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# Performance Analysis of 5G Mobile Network Using Massive MIMO and AMC

Sherif Saber[1], Zeyad Sayed[1], Ibrahim Yasser[1], Mohamed Salah [1], Dawlat Ibrahim[1], Aya Fathy[1], Nora Ali[2]
[1] *Communications and Electronics Engineering Department, Giza Engineering Institute, Giza, Egypt*
[2]*Egyptian Chinees Collage of Applied Technology, ECCAT, Suez Canal University*
Sherif.20190158@gei.edu.eg, Zeyed.20190033@gei.edu.eg, Ibrahim.20190056@gei.edu.eg
Mohamed.20190044@gei.edu.eg, Dawlat.20190018@gei.edu.eg, Aya.fatay@gei.edu.eg, nora.eccat@suez.edu.eg

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***Abstract-*** The progress of telecommunications has been characterized by successive generations, each revolutionizing connectivity and communication. Innovations have changed the landscape from the first generation (1G) of analog voice transmission to the start of the fifth generation (5G) era. This article traces this path taking into consideration the crucial role of Massive Multiple-Input Multiple-Output (MIMO) technology in shaping the future of 5G networks. Massive MIMO offers improved performance in terms of data rate and spectral efficiency while accommodating numerous users.

This paper aims to offer a comprehensive yet introductory exploration of MIMO technology evolution and challenges. By examining potential system improvements, it aims to shed light on the path toward harnessing Massive MIMO's transformative potential in the realm of 5G telecommunications.

Also, the paper investigates the 5G performance in the presence of adaptive modulation. Adaptive Modulation and Coding (AMC) is considered a crucial advancement in achieving the 5G objectives. AMC signifies a fundamental shift in wireless communication, allowing for real-time adjustments of modulation schemes and coding rates based on the current wireless channel conditions.

***Keywords***: *5G, Massive MIMO, Beamforming, Adaptive Modulation.*

## *I. INTRODUCTION*

The evolution of cellular infrastructure began with 1G analog system in the 1980s, followed by 2G digital systems such as GSM. In more recent 3G and 4G systems, distributed networks are employed instead of the traditional networks in 1G and 2G. Within distributed networks, the radio unit, encompassing all transmitting and receiving components with amplifiers, is separated from the baseband unit and positioned on top of the antenna tower [1]. In 4G and 5G systems, the centralization of the base-band processing unit will occur. Hundreds of antenna elements will be directly integrated with the remote radio unit, thus creating the massive MIMO scheme as shown in Fig.1[1-2]. The substantial increase in wireless data traffic worldwide is placing considerable strain on existing wireless communication systems. The scarcity of available spectrum has prompted telecom engineers to focus on Millimeter Wave (mm-Wave) frequencies, which necessitate small radiating elements. The reduction in the size of antenna elements aligns perfectly with the requirements of massive MIMO, making these large-scale antenna arrays a promising technology.

Moreover, a higher number of antenna elements results in enhanced performance and an improved signal to interference-plus-noise ratio (SINR). Massive MIMO represents a revolutionary advancement in wireless communication systems.

Unlike traditional MIMO systems, which typically utilize a limited number of antennas at the base station and user devices, massive MIMO systems are characterized by the deployment of many antennas at the base station and potentially into the hundreds or even thousands [2].

By increasing the number of elements in the antenna array, significant improvements in the throughput and the coverage can be attained. In addition, the increased path loss at higher frequencies can be addressed by utilizing multiple antenna elements to combine energy in specific directions. This involves integrating beamforming techniques into MIMO, focusing radio energy in smaller angular sectors, leading to a notable enhancement in spectral efficiency. The advent of massive MIMO has introduced a promising new approach by leveraging the elevation angle, known as 3D MIMO, which involves deploying antenna elements in both horizontal and vertical dimensions.

