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Millimeter Wave Transmission Improvement Using Massive MIMO in Modern Communications System

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Abstract
The massive multiple-input multiple-output (mMIMO) technique forms a fundamental component of fifth-generation (5G) communication systems, as it significantly enhances network capacity by integrating a large number of antennas within limited physical space. Initially developed for sub-6 GHz frequencies, mMIMO has also been extended to support millimeter-wave (mmWave) bands that operate within 30–300 GHz and provide extremely high data rates but limited coverage. This study examines the performance of mMIMO across both sub-6 GHz and mmWave frequencies, emphasizing its capability to improve mmWave transmission efficiency. The simulation-based evaluation considers non-line-of-sight (NLOS) conditions and benchmarks mMIMO against conventional MIMO systems. The obtained results demonstrate that mMIMO enhances the signal-to-noise ratio (SNR) by up to 85.5% at a distance of 100 m for 10 users, with an average improvement of 56.39% across various distances. Nonetheless, performance benefits gradually decrease as the number of users grows, revealing a trade-off between scalability and efficiency. Furthermore, the study explores beamforming mechanisms, channel modeling, and antenna array configurations, providing valuable insights for optimizing mMIMO deployment in practical 5G scenarios.

Keywords: Massive MIMO, 5G networks, mmWave, Sub-6GHz, beamforming, SNR optimization.

1 Introduction

Modern communications seek to find or develop new technologies and algorithms to keep pace with the growing demand for increased capacity and improved performance. mMIMO is prominent innovations in fifth generation (5G) system, contributing positively to raising SNR and improving the system's ability to accommodate an increasing number of users [1, 2]. This technology uses a huge elements antenna in the Tower, allowing for increased directional gain and spatial shaping of beams, leading to improved transmission and reception quality. The narrow bandwidth used at frequencies below 6 GHz has led to the development of larger frequency ranges such as millimeter waves (mmWave) that provide wider bandwidth [3]. While mmWave offers ultra-fast data transfer speeds and large bandwidth, its physical characteristics, such as rapid attenuation and poor propagation in indirect environments, have become a significant obstacle to achieving reliable coverage (increasing transmission range) [4-6]. Therefore, it was necessary to combine mMIMO with mmWave, leveraging the advantages of both technologies in terms of reducing interference and compensating for power loss resulting from distance or obstacles [7, 8].

In this paper, a model is created to combine the two technologies to achieve an increased SNR, which leads to an improvement in the transmission range of mmWave and to achieve the wideband utilization of the second technology (mmWave). The impact of the path loss exponent (PLE) on the technologies used was taken into account, as well as the impact of increasing users of each technology on the SNR. The manuscript is organized after the introduction view as follows: Some related paper to demonstrate the importance of the two techniques, followed by a modeling and simulation section, a results and discussion section, and finally, a conclusion section. This study highlights a fundamental challenge in modern wireless communications enhancing the performance of millimetre-wave (mmWave) transmission using (Massive MIMO) technology, particularly in 5G networks and (NLOS) environments. It also addresses the limitations of traditional MIMO systems, especially when the number of users increases, leading to a greater need for pilot signals (over load pilot). The importance of this topic stems from the inherent limitations of mmWave technology, which, while offering high data rates, suffers from poor coverage due to rapid signal attenuation and difficulty in propagating through obstructed environments. The importance of this research lies in its analysis of (SNR) improvements within millimetre-wave environments characterized by variations in user density, the number of antennas, and wireless channel conditions. These factors are often simplified or their impact overlooked in traditional models, despite their significance in evaluating the realistic performance of networks. Below are some of the previous studies on this topic.

