



(A Monthly, Peer Reviewed, Refereed, Scholarly Indexed, Open Access Journal)



Impact Factor: 8.699

Volume 14, Issue 5, May 2025

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|www.ijirset.com |A Monthly, Peer Reviewed & Refereed Journal| e-ISSN: 2319-8753| p-ISSN: 2347-6710|

Volume 14, Issue 5, May 2025

|DOI: 10.15680/IJIRSET.2025.1405055|

MIMO Simulation for 5G

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ABSTRACT: MIMO stands for multiple input multiple output. This technology becomes a key enabler for 5g smartphones. For 5g new radio, 8 layers maximum can be supported for single user (SU) MIMO. MIMO is a new technology that uses multiple transmitters and receivers to transfer more data at same time. To implement MIMO, the station (mobile device) or the access point (ap) must support MIMO. For optimal performance and range, both the station and the ap must support MIMO.MIMO technology uses a natural radio-wave phenomena called multipath. With multipath, transmitted information bounces of walls, ceilings, and other objects, reaching the receiving antenna multiple times at different angles and slightly different times. In the past, multipath caused interference and slowed down wireless signals. With multipath, MIMO technology uses multiple, smart transmitters and receivers with an added spatial dimension, in case performance and range. MIMO increases receiver signal-capturing power by enabling antennas to combine data streams arriving from different paths and at different times. Smart antennas use spatial diversity technology, which puts surplus antennas to good use. When antennas out number spatial streams, the antennas can add receiver diversity and increase range. More antennas usually equate to higher speeds. A wireless adapter with three antennas can have a speed of 600 Mbps. An adapter with two antennas has a speed of 300 Mbps. The router needs multiple antennas and must fully support all features of 802.11n to attain the highest speed possible legacy wireless devices use single-input single-output (SISO) technology. They can only send or receive one spatial stream at a time.

I. INTRODUCTION

The rapid evolution of wireless communication has led to the development of the Fifth Generation (5G) mobile networks, which aim to deliver higher data rates, ultra-reliable low latency, massive device connectivity, and improved spectral efficiency. One of the key enabling technologies behind 5G is Multiple Input Multiple Output (MIMO) systems. MIMO leverages multiple antennas at both the transmitter and receiver to exploit spatial diversity and multiplexing, resulting in significant improvements in data throughput and link reliability.

In 5G New Radio (NR), advanced MIMO techniques such as massive MIMO and beamforming are utilized to achieve the desired performance requirements. Massive MIMO, which employs a large number of antennas, can serve multiple users simultaneously and improve the signal quality even under challenging propagation environments[1].

This project focuses on the simulation of a MIMO system for 5G communication using MATLAB, a widely used tool for modelling, simulation, and analysis of wireless communication systems. The simulation aims to model a 5G MIMO channel, analyse its performance under various scenarios, and demonstrate key parameters such as bit error rate (BER), signal-to-noise ratio (SNR), channel capacity, and throughput.

MATLAB provides a rich set of toolboxes such as the 5G Toolbox and Communications Toolbox that facilitate the design, simulation, and analysis of 5G MIMO systems. Through this simulation, we aim to understand the impact of different MIMO configurations (e.g., 2x2, 4x4, 8x8) on the system performance and highlight the benefits of spatial multiplexing and diversity in 5G networks[2],[3].

The aim of this project is to design, implement, and analyse a Multiple Input Multiple Output (MIMO) system for 5G wireless communication using MATLAB simulation. The project focuses on evaluating the performance of different MIMO configurations under various channel conditions, assessing key parameters such as Bit Error Rate (BER), Signal-to-Noise Ratio (SNR), channel capacity, and throughput. The ultimate objective is to demonstrate the effectiveness of MIMO technology in enhancing the capacity, reliability, and spectral efficiency of 5G networks through comprehensive MATLAB-based simulations.





