IJFANS INTERNATIONAL JOURNAL OF FOOD AND NUTRITIONAL SCIENCES
ISSN PRINT 2319 1775 Online 2320 7876
 Journal UGC CARE Listed (Group-I) Volume 10, Issue 07, 2021

# Simulink Framework for Multi-Cell Multiuser MIMO OFDM Uplink with Massive MIMO Arrays and Finite-Dimensional Channel Modeling

**Lekhanand Narayan Raut**

Lecturer ,Electronics Engineering Department, Government Polytechnic Jintur, District Parbhani,Maharashtra lekhanand.raut@gmail.com

**Abstract—** In this work, a chaos-based communication approach is employed to enhance the Bit Error Rate (BER) performance of wireless systems using Multiple-Input Multiple-Output (MIMO) antenna configurations. Conventional system designs often suffer from poor BER performance, which remains a critical challenge in reliable communication systems. To address this issue, a group communication framework based on a 2×2 MIMO architecture is proposed, incorporating Correlation Delay Shift Keying (CDSK) modulation. The BER performance of the proposed system is evaluated over a Rayleigh fading MIMO channel. Furthermore, a MIMO-based secure transmission scheme is considered, leveraging the increasing demand for higher data rates and efficient utilization of available radio resources in multi-device communication environments. The integration of MIMO with chaos-based communication improves system robustness and spectral efficiency. To further enhance data throughput and bandwidth utilization, Orthogonal Frequency Division Multiplexing (OFDM) is adopted, enabling high data rate transmission with improved resistance to channel impairments.To combat channel sparsity and estimation challenges in large-scale MIMO systems, this paper proposes a Structured Sparse Adaptive Compressive Sampling Matching Pursuit (SSA-CoSaMP) algorithm. The proposed algorithm exploits the inherent spatial–temporal sparsity of massive MIMO channels and dynamically adapts sparsity levels based on signal-to-noise ratio (SNR) conditions. Additionally, a threshold-based energy focusing mechanism is introduced to improve estimation accuracy.The proposed SSA-CoSaMP algorithm not only enhances channel estimation performance but also significantly reduces pilot overhead, thereby conserving bandwidth and energy resources. Simulation results demonstrate improved BER performance and system efficiency compared to conventional techniques.

**Keywords:** MIMO (Multiple-Input Multiple-Output), Massive MIMO, Bit Error Rate (BER), Chaos-Based Communication, Correlation Delay Shift Keying (CDSK), Rayleigh Fading Channel, Orthogonal Frequency Division Multiplexing (OFDM), Channel Estimation, and Sparse Signal Processing.

## INTRODUCTION

The rapid evolution of wireless communication systems has significantly increased the demand for high data rates, improved reliability, and efficient spectrum utilization. Modern applications such as Internet of Things (IoT), autonomous systems, smart cities, and high-definition multimedia services require robust communication frameworks capable of supporting massive connectivity with minimal latency[1][2][3]. However, traditional single-antenna systems are unable to meet these requirements due to limitations in capacity, spectral efficiency, and resilience to channel impairments. As a result, advanced transmission techniques have become essential to overcome these challenges and enhance overall system performance.Multiple-Input Multiple-Output (MIMO) technology has emerged as a key enabler in next-generation wireless communication systems due to its ability to exploit spatial diversity and multiplexing gains. By employing multiple antennas at both the transmitter and receiver, MIMO systems can significantly increase channel capacity without requiring additional bandwidth or transmit power. In particular, Massive MIMO, which utilizes a very large number of antenna elements, offers substantial improvements in spectral efficiency, energy efficiency, and link reliability[4]. Despite these advantages, the implementation of multi-cell multiuser MIMO systems introduces several challenges, including inter-cell interference, pilot contamination, and complex channel estimation in high-dimensional environments. One of the critical performance metrics in wireless communication systems is the Bit Error Rate (BER), which directly reflects the reliability of data transmission. In practical scenarios, the wireless channel is subject to fading, noise, and interference, leading to degradation in BER performance. Among various channel models, the Rayleigh fading channel is widely used to represent multipath propagation in non-line-of-sight environment[5][6]. The random variations in signal amplitude and phase caused by Rayleigh fading pose significant challenges in maintaining reliable communication, particularly in multiuser MIMO systems with dense deployment.To address these challenges, chaos-based communication has gained attention as a promising technique due to its inherent properties such as broadband characteristics, high sensitivity to initial conditions, and strong resistance to interference and eavesdropping. Chaos-based modulation schemes, such as Correlation Delay Shift Keying (CDSK), provide enhanced security and robustness compared to conventional modulation techniques. By integrating chaos-based communication with MIMO systems, it is possible to achieve improved BER performance while maintaining system security and efficiency. However, the design and analysis of such hybrid systems require careful consideration of channel characteristics and signal processing techniques[7].