The authors discuss how the arrangement of the antenna arrays used in beamforming significantly affects system behavior and efficiency. The positioning of the hybrid antenna array is influenced not only horizontally but also vertically. To simulate and evaluate the system, the widely used MathWorks Simulink software was employed alongside a dedicated FPGA board. The combination of optimization techniques and their use of an array of antenna elements results in a highly efficient beamformer [9]. The MIMO with a cooperative system showed an improvement compared to the SISO system and the MIMO without a cooperative system, as the improvement rate was 22% SNR for the MIMO with a cooperative with SISO and 9% for the MIMO without a cooperative system. As for the capacity, the improvement rate was 12% and 7% for the SISO and simple MIMO systems, respectively [10]. The authors [11] analyze the average bit error rate (BER) for some receiver detectors, such as maximal ratio combining (MRC) to increase received SNR, zero forcing (ZF) for a simple model, and minimum mean square error (MMSE) to increase the accuracy of mMIMO systems with time-invariant channels. Simpler lower bounds for M-MIMO are tight in the low Eb/N0 region, while the asymptotic upper bound is accurate in the high Eb/N0 region. It also evaluates the Eb/N0 penalty caused by imperfect Channel State Information (CSI), which remains consistent as Noise increases in the asymptotic region but slightly varies in the low energy to noise bit (Eb/N0) region. Using more pilot symbols reduces the penalty but affects spectral efficiency. By using a factor greater than 1, spectral efficiency can be maximized with minor Eb/N0 losses. Lastly, the study highlights the significance of mMIMO in 5G systems and suggests future research on the effects of imperfect CSI on both BER and SE in coded mMIMO.

The authors [12] address key challenges in data detection for M-MIMO uplink systems. It examines the performance and complexity of various detectors using iterative methods across different MIMO sizes and iteration levels. The GS detector performs best when λ is small, but all detectors experience significant performance loss at $\lambda = 1$. Optimal ω values are identified for both methods (RI, and SOR). On other side, many studies that assume spatially uncorrelated channels, this paper highlights that such assumptions can lead to inaccuracies. Detectors using these methods to get higher efficiency in proposed channels. OCD method offers less complexity. Researchers [13] used a new Reconfigurable Intelligent Surface (RIS) technique to increase SNR and range. They proposed a model illustration the effect of change dimensions, such as varying incidence and reflection angles of RIS, on SNR value. Simulation results showed that the maximum SNR occurs when the height of RIS is a quarter of the distance between the transmitter (TX) and receiver (RX), with the RIS positioned close to either TX or RX. If the RIS height is half the distance, the maximum SNR is achieved when the RIS is in the middle. For heights greater than the midpoint, the optimal SNR is obtained when the RIS is placed centrally between the transmitter and receiver [14]. The system was evaluated with four users. Each user supports independent data streams. Both SE and BER were analyzed and evaluated to fully digital beamforming using optimal precoding weights. Results showed that hybrid beamforming achieved SE values comparable to optimal precoding while maintaining an acceptable BER rate. Additionally, the variation in the number of transmit and receive antennas assigned to each user has a clear impact on the overall system performance. The proposed hybrid beamforming system delivers near-optimal results with reduced hardware complexity, lower cost, and minimal power loss [15]. Researchers have proposed a generalized frequency-division multiplexing (GFDM) technique instead of orthogonal FDM to improve mmWave performance in Rayleigh channels under adverse weather conditions such as dust storms [16].

The contributions of this paper can be summarized as follows:

- Developing a performance evaluation model that analyzes the impact of increasing user density on the SNR in mmWave environments using massive MIMO, which is crucial for realistic 5G scenarios.
- Investigating the limits of transmission range and signal degradation under varying system parameters such as number of users and channel conditions, which are often assumed ideal or neglected in many existing studies.
- Presenting simulation results that reflect critical practical implications — for instance, how SNR behavior changes with user load and antenna count — which are essential for network planning and optimization in real-world mmWave systems.

2 Modelling massive MIMO system

This SNR was measured in the NLOS case, where we assumed that there was an obstacle between the transmitter and the users. The obstacle was placed 30 meters away from the transmitter, and the comparison was made using MIMO and mMIMO technologies as shown in Figure 1 [17,18].