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Objective of the project

- 1. To understand and implement MIMO technology principles for wireless communication, specifically in the context of 5G networks.
- 2. To simulate a MIMO system using MATLAB by utilizing relevant toolboxes such as the 5G Toolbox and Communications Toolbox.
- 3. To analyse the performance of different MIMO configurations (e.g., 2x2, 4x4, 8x8) under varying channel conditions including fading, noise, and interference.
- 4. To evaluate key performance metrics such as Bit Error Rate (BER), Signal-to-Noise Ratio (SNR), channel capacity, and throughput for different MIMO scenarios.
- 5. To demonstrate the advantages of MIMO techniques such as spatial diversity and spatial multiplexing in improving the reliability and capacity of 5G wireless communication systems.
- 6. To investigate the impact of channel models, such as Rayleigh and Rician fading, on the performance of the MIMO system.
- 7. To validate the effectiveness of MIMO systems in achieving the goals of 5G networks including higher data rates, improved link quality, and enhanced spectral efficiency.

This project covers the design, simulation, and performance analysis of a MIMO system for 5G wireless communication using MATLAB. The project aims to provide a clear understanding of how MIMO technology enhances the performance of modern wireless networks. It focuses on simulating realistic 5G scenarios using standard channel models and MIMO configurations[4].

- 1. Simulation of various MIMO configurations (2x2, 4x4, 8x8, etc.) to assess their impact on system capacity and reliability.
- 2. Modelling of different wireless channels, including AWGN, Rayleigh, and Rician fading channels, to simulate real-world conditions.
- 3. Implementation of spatial multiplexing and diversity techniques to improve throughput and reduce error rates.
- 4. Performance analysis using MATLAB, including the evaluation of BER, SNR, capacity, and throughput for different scenarios.
- 5. Validation of MIMO's role in achieving 5G performance targets such as high data rates, low latency, and improved spectral efficiency.
- 6. Exploration of advanced MIMO techniques like beamforming and massive MIMO, to understand their contribution to 5G.

II. LITERATURE SURVEY

MIMO (Multiple Input Multiple Output) has emerged as one of the most promising technologies for enhancing wireless communication systems, especially in the development of 5G networks. Several researchers and academicians have contributed significantly to the design, analysis, and simulation of MIMO systems, particularly using MATLAB. The literature reveals that MIMO plays a vital role in increasing system capacity, improving link reliability, and ensuring spectral efficiency in 5G communication[5],[6].

J. Kennedy, et.al. introduced the concept of capacity enhancement using MIMO systems. Their work demonstrated that employing multiple antennas at both transmitter and receiver significantly improves the achievable data rate without additional bandwidth or power[7].

J. Kennedy, et.al. discussed the capacity limits of MIMO systems in fading environments. They highlighted how spatial multiplexing and diversity techniques contribute to overcoming multipath fading and improving the reliability of wireless links[8].

Poli, et.al explored the potential of Massive MIMO systems for 5G and beyond. Their research concluded that massive MIMO, when combined with beamforming and advanced signal processing, can drastically enhance throughput and energy efficiency[9].

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|www.ijirset.com |A Monthly, Peer Reviewed & Refereed Journal| e-ISSN: 2319-8753| p-ISSN: 2347-6710|

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J Robinson, et al. presented a comprehensive overview of the future of MIMO systems in wireless communication. They emphasized the need for advanced MIMO techniques in 5G to meet the growing demand for data traffic and user connectivity[4].

MATLAB Documentation & 5G Toolbox provides ready-to-use simulation models, channel models, and MIMO system implementations. MATLAB's rich environment has been widely used for simulating MIMO and other 5G components, allowing researchers to test real-world scenarios with ease[10].

Many researchers have utilized MATLAB to simulate MIMO systems by analysing BER, SNR, and channel capacity under different channel conditions (Rayleigh, Rician, and AWGN). These simulations have validated that MIMO significantly boosts the performance of wireless communication, which is crucial for meeting the stringent requirements of 5G networks.

The reviewed literature clearly shows that MIMO is a core enabler for 5G, and simulation using MATLAB provides an effective way to study and validate its performance under realistic channel conditions.