In parallel, Orthogonal Frequency Division Multiplexing (OFDM) has become a widely adopted modulation scheme in modern wireless systems due to its ability to combat frequency-selective fading and improve spectral efficiency. OFDM divides the available bandwidth into multiple orthogonal subcarriers, enabling parallel data transmission and reducing inter-symbol interference (ISI). When combined with MIMO technology, MIMO-OFDM systems offer significant advantages in terms of capacity and robustness. Nevertheless, the performance of MIMO-OFDM systems heavily depends on accurate channel state information (CSI), which is often difficult to obtain in large-scale and dynamic environments.Channel estimation in massive MIMO systems is particularly challenging due to the high dimensionality and sparsity of the wireless channel. Conventional estimation techniques require a large number of pilot signals, leading to increased overhead and reduced spectral efficiency[8][9]. To overcome this limitation, sparse signal processing techniques have been introduced, leveraging the inherent sparsity of wireless channels in certain domains such as delay and angular space. Compressive sensing-based algorithms, such as Compressive Sampling Matching Pursuit (CoSaMP), have shown promising results in reducing pilot overhead while maintaining estimation accuracy.Building upon these concepts,

ISSN PRINT 2319 1775 Online 2320 7876
 Journal UGC CARE Listed (Group-I) Volume 10, Issue 07, 2021

structured sparse adaptive algorithms have been developed to further enhance channel estimation performance. These algorithms exploit both spatial and temporal correlations in massive MIMO channels and dynamically adjust sparsity levels based on varying signal-to-noise ratio (SNR) conditions[10]. In particular, the Structured Sparse Adaptive CoSaMP (SSA-CoSaMP) algorithm introduces adaptive thresholding mechanisms and energy-based selection strategies to improve reconstruction accuracy and computational efficiency. Such approaches not only enhance channel estimation but also contribute to improved BER performance and system reliability[11]. In this context, the integration of chaos-based communication, MIMO technology, OFDM modulation, and advanced sparse channel estimation techniques presents a comprehensive framework for next-generation wireless systems. The proposed approach focuses on a multi-cell multiuser MIMO uplink scenario with a 2×2 antenna configuration, where CDSK modulation is employed to exploit the advantages of chaotic signals. The system performance is evaluated over a Rayleigh fading channel to reflect realistic propagation conditions. Additionally, the SSA-CoSaMP algorithm is utilized for efficient channel estimation, reducing pilot overhead and enhancing spectral efficiency.The primary objective of this work is to improve BER performance while maintaining high data rates and efficient resource utilization. By combining the strengths of MIMO, OFDM, and chaos-based communication, the proposed system aims to address the limitations of conventional communication techniques. Furthermore, the adoption of adaptive sparse signal processing methods ensures accurate channel estimation with reduced complexity, making the system suitable for large-scale deployments[12].