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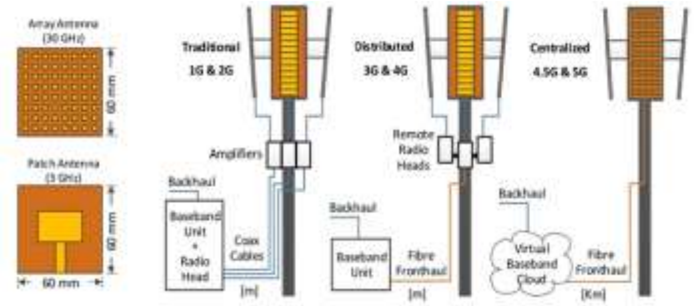


*Figure (1): Cellular infrastructure using MIMIO technique*

Also, the paper investigates the performance in the presence of Adaptive Modulation and Coding (AMC). The concept of AMC has become increasingly important in 5G networks. It builds upon the adaptive modulation techniques present in previous generations but elevates them in terms of efficiency and sophistication. In 5G, AMC is not merely an option but a necessity to fully utilize the potential of high-frequency bands and the diverse range of usage scenarios.

The heart of AMC lies in its capability to adaptively modify the modulation scheme and coding rate in real time based on the current wireless channel conditions. The choices concerning modulation and coding are tied to channel parameters like Signal-to-Noise Ratio (SNR), Bit Error Rate (BER), and Channel Quality Indicator (CQI). When the channel conditions are favorable, higher-order modulation schemes and more aggressive coding rates can be utilized to achieve higher data rates. Conversely, in challenging conditions, the system can switch to more resilient schemes to ensure dependable transmission [3-4].

## II. SIGNAL PROCESSING TECHNIQUES USING MASSIVE MIMO

Signal processing plays a crucial role in achieving efficient communication performance. The signal processing tasks involved in the massive MIMO systems can be explained according to the following steps [4].

1. **Channel Estimation**: to effectively direct the signals to the users, the channel must be estimated. By assuming reciprocity, it is sufficient to estimate the channel in one direction. In massive MIMO, due to having more base station antennas than users, the uplink channel will be estimated. Therefore, the coherence block of a conventional massive MIMO system splits into three parts: the uplink training phase, the uplink data phase, and the downlink data phase as shown in Fig. 2. The training phase can be placed anywhere in the coherence block before the downlink data phase.

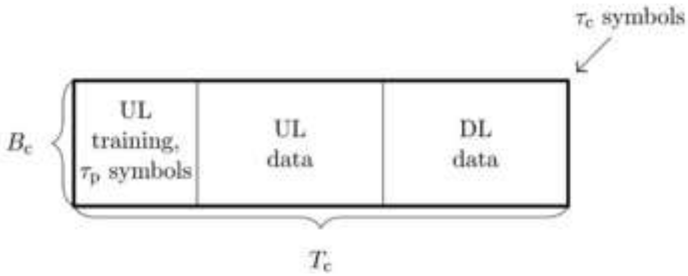


*Figure (2): Channel Estimation Phases*

2. **Precoding and Beamforming:** Massive MIMO systems employ precoding and beamforming techniques to spatially multiplex multiple users in the same time frequency resource. Precoding refers to the manipulation of transmitted signals at the transmitter side to optimize the received signal quality at the users. On the other hand, Beam-forming involves steering the transmitted signal in specific directions to enhance the received signal power at the receiver while minimizing interference to other users as shown in Fig.3 [4].

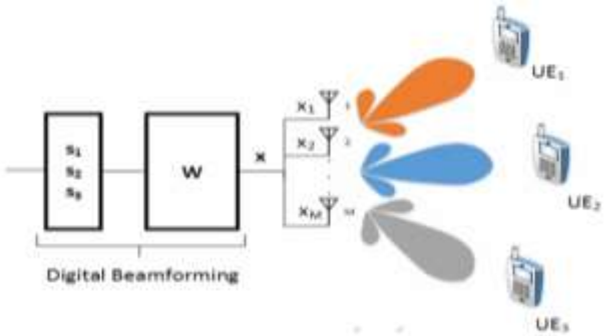


*Figure (3): Precoding & Beamforming*

3. **Channel Equalization**: In multi-user massive MIMO systems, where multiple users share the same time-frequency resource; channel equalization techniques are employed to mitigate the effects of inter-user interference. Equalization algorithms aim to recover the transmitted symbols by compensating for the channel distortions and interference caused by other users [4].
4. **Pilot Contamination Mitigation** occurs when pilot signals intended for channel estimation are contaminated by signals from other users, leading to inaccuracies in channel estimation and performance degradation. Signal processing techniques such as pilot decontamination and interference suppression are utilized to mitigate this effect and improve the accuracy of channel estimation [4].
5. **Synchronization: Synchronization** is essential to ensure proper coordination among the multiple antennas and users in a massive MIMO system. Signal processing algorithms are employed to synchronize the timing, the frequency, and the phase of transmitted signals at the

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transmitter and receiver ends to facilitate efficient communication [4].