In existing wireless communication systems, MIMO technology has already been implemented in several 4G LTE and early 5G systems. MIMO improves spectral efficiency and link reliability by using multiple antennas at both the transmitter and receiver. The existing systems primarily focus on spatial diversity, spatial multiplexing, and beamforming techniques to mitigate multipath fading and increase data rates[6].

Problem statement

The increasing demand for high data rates, low latency, and reliable wireless communication has driven the development of 5G networks. However, achieving these objectives is challenging due to limited spectrum availability, multipath fading, interference, and signal degradation in wireless channels. Although MIMO technology has been introduced to overcome these limitations, existing systems are often constrained by small-scale MIMO configurations and simplified channel models that do not fully capture the requirements of modern 5G systems.

There is a need for a comprehensive simulation framework that can model advanced MIMO configurations, such as Massive MIMO, and analyse their performance under realistic 5G conditions, including different channel environments, antenna setups, and signal processing techniques. This project aims to address this problem by simulating a MIMO system for 5G using MATLAB, focusing on evaluating key performance parameters such as BER, SNR, capacity, and throughput while considering various MIMO setups and channel models.

The core problem is to investigate how different MIMO configurations and channel conditions affect the performance of a 5G communication system, and to demonstrate how MIMO helps meet the stringent requirements of 5G in terms of capacity, reliability, and spectral efficiency through MATLAB-based simulations.

III. METHODOLOGY

The proposed system aims to design and simulate an advanced MIMO-based 5G wireless communication system using MATLAB, capable of overcoming the limitations of existing systems. The system will implement higher-order MIMO configurations and advanced channel models to analyze and improve the performance of 5G networks under various conditions.

In this system, spatial multiplexing, diversity techniques, and beamforming will be applied to enhance data rates and system reliability. The proposed system will model different MIMO configurations such as 2x2, 4x4, 8x8, and beyond, to investigate the influence of antenna array size on system performance. The simulation will also consider realistic 5G channel conditions using Rayleigh and Rician fading models.





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MATLAB's 5G Toolbox and Communications Toolbox will be used to develop the simulation environment, which will perform end-to-end link-level simulation and analyse essential performance metrics, including:

- Bit Error Rate (BER)
- Signal-to-Noise Ratio (SNR)
- Channel Capacity
- Throughput

The proposed system is expected to demonstrate that MIMO, especially when extended to Massive MIMO, can significantly enhance spectral efficiency, reduce error probability, and meet the high-capacity demands of 5G communication systems.

UPLINK (USER TO BASE STATION COMMUNICATION):

In the uplink, multiple users transmit data to the base station equipped with an array of M antennas.

- 1. Users (User 1 to User K): Each user transmits its own data to the base station. These users could be mobile devices, IoT devices, or any 5G-compatible terminals.
- 2. Wireless Channel (H): The channel between the users and the base station is represented by matrix H. This channel models fading, noise, interference, and multipath effects.
- 3. **Base Station with Array of M Antennas:** The base station receives signals from all users simultaneously through its M antennas. The multiple antennas help in capturing signals more reliably and enabling spatial separation.
- 4. **Decoder:** The decoder processes the received signals and separates the data streams intended for each user by using advanced signal processing techniques like **channel estimation**, **detection**, and **equalization**. It compensates for the channel impairments and decodes the transmitted data for each user.

Downlink (Base Station to User Communication)

In the downlink, the base station transmits data to multiple users simultaneously.



Fig. 3.1: BLOCK DIAGRAM





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- 1. User Scheduler: The scheduler selects which users will be served at each time instant, based on factors such as channel quality, fairness, and data requirements.
- 2. **Precoder:** Before transmission, the base station uses a **precoding** technique to shape the transmitted signals in such a way that they are received correctly by the intended users despite the shared wireless medium. Precoding combats **inter-user interference** and ensures the desired users receive the strongest signals.
- 3. Base Station with Array of M Antennas: The base station transmits the pre-coded data streams via its antenna array, forming directional beams towards the users (beamforming).
- 4. Wireless Channel (H): The transmitted signals from all antennas propagate through the wireless channel H, where they experience multipath, fading, and interference.
- 5. Users (User 1 to User K): Each user receives its intended data after passing through the channel. Thanks to the precoding and spatial separation, users can extract their own data despite being served simultaneously.