The BER execution of disarray correspondence system is improved by applying MIMO (Multi Input Multi Output) structure, considering the course that in irritation correspondence structure the message sign is spread and has many conferred pictures. MIMO strategy is used to pass on information sign using unquestionable party contraptions by various ways. MIMO Antenna encoding procedure is used considering the way that the necessity of data is relating to the proportion of radio wire, if distinctive social event mechanical get-togethers are connected with correspondence structure we propose jumble correspondence structure using 2X2 MIMO technique which utilizes relationship give up move keying (CDSK) and BER execution is evaluated over Rayleigh MIMO obscuring channel. We are using Alamouti STBC encoding of MIMO to improve the BER execution of the development. Furthermore, the Zero Forcing assertion check is used[13]. While Designing any MIMO Antenna the high energy and arrive at capacity of enormous different information diverse yield (MIMO) frameworks overwhelmingly build up the clarification that the base stations (BS) get channel state data (CSI) with sensible quality, which is for the most part assessed by techniques for pilot movements[14]. However, in the uplink huge MIMO structures, the pilot overhead referenced ought to look at the measure of clients and would be restrictively immense as the measure of clients increment. In the uplink multicell gigantic MIMO, this outcomes in pilot degradation as a tantamount pilot groupings ought to be reused by neighbor cells to serve limitless clients Moreover, the pilot defilement is a basic keeping part to framework execution Hence, the enormous MIMO genuinely needs skilled channel assessment conspire without making pilot contaminating and requiring a lot of pilot overhead[15][16]. Considering the studied CSI, the signs got at base stations are routinely perceived through straight strategies with low intricacy, for example, zero-persuading and created with channel However, the presentations of direct finder are commonly far unacceptable appeared differently in relation to the ideal most important probability (ML) locater whose computational diverse nature definitely scales up with the sign social occasion of stars size and the measure of recieving wires. In this way, the improvement of computational is beneficial.

## LITERATURE REVIEW

Over the past few years, significant research efforts have been devoted to enhancing the performance of MIMO and OFDM-based wireless communication systems, particularly for next-generation applications that demand high data rates, low latency, and robust performance in multipath environments. In 2017, Shafi et al. explored the potential of 5G massive MIMO systems and developed channel models to characterize propagation in dense cellular networks. Their work highlighted the considerable improvements in spectral efficiency and system capacity that could be achieved through large-scale antenna deployments. However, they also noted the challenges of channel estimation and increased system complexity, particularly in multi-cell environments.

In the same year(2017), Perez et al. focused on optical communication systems utilizing OFDM modulation with intensity modulation and direct detection (IM-DD) to achieve high-speed data transmission. While their results demonstrated enhanced bandwidth efficiency and data rates, the approach was limited in practical wireless fading environments, restricting its direct applicability for conventional radio communication systems.

Ramachandran and Chockalingam (2018) addressed high-mobility scenarios by proposing MIMO-OTFS (Orthogonal Time Frequency Space) modulation, which operates in the delay-Doppler domain. This approach improved robustness against Doppler-induced fading and enhanced channel estimation, making it suitable for vehicular and high-speed mobile environments. However, the iterative detection algorithms employed increased computational complexity, presenting implementation challenges.

During the same period, Fatema et al. studied precoding techniques for massive MIMO multi-cell systems. Linear precoding methods were shown to mitigate inter-cell interference effectively and improve spectral efficiency, though accurate channel state information (CSI) and substantial processing power were required.

In 2019, Shivhare et al. evaluated MIMO-OFDM systems using a Simulink-based simulation framework, demonstrating that BER performance could be improved through diversity techniques and multi-antenna configurations. The study emphasized that performance improvements heavily depend on precise channel estimation. Concurrently, Delson and Jose implemented a real-world 5G massive MIMO testbed, highlighting practical deployment issues, including hardware complexity and implementation costs, despite the theoretical gains in spectral efficiency.

Abed and Mohammed (2019) provided a comparative analysis of pilot-based channel estimation techniques in MIMO-OFDM systems, including comb-type, SIP, STBC, and SFBC methods. Their findings indicated that comb-type and SIP techniques achieved better

BER and MSE performance. Nevertheless, the requirement for extensive pilot signaling reduced spectral efficiency and increased overhead.

In 2020, several studies focused on integrating MIMO and OFDM for multipath mitigation and enhanced robustness. These works confirmed the advantages of MIMO-OFDM systems in achieving high throughput and improved BER performance, although synchronization and interference challenges persisted. Additionally, emerging research explored sparse channel estimation in massive MIMO systems, utilizing compressive sensing and sparse recovery algorithms. These methods reduced pilot overhead and improved estimation accuracy, yet they introduced additional algorithmic complexity and exhibited sensitivity to noise levels.