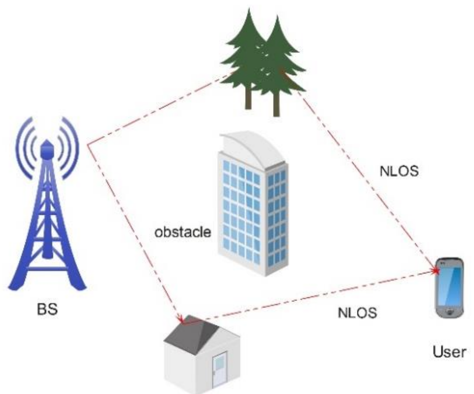

Figure 1: Simplified Model of NLOS Communication.

2. 1 MIMO System

MIMO technology enhances system capacity without requiring additional bandwidth or higher transmission power by utilizing multiple transmitting and receiving antennas. By employing N transmitter antennas and M receiver antennas, the system can efficiently collect and process the transmitted signal [19].

2. 2 Massive MIMO Scenario

The system model takes into account the blockage scenario, where direct path from the BS to users is blocked by tall buildings or natural terrain. Therefore, an amplified MIMO system is deployed to study the transmitted signal in this scenario, where the received signal is represented as follows [20].

$$Y = H_{ef} + n \quad (1)$$

where Y is the received signal, and $H_{eq} \in \mathbb{C}^{N_R \times N_T}$ is mMIMO channel in NLOS link between BS and users, N_R Number of transmitted antenna with Uniform Liner Array (ULA) transmitter BS, N_T equals to Number of single antennae Multi user. x is the transmitter wave and n is the value of white Gaussian noise (AWGN) vector. Capacity may be expressed in the equation for capacity given by [21]:

$$C = B\, log_2(1 + diag\,(|H * W|^2)/\sigma^2) \quad (2)$$

Where W is Pre-coding matrix W = [W1, W2, …, WK], this signal using different techniques such as MU-mMIMO comparing with MU-MIMO in NLOS. SNR scenario for ZF is calculated as follows [21]:

$$SNR = diag\,(|H * W|^2)/\sigma^2 \quad (3)$$

Zero-Forcing (ZF) precoding removes inter-user interference entirely by aligning the transmitted signals with the null space of the interference components. However, it does not take noise amplification into account, which can degrade performance in low-SNR regimes (Sun, 2016). The transmitter station, positioned at a height of 15 meters, utilized a Uniform Linear Array (ULA) antenna configuration with Ntx antennas. Meanwhile, the user, equipped with a single antenna, was situated at a height of 1.5 meters. Number of user K and the large-scale fading based on close-in (CI) model equation [22].

$$PL^{CI}(f,d)[dB] = FSPL(f,1m)[dB] + 10nlog_{10}(d) + X_{\sigma}^{CI} \quad (4)$$

where d ≥ 1 m, n denotes the single model parameter, the *path loss exponent* (PLE), with (10nlog10 (d)) describing path loss in dB in terms of decades of distances beginning at 1 m.

$$FSPL(f,1m) = 20log_{10}\left(\frac{4\pi f}{c}\right) \quad (5)$$

FSPL denotes the free space path loss in dB at a Tx-Rx separation distance of 1 m at the carrier frequency f, where c is the speed of light. we use a path-loss exponent n=3.75 between (BS) and users and we Assum Perfect channel state Information (CSI) and Rayleigh channel small scale fading and uniform power allocation, the mMIMO systems. The power spectral density for the additive noise is [21]:

$$\sigma^2 = -174 + 10log_{10}(B) + NF \quad (6)$$

Here, B represents the transmission bandwidth, while NF denotes the noise figure expressed in decibels. The simulation was conducted using the model parameters listed in Table 1.