6. **Interference Management**, Due to the high spatial multiplicity in massive MIMO systems, interference management becomes a critical aspect of signal processing. Techniques such as interference alignment, spatial precoding, and interference cancellation are utilized to mitigate interference and improve the overall system performance [4]. Overall, signal processing in massive MIMO involves a combination of techniques aimed at optimizing channel estimation, spatial multiplexing, interference management, and synchronization to achieve high spectral efficiency and reliable communication in large-scale antenna systems [3, 4].

## *III. THE SYSTEM MODEL AND NETWORK ARCHITECTURE*

The system under consideration employs a Cyclic Prefix (CP) length of 64, ensuring robustness against inter-symbol interference. It utilizes 234 carriers, with specific allocations for null and pilot carriers. The system operates with a code rate of 1/3, which provides a balance between redundancy and efficiency. Additionally, there are 6 termination tail bits to properly conclude the coded sequences. Modulation is handled using 16QAM, offering a good trade-off between spectral efficiency and noise resilience. The system is designed to achieve a maximum range of 1000 meters, with a noise figure of 7, ensuring reliable performance in varying environmental conditions [5].

## *IV. PERFORMANCE METRICS*

The performance is evaluated using different metrics such as, Signal to Noise ratio (SNR) which is the ratio between the desired signal power and the noise power as shown in the following equation:

$$SNR = \frac{P_R}{P_N} \quad (1)$$

Where $P_R$ is the average received power and $P_N$ is the noise power.

The second metric is the Antenna Gain (G) which is the most important parameter in the design of an antenna system. Antenna gain is a measure of maximum effectiveness which can radiate the power delivered by the transmitter towards the target. The antenna gain is defined as the following equation:

$$\text{Antenna Gain} = D \times \eta \quad (2)$$

Where D = Directivity and η = Antenna Efficiency.

The third metric is the Antenna Directivity (D), the directivity of an antenna refers to how concentrated its radiation pattern is in a specific direction. When directivity is higher, the antenna's beam is more focused. It's a measure of how effectively the antenna directs energy in a specific direction. The directivity of an antenna is defined according to the following equation:

$$D = \left( \frac{4 \times \pi \times Gain_{\max}}{\text{Total \_Power \_Isotropic}} \right) \times \left( 4 \times \pi \left( \frac{\lambda}{2} \right)^2 \right) \quad (3)$$

Where,

$$\text{Total Power Isotropic} = \frac{P_t}{P_{rm.num} \_ T_x} \quad (4)$$

Where Pr is the total transmits power and Prm.num_Tx is the number of BS transmit antenna.

The fourth metric is the Bit Error Rate (BER), which is a crucial parameter for transmitting data over wireless or wired links. It measures the number of errors in the data received at the remote end. A low bit error rate indicates a good medium and high signal-to-noise ratio between the transmitter and receiver [6].

## *V. SIMULATION RESULTS OF MASSIVE MIMO*

The proposed model is investigated using the MATLAB simulation tool. The simulation results of the previous metrics are shown in the next figures.

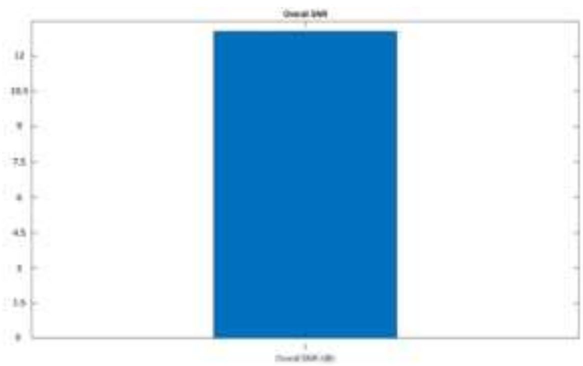

*Figure (4): SNR of massive MIMO*

It is shown from the figure that the average overall SNR value in the system is 12.518736310619dB. The next figures show the antenna gain, directivity and BER respectively.