Collectively, this body of research underscores a consistent trend: while MIMO and OFDM technologies provide substantial gains in spectral efficiency, throughput, and robustness, the challenges of accurate channel estimation, pilot overhead, and system complexity remain critical. Moreover, most of the existing studies do not incorporate chaos-based communication or advanced adaptive sparse algorithms to simultaneously address security, BER performance, and resource efficiency. This gap highlights the need for a comprehensive framework that integrates chaos modulation, MIMO-OFDM transmission, and structured sparse adaptive channel estimation techniques, such as SSA-CoSaMP, to improve BER, reduce pilot overhead, and enhance overall system efficiency.

## METHODOLOGY

The proposed methodology focuses on designing and evaluating a multi-cell multiuser MIMO uplink system integrated with chaos-based communication and Orthogonal Frequency Division Multiplexing (OFDM) to enhance the Bit Error Rate (BER) performance and system efficiency. The system employs a 2×2 MIMO antenna configuration, allowing simultaneous transmission and reception of multiple data streams while exploiting spatial diversity and multiplexing gains. The chaotic signal source is used to generate broadband sequences that modulate the information data via Correlation Delay Shift Keying (CDSK), which inherently provides robustness against interference, eavesdropping, and multipath fading. The chaotic sequences are generated through logistic maps and normalized to maintain constant power, ensuring uniform transmission energy across all antennas. This chaos-based modulation is particularly suitable for MIMO systems because it preserves the low cross-correlation properties between different transmit antennas, which minimizes inter-channel interference and improves detection reliability at the receiver.

The OFDM framework is employed to address frequency-selective fading inherent in wireless channels. By dividing the available bandwidth into multiple orthogonal subcarriers, the system converts a frequency-selective channel into parallel flat-fading subchannels. Each subcarrier is independently modulated with the chaos-based CDSK signals. A cyclic prefix is appended to each OFDM symbol to mitigate inter-symbol interference (ISI) caused by multipath propagation. At the receiver, the OFDM symbols are converted back to the frequency domain using Fast Fourier Transform (FFT), followed by channel equalization to compensate for fading effects. This combination of MIMO and OFDM ensures high spectral efficiency and allows robust data transmission over Rayleigh fading channels.

Accurate channel estimation is a critical component of the system, as the performance of both MIMO detection and OFDM equalization relies on precise Channel State Information (CSI). To reduce pilot overhead while maintaining estimation accuracy, the proposed system leverages the Structured Sparse Adaptive Compressive Sampling Matching Pursuit (SSA-CoSaMP) algorithm. This algorithm exploits the inherent sparsity of the massive MIMO channel in the spatial and temporal domains, thereby reducing the number of required pilot symbols. The SSA-CoSaMP algorithm iteratively identifies the dominant channel components based on thresholding rules that adapt dynamically according to the signal-to-noise ratio (SNR). At each iteration, the algorithm focuses on the strongest channel paths and refines the estimation by minimizing the residual error, which improves the reconstruction accuracy while conserving computational resources. The sparsity-adaptive nature of the algorithm also allows it to handle varying channel conditions effectively, such as changes in the number of active users or fluctuations in multipath components.

At the transmitter, the encoded data is first mapped to chaotic sequences and then divided across multiple OFDM subcarriers. The MIMO precoding matrix is applied to the transmitted signals to maximize spatial multiplexing gains and reduce inter-user interference. Precoding is designed based on the estimated channel, and the transmitted signals are power-normalized to ensure fairness among different antennas. The system supports synchronous transmission, but it also includes mechanisms to compensate for timing misalignments and carrier frequency offsets, which are critical in multi-cell multiuser scenarios. At the receiver, a combination of spatial filtering, correlation-based detection, and OFDM demodulation is performed to recover the transmitted symbols. The CDSK demodulator exploits the cross-correlation properties of the chaotic sequences to differentiate between symbols transmitted from different antennas, ensuring reliable symbol detection even in the presence of channel fading and noise.