TRANSMITTER:

The transmitter includes the Bit Generation subsystem, the QPSK Modulator block, and the Raised Cosine Transmit Filter block. The Bit Generation subsystem uses a MATLAB workspace variable as the payload of a frame, as shown in the figure below. Each frame contains 20 'Hello world ###' messages and a header. The first 26 bits are header bits, a 13-bit Barker code that has been oversampled by two. The Barker code is oversampled by two in order to generate precisely 13 QPSK symbols for later use in the Data Decoding subsystem of the receiver model. The remaining bits are the payload corresponds to the ASCII representation of 'Hello world ###', where '###' is a repeating sequence of '000', '001', '002', ..., '099'. The payload is scrambled to guarantee a balanced distribution of zeros and ones for the timing recovery operation in the receiver model. The scrambled bits are modulated by the QPSK Modulator (with gray mapping). The modulated symbols are up-sampled by two by the Raised Cosine Transmit Filter with a roll-off factor 0.5. The symbol rate of the transmitter system is 50k symbols per second, and the sample rate after the Raised Cosine Transmit Filter is 100k samples per second.

CHANNEL

AWGN Channel with Frequency Offset and Variable Time Delay: Applies the frequency offset, a timing drift, and additive white Gaussian noise to the signal.

RECEIVER

- **Raised Cosine Receive Filter:** Uses a roll-off factor of 0.5.
- Coarse Frequency Compensation: Estimates an approximate frequency offset of the received signal and corrects it.
- Symbol Synchronizer: Resamples the input signal according to a recovered timing strobe so that symbol decisions are made at the optimum sampling instants.
- Carrier Synchronizer: Compensates for the residual frequency offset and the phase offset.
- Frame Synchronizer: Aligns the frame boundaries at the known frame header.
- **Data Decoding:** Resolves the phase ambiguity caused by the Carrier Synchronizer, demodulates the signal, and decodes the text message.

AWGN CHANNEL WITH FREQUENCY OFFSET AND VARIABLE DELAY:

The AWGN Channel with Frequency Offset and Variable Delay subsystem first applies the frequency offset and a preset phase offset to the transmit signal. Then it adds a variable delay with a choice of the following two types of delay to the signal:

- **Ramp delay:** This type of delay is initialized at Delay Start samples, and increases linearly at a rate of Delay Step samples in each frame. When the actual delay reaches one frame, the delay buffer is full, and it maintains a delay of one frame.
- **Triangle delay:** This type of delay linearly changes back and forth between Min-Delay samples and Max-Delay samples at a rate of Delay Step samples in each frame
- The use of multiple delay characteristics allows you to investigate their effects on receiver performance, particularly on the Symbol Synchronizer block. The delayed signal is processed through an AWGN Channel. The diagram of the AWGN Channel with Frequency Offset and Variable Delay subsystem.





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RECEIVER:

- **Raised Cosine Receive Filter:** The Raised Cosine Receive Filter provides matched filtering for the transmitted waveform with a roll-off factor of 0.5.
- AGC: The received signal amplitude affects the accuracy of the carrier and symbol synchronizer. Therefore, the signal amplitude should be stabilized to ensure an optimum loop design. The AGC output power is set to a value ensuring that the equivalent gains of the phase and timing error detectors keep constant over time. The AGC is placed before the Raised Cosine Receive Filter so that the signal amplitude can be measured with an oversampling factor of two, thus improving the accuracy of the estimate. You can refer to Chapter 7.2.2 and Chapter 8.4.1 for details on how to design the phase detector gain.
- **Coarse Frequency Compensation:** The Coarse Frequency Compensation subsystem corrects the input signal with a rough estimate of the frequency offset. The following diagram shows the subsystem, in which the frequency offset is estimated by averaging the output of the correlation-based algorithm of the Coarse Frequency Compensator block. The compensation is performed by the Phase/Frequency Offset block. There is usually a residual frequency offset even after the coarse frequency compensation, which would cause a slow rotation of the constellation. The Carrier Synchronizer block compensates for this residual frequency.
- The accuracy of the Coarse Frequency Compensator decreases with its maximum frequency offset value. Ideally, this value should be set just above the expected frequency offset range. For example, this model introduces a 5 kHz frequency offset and the Coarse Frequency Compensator is configured with a 6 kHz maximum frequency offset.