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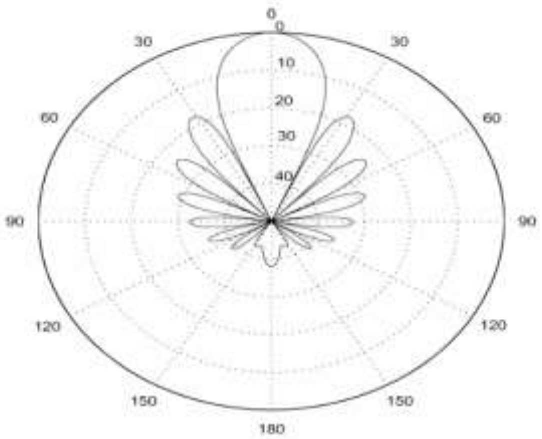


*Figure (5): Gain of Massive MIMO*

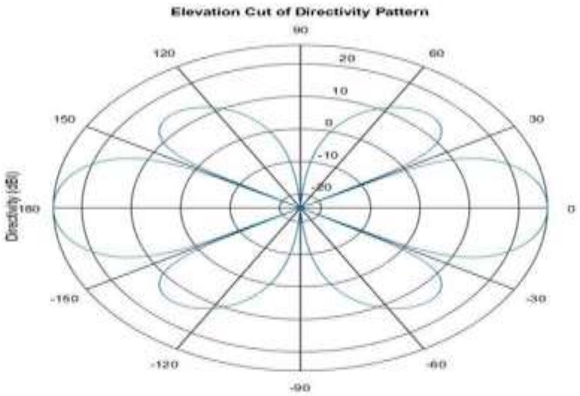


*Figure (6): Directivity Elevation View*

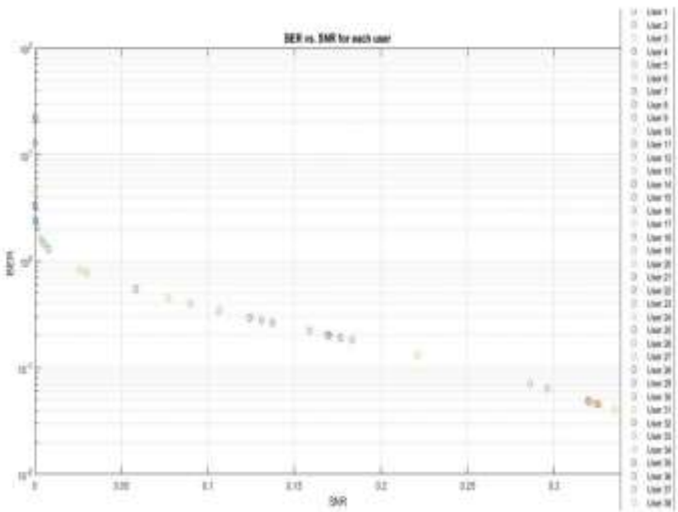


*Figure (7): BER Vs SNR for each user*

It is shown from Fig. 7 that the system's average BER output value is 0.000007720861596.

## VI. ADAPTIVE MODULATION AND CODING (AMC)

The continuous improvement of cellular networks has been fueled by the relentless pursuit of efficiency, reliability, and better user experiences. Within 5G networks, Adaptive Modulation and Coding (AMC) is a crucial advancement in achieving these objectives. AMC signifies a fundamental shift in wireless communication, allowing for real-time adjustments of modulation schemes and coding rates based on the current wireless channel conditions. This innovation tackles the challenges posed by the dynamic and variable nature of wireless communication environments, ultimately leading to improved spectral efficiency, throughput, and overall network performance [7].

Adaptive modulation facilitates higher data rates by optimizing the selection of modulation schemes based on the prevailing channel conditions. This adaptability allows for enhanced data throughput and efficient communication, in contrast to systems using fixed modulation schemes. Wireless communication channels are distinguished by their variability, signal strength fluctuations, and fading effects caused by multipath propagation can lead to signal distortion. These dynamic channel conditions introduce uncertainties in the communication process, necessitating adaptive strategies to ensure reliable data transmission [7]. AMC is fully integrated into the infrastructure of 5G networks as shown in Fig.8.