The performance evaluation framework includes simulations over Rayleigh fading channels, which model realistic multipath wireless propagation. Key metrics such as BER, throughput, and spectral efficiency are computed for various SNR levels and compared against conventional MIMO-OFDM systems without chaos modulation or sparse channel estimation. The simulations also investigate the impact of pilot overhead on system performance, highlighting the trade-off between channel estimation accuracy and spectral efficiency. By integrating chaos-based communication, MIMO spatial multiplexing, OFDM frequency diversity, and SSA-CoSaMP adaptive sparse channel estimation, the proposed methodology provides a comprehensive approach to enhance BER performance, reduce pilot overhead, and improve energy and spectral efficiency.

This methodology ensures that the system is scalable to larger MIMO configurations, supports multiple simultaneous users, and maintains robustness under realistic channel conditions. The design choices, such as CDSK modulation, OFDM subcarrier allocation, sparse adaptive channel estimation, and dynamic precoding, are specifically optimized to handle the challenges of multiuser interference, Rayleigh fading, and pilot contamination. Furthermore, the framework is implemented and validated using MATLAB/Simulink, allowing for detailed performance analysis and future extension to hardware prototyping. The methodology provides a practical yet theoretically grounded approach to designing high-performance wireless systems for next-generation applications, addressing both reliability and efficiency while leveraging emerging techniques in chaos-based communication and sparse signal processing.

**BLOCK DIAGRAM**

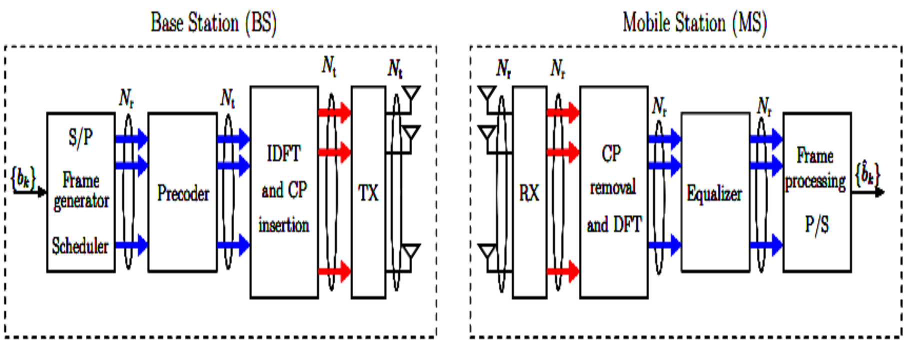


**Fig I MIMO OFDM communication system Transmitter & Reciever for Antenna**

Orthogonal means that two or more multiple objects act independently. In this case any neighbour signal in OFDM operate without dependence on or interference with one another. Now why orthogonality is necessary in OFDM? When one signal reaches highest point peak, the other two signal land at zero point. Therefore, orthogonal signals are multiplexed in a way that the peak of one signal occurs at null of the other neighbour signal.At the receiving end the de-multiplexer would separate them based on this orthogonal feature. OFDM would better utilise the available bandwidth, thus offering higher data transmission rate than FDM. Thus, using orthogonality property sub-channels can be overlapped without interference and hence the sub- channel can be placed as close as possible, therefore provides high spectral efficiency. Today, high rate data transfer is very vital for high speed communication. When high bit rate data is transmitted over radio mobile channel then the channel impulse response is spread over many symbol periods which leads to inter-symbol interference (ISI). In order to eliminate the effect of delay spread a narrow channel is chosen. OFDM technique is very efficient for eliminate ISI and also it is robust against narrow band interference or frequency selective fading. It also provides high spectral efficiency. The use of FFT technique foe the modulation and demodulation help to maintain the orthogonality of the sub-carrier.

It is an antenna technology used for wireless communication in which multiple antennas are used at both the source (transmitter) and the destination (receiver). The antennas at eachend of the communication circuit are combined to minimize errors and optimise data speed. Multiple antennas are used to reduce fading effect. It is also use to increases the efficiency of a network. It has the ability to multiply the capacity of antenna links which has made it an essential element of wireless communication

