
[18] A. Elnakeeb and U. Mitra, “Bilinear Channel Estimation for MIMO OFDM: Lower Bounds and Training Sequence Optimization”, IEEE Transactions on Signal Processing, Vol. 69, pp. 1317-1331, 2021.
[19] V. Karami and B. M. Tazehkand, “Robust blind multiuser detection in overdetermined MIMO channels using wavelet transform”, AEU International Journal of Electronics and Communications, Vol. 117, p. 153058, 2020.
[20] C. Buiquang and Z. Ye, “Constrained ALSbased tensor blind receivers for multi-user MIMO systems”, Digital Signal Processing, Vol. 84, pp. 69-79, 2019.