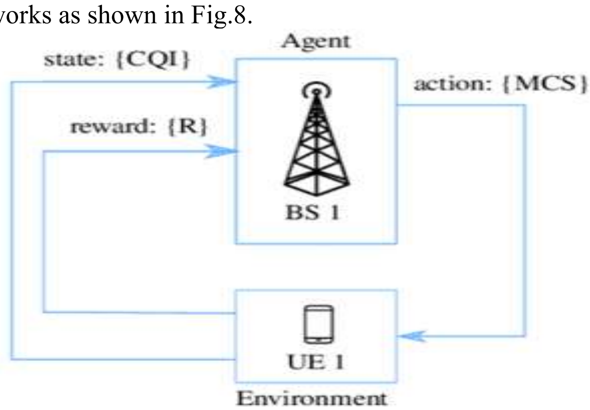


*Figure (8): AMC*

## VII. AMC IMPLEMENTATION USING MACHINE LEARNING

Machine learning has the capability to process vast amounts of data and achieve higher accuracy than humans. It can save time and money by handling tasks such as addressing customer issues to enhance satisfaction, automating support tickets, and extracting data from various sources. Unlike manual processes, machine learning allows machines to solve problems independently and make decisions based on past observations. This transformative field within AI enables computers to learn and enhance their performance without explicit programming, enabling them to recognize patterns, make predictions, and optimize decisions based on the used data. Machine learning has significantly transformed multiple industries, leading to improved innovation

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and efficiency, from recommendation systems in e-commerce to healthcare diagnosis [8]. The process of machine learning consists of three main steps as follows:

- Providing input datasets to train the machine learning model, such as customer comments from social media or customer service information.
- Associating training data with a desired output, for example, instructing a sentiment analysis model to categorize each comment or data point as Positive, Neutral, or Negative. The model then converts the training data into numerical representations known as text vectors, which capture data features.
- Evaluating the model by exposing it to testing data. Through training on manually labeled samples, algorithms are taught to link feature vectors with labels and then make predictions when processing new data [9].

If the newly developed model meets your standards and criteria during testing, it will be ready to be employed on various new data. If it fails to perform accurately, further training is required. Moreover, as human language and industry-specific terminology evolve, ongoing training with new information may be necessary [10].

## VII. SIMULATION RESULTS OF AMC

The simulation is obtained using a dataset containing different modulation techniques such as QAM, AM, FM, BPSK, 8PSK, and QPSK under different channel conditions. Relevant features were extracted by analyzing the collected data using the Jupiter tool on the Anaconda platform. These features describe the channel conditions and interference levels, including frequency, signal strength, bandwidth, device type and antenna type. An appropriate machine learning algorithm has been chosen for the task, including decision tree, K-Nearest Neighbors (KNN), and Support Vector Machine (SVM). The dataset is separated into training and testing sets. The training set is utilized for model training, while the testing set is used to assess the ultimate performance.

The model is trained using different algorithms and the performance of the trained model was assessed using the testing set. Accuracy metrics were utilized for this purpose as they can gauge the model's efficiency in selecting the correct modulation scheme and the accuracy of the examined algorithms is shown on Fig. 9.

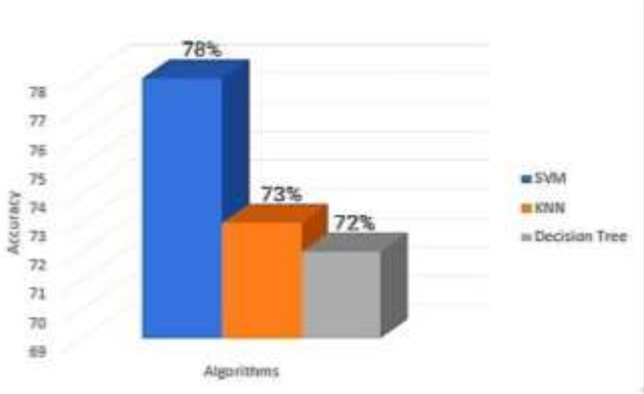


*Figure (9): Accuracy of ML models*

## VIII. CONCLUSION

This paper and its accompanying simulations offer a comprehensive understanding of how massive MIMO, adaptive modulation could impact 5G wireless communications. Our findings indicate that the implementation of these technologies will be crucial for efficient communication networks. The utilization of these technologies is poised to bring about significant advancements in the telecommunications field as we continue to research and develop them. While massive MIMO and adaptive modulation are novel concepts in 5G systems, their potential benefits are substantial. Future progress will be directed towards furthering these technologies, harnessing their full capabilities, and addressing any potential challenges that may arise during their implementation. The amalgamation of these cutting-edge technologies is expected to transform wireless communication, ushering in a new era of performance and connectivity unlike anything seen before.

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