Table 1: Proposed Model Parameters

Parameters	**Value**
f	28GHz
Transmit power (Pt)	2W
Bandwidth (B)	1GHz
Noise Figure (NF)[15]	9dB
Gt	30dBi
Gr	10dBi
hBs	15m
hUs	1.5m

3 Result and Discussion

In this section, MATLAB R2023b was employed to evaluate the channel between the base station (BS) and users under NLOS conditions. Figure 2 shows the change in SNR value with the distance between the base station (BS) and the users. Also, it includes a comparison between the performance of with and without Massive MIMO (mMIMO) systems using different numbers of antennas in mmWave environments. All curves show a gradual decrease in SNR with increasing distance between the BS and the users, which is expected behavior in an NLOS environment due to the increase in attenuation and power loss with distance. It can be observed that the more antennas in the system, whether in MIMO or mMIMO, the better the SNR value at all distances. Similarly, mMIMO with 64 antennas achieved the highest SNR value over the entire distance, proving the effectiveness of massive systems in compensating for signal losses resulting from attenuation and reflections in NLOS environments.

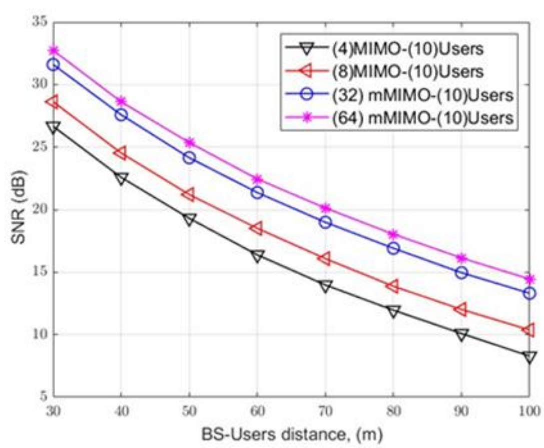

Figure 2: The SNR varied with user distance at (PLE=3.75, users =10).

Tables 2 and 3 show the actual SNR values when using several techniques, as well as the percentage SNR improvement between the last technique (64 mMIMO) and the first (4 MIMO) in the case of 10 and 20 users.

Table 2: SNR Result with 10 Users

Techniques /distance	50m	70m	100m
4 MIMO	19.2224dB	13.9211dB	8.324dB
8 MIMO	21.2069dB	16.0805dB	10.3724dB
32 mMIMO	24.1524dB	18.9869dB	13.31dB
64 mMIMO	25.3643dB	21.1246dB	14.4414dB
Improvement %	31.95%	51.74%	85.5%

Table 3: SNR Result with 20 Users

Techniques /distance	50m	70m	100m
4 MIMO	19.261dB	14.0267dB	8.4778dB
8 MIMO	21.2172dB	15.9694dB	10.3463dB
32 mMIMO	24.1962dB	18.999dB	13.3124dB
64 mMIMO	25.3312dB	20.1394dB	14.3909dB
Improvement %	31.51%	43.57%	69.75%

The best performance case is at 10 users, where interference is minimal and resources are distributed among a smaller number. The worst case is at 50 users, where performance degradation is greatest due to the high sharing of resources. Any network model using MIMO is affected by the increasing number of users, as shown in Figure 3. Distance and the number of users directly affect network performance in terms of SNR and coverage. Figure 3 indicates that maintaining a moderate number of users within a suitable distance from the base station ensures high connection quality.

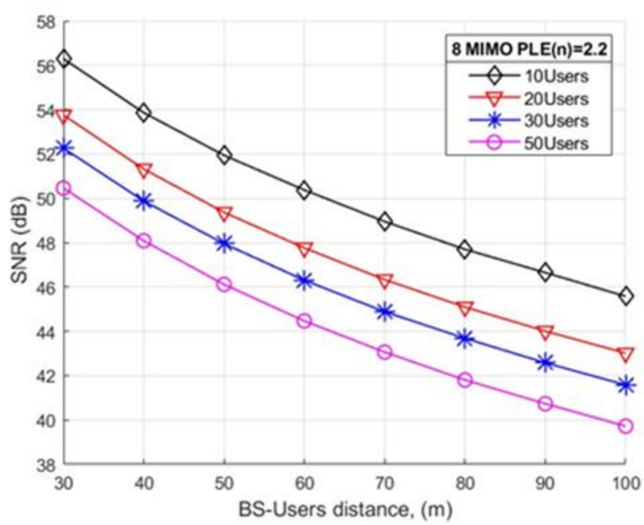

Figure 3: The SNR varied with user distance at (PLE=2.2, 8MIMO, users =10, 20, 30 and 50).