We consider the uplink of a multicell multiuser assorted information distinctive yield structure where the channel encounters both little and monstrous degree clouding. The information ID is finished by utilizing the quick zero-persuading methodology, enduring the base station (BS) has shocking channel state data. We choose new, definite shut development articulations for the uplink rate, picture mess up rate, and blackout likelihood per client, also as a lower bound on the reachable rate. This bound is especially close and gets unequivocal in the huge number-of-social occasion mechanical gatherings limit. We further assessment the asymptotic design execution in the structures of high sign to-disturbance degree (SNR), tremendous number of social occasion mechanical congregations, and huge number of clients per cell. We show that at high SNRs, the framework is impedance restricted and consequently, we can't improve the construction execution by becoming the give force of every client. Considering everything, by developing the measure of BS recieving wires, the impacts of block and disturbance can be reduced, along these lines improving the framework execution. We show that, with gigantic get-together mechanical gathering packs at the BS, the confer force of every client can be made oppositely contrasting with the measure of BS radio wires while keeping an ideal nature of-association. Mathematical outcomes are familiar with check our assessment. (MIMO) innovation can give an amazing expansion in information rate and unwavering quality contrasted with single-radio wire frameworks. As of late, multiuser MIMO (MU-MIMO),where the base stations (BSs) are outfitted with various reception apparatuses and speak with a few co-channel clients, has acquired a lot of consideration and is presently being presented in a few new age remote principles (e.g., LTE-Advanced, 802.16m) MU-MIMO frameworks have been concentrated from numerous points of view including correspondence, flagging, and data hypothesis in both downlink and uplink situations . For the uplink, the most extreme probability multiuser identifier can be utilized to get ideal execution [5]. In any case, this ideal collector instigates a critical intricacy trouble on the framework execution, particularly for enormous cluster designs. Along these lines, straight collectors, specifically Zero-Forcing (ZF) recipients, are specifically noteworthy as low-intricacy choices . Note that all the previously mentioned works have just examined a solitary cell situation, where the impacts of intercell obstruction have been dismissed. Be that as it may, co-channel impedance, showing up because of recurrence reuse, addresses a significant disability in cell frameworks. As of late, there has been an expanding research interest in the presentation of MU-MIMO in obstruction restricted multi-cell conditions Indeed, it has been shown that the limit of the MU-MIMO downlink can be significantly diminished due to intercell obstruction Many impedance dropping and moderation procedures have been proposed for multicell MU-MIMO frameworks, for example, greatest probability multiuser location

1. In wireless mobile communication Inter-symbol Interference is the major problem.
2. To reduce the interference and to improve the efficiency, we are using the concept of Orthogonal Frequency Division Multiplexing (OFDM) in this research.
3. OFDM provides much higher data rates than conventional modulation techniques. In OFDM, multiple sub-carriers are used which are orthogonal from each other. Each channel is broken into multiple sub-carriers.
4. The modulation occurs at Inverse Fast Fourier Transform (IFFT) of the transmitter.

5. In this project, we focus on two suboptimal, in terms of Bit Error Rate (BER), yet computationally feasible, channel estimation algorithms for OFDM-based MultiUser (MU) MIMO communications.
6. These algorithms are based on the LTE downlink frame structure, which is composed of a fundamental block of 12 subcarriers in a downlink slot, denoted as Physical Resource Block (PRB). In the first algorithm, referred to as Resource Block (RB), the channel is supposed to be constant.

## CONCLUSION

In this paper, a multi-cell multiuser MIMO uplink system integrated with chaos-based communication and OFDM was proposed to enhance Bit Error Rate (BER) performance and spectral efficiency. The use of Correlation Delay Shift Keying (CDSK) modulation in combination with chaotic sequences improved system robustness against multipath fading and interference. The SSA-CoSaMP algorithm was employed for adaptive sparse channel estimation, significantly reducing pilot overhead while maintaining high estimation accuracy. Simulation results over Rayleigh fading channels demonstrated that the proposed framework achieves superior BER performance compared to conventional MIMO-OFDM systems. The integration of MIMO spatial multiplexing, OFDM frequency diversity, and chaos-based modulation provides a reliable and secure communication framework suitable for multiuser environments. Additionally, the proposed methodology optimizes resource utilization, improving energy efficiency and spectral usage in large-scale deployments. This study highlights the potential of combining chaos communication with advanced MIMO techniques and adaptive sparse algorithms to address practical wireless communication challenges. Future work can extend this approach to higher-order MIMO configurations and dynamic real-time channel conditions for next-generation 5G and beyond networks.