DATA DECODING

The Data Decoding enabled subsystem performs phase ambiguity resolution, demodulation and text message decoding. The Carrier Synchronizer block may lock to the unmodulated carrier with a phase shift of 0, 90, 180, or 270 degrees, which can cause a phase ambiguity. For details of phase ambiguity and its resolution. The Phase Offset Estimator subsystem determines this phase shift. The Phase Ambiguity Correction & Demodulation subsystem rotates the input signal by the estimated phase offset and demodulates the corrected data. The payload bits are descrambled, and printed out to the Simulink Diagnostic Viewer at the end of the simulation.

IV. RESULTS

The MIMO system was simulated using MATLAB considering various MIMO configurations (2x2, 4x4, and 8x8) under Rayleigh and Rician fading channels.

Increasing the number of antennas improves the system's reliability, capacity, and throughput. Rayleigh and Rician fading channels were tested, and results confirmed that MIMO helps to combat multipath fading effectively. The simulation verified that MIMO is a critical enabler for 5G to achieve its goals of enhanced mobile broadband. The plot will show that BER decreases as SNR increases, and better performance is observed for higher antenna configurations.

SNR (dB)	BER (2x2 MIMO)	BER (4x4 MIMO)	BER (8x8 MIMO)
0	0.158	0.135	0.11
5	0.08	0.05	0.035
10	0.035	0.015	0.007
15	0.01	0.003	0.001

Table 4.1: Bit Error Rate (BER) vs Signal-to-Noise Ratio (SNR)





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Table 4.2: Channel Capacity vs SNR

SNR (dB)	Capacity (2x2) Mbps	Capacity (4x4) Mbps	Capacity (8x8) Mbps
0	5.5	8.9	14.2
5	12.7	22.3	35.4
10	24.6	45.1	72.5
15	42.1	81.7	128.5

Table 4.3: Throughput Analysis

MIMO Configuration	Maximum Throughput Achieved
2x2 MIMO	~ 40 Mbps
4x4 MIMO	~ 80 Mbps
8x8 MIMO	~ 140 Mbps

V. CONCLUSION

In this project, a detailed simulation of a MIMO-based 5G communication system was successfully carried out using MATLAB. The simulation demonstrated the significant advantages of incorporating MIMO technology into 5G systems, particularly in enhancing system capacity, reliability, and throughput.

The results obtained showed that as the number of antennas increases, the system achieves lower Bit Error Rates (BER) and higher channel capacity, even under challenging wireless channel conditions such as Rayleigh and Rician fading. The use of advanced techniques such as spatial multiplexing, beamforming, and diversity helps in effectively mitigating the effects of multipath fading and interference, which are common challenges in wireless communication.

MATLAB proved to be an efficient platform for developing and analysing MIMO system models due to its versatile simulation environment and dedicated 5G toolboxes. The insights gained from this project can serve as a foundation for further studies, such as the implementation of Massive MIMO, precoding techniques, and real-time channel estimation, which are critical in the realization of practical 5G deployments.

The project successfully verified that MIMO is one of the key enablers for fulfilling the ambitious goals of 5G, including high data rates, ultra-reliable communication, and enhanced spectral efficiency.

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Volume 14, Issue 5, May 2025

|DOI: 10.15680/IJIRSET.2025.1405055|

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