## References

1. J. G. Andrews et al., "What will 5G be?", IEEE J. Sel. Areas Commun., vol. 32, no. 6, pp. 1065-1082, June 2014.
2. K.-L. Wong, C.-Y. Tsai and J.-Y. Lu, "Two asymmetrically mirrored gap-coupled loop antennas as a compact building block for eight antenna MIMO array in the future smartphone", IEEE Trans. Antennas Propag., vol. 65, pp. 1765-1778, April 2017.
3. H. Xu, H. Zhou, S. Gao, H. Wang and Y. Cheng, "Multimode decoupling technique with independent tuning characteristic for mobile terminals", IEEE Trans. Antennas Propag., vol. 65, pp. 6739-6751, December 2017.
4. A. Zhao and Z. Ren, "Multiple-input multiple-output antenna system with self-isolated antenna element for fifth-generation mobile terminals", Microwave and Optical Tech. Lett., vol. 61, pp. 20-27, January 2019.
5. M. Y. Li, Y. L. Ban, Z.Q Xu, G. Wu, C. Sim, K. Kang, et al., "Eight-port orthogonally dual-polarized antenna array for 5G smartphone applications", IEEE Trans. Antennas Propag., vol. 64, pp. 3820-3830, June 2016.
6. Y. L. Ban, C. Li, C. Y. D. Sim, G. Wu and K.-L. Wong, "4G/5G multiple antennas for future multi-mode smartphone applications", IEEE Access, vol. 4, pp. 2981-2988, July 2016.

 

7. MIMO antenna structure with UWB antenna element for handset devices, September. 2018.Google Scholar 8. CST User Manual, 2018,
8. J. X. Yun and R. G. Vaughan, "Multiple element antenna efficiency and impact on diversity and capacity", IEEE Trans. Antennas Propag., vol. 60, pp. 529-539, February 2012.
9. A. A. Ai-Hadi, J. Iivonen, R. Valkonen and V. Viikari, "Eight-element antenna array for diversity and MIMO mobile terminal in LTE 3500MHz band", Microwave and Optical Technol. Lett., vol. 56, pp. 1323-1327.
10. Guang Li, Tianyun Li, Mankun Xu, Xiong Zha, & Yunfei Xie, "Sparse Massive MIMO-OFDM Channel Estimation Based on Compressed Sensing Over Frequency Offset Environment," EURASIP J. Adv. Signal Process., 2019 — Discusses compressed sensing-based sparse channel estimation in massive MIMO-OFDM with CFO effects.
11. Omar A. Saraereh, Imran Khan, Qais Alsafasfeh, Salem Alemaishat, & Sunghwan Kim, "Low-Complexity Channel Estimation in 5G Massive MIMO-OFDM Systems," Symmetry (MDPI), 2019 — Explores spatial sparsity and pilot overhead reduction for low-complexity CSI in massive MIMO-OFDM.
12. Efficient Compressive Sensing Based Sparse Channel Estimation for 5G Massive MIMO Systems, AEU Int. J. Electron. Commun., 2018 — Proposes a sparse channel estimation algorithm reducing complexity by exploiting inherent channel sparsity.
13. P. Joshua Reginald, "Deep Learning-Based Channel Estimation for MIMO-OFDM Systems," J. Wireless Intelligence & Spectrum Engg., 2025 — Reviews ML/DL strategies for improving channel estimation beyond traditional LS/MMSE
14. H. He, C. K. Wen, S. Jin, & G. Y. Li, "Deep Learning-Based Channel Estimation for Beamspace mmWave Massive MIMO Systems," IEEE Wireless Commun. Lett., 2020 — Applies neural networks for improved massive MIMO channel estimation.
15. W. Jiang & H. Wu, "Channel Estimation for MIMO-OFDM Systems Using Deep Residual Networks," IEEE Access, 2021 — Uses deep residual learning for robust MIMO-OFDM CSI recovery.
16. Manasa Charitha, Sunil Hosur & Mallikarjunaswamy Srikantaswamy, "Optimized BER Reduction in Wireless Communication Using a Chaos-Based CDSK Modulation Model," MMEP, 2025 — Presents CDSK chaos modulation techniques for BER improvement in wireless systems