In a realistic urban environment, PLE increases due to the presence of multipath effects. Therefore, PLE negatively impacts performance, especially SNR, as shown in Figure 4. A significant decrease in SNR is observed from 50 dB to approximately 33 dB. 64mMIMO technology was used to improve SNR and performance in these adverse conditions, as shown in Figure 5.

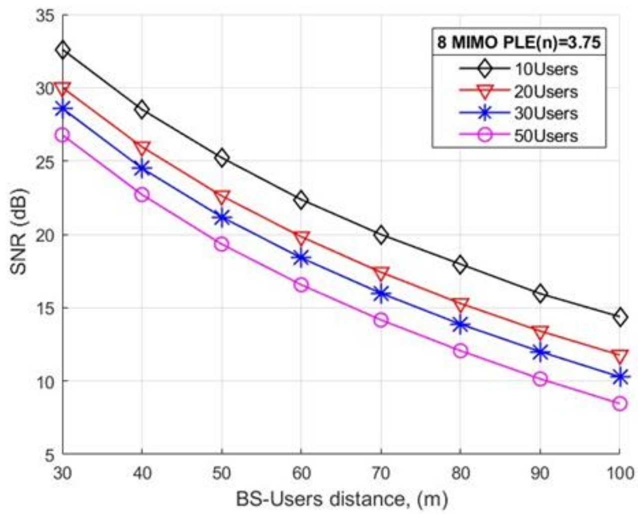

Figure 4: The SNR varied with user distance at (PLE=3.75, 8MIMO, users =10, 20, 30 and 50).

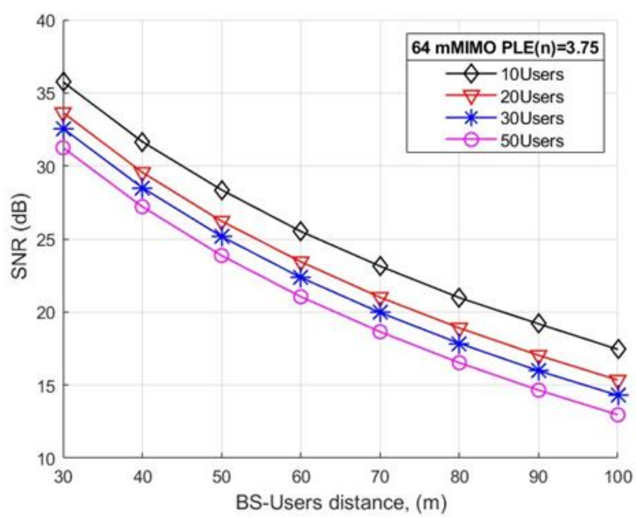

Figure 5: The SNR varied with user distance at (PLE=3.75, 64MIMO, users =10, 20, 30 and 50).

Tables 4 and 5 show SNR values for several scenarios and the magnitude of the improvement for each. Furthermore, 64-MIMO achieves better performance in all scenarios, demonstrating its superior ability to handle interference and improve signal quality due to the larger number of antennas. It is clear that the use of mMIMO significantly improves network efficiency, especially in long-range or high-density environments. The improvement in SNR becomes more pronounced as the number of users or distance increases. This highlights the need to adopt multi-antenna technologies in 5G and beyond systems.

Table 4: SNR Result with different number of Users at 50m distance and PLE=3.75

Technique	SNR at distance (50) and PLE (n)=3.75			
	10 User	20 User	30 User	50 User
8 MIMO	25.229	22.626	21.186	19.336
64 mMIMO	28.357	26.216	25.168	23.861
Improvement %	12.40%	15.87%	18.79%	23.41%

Table 5: SNR Result with different number of Users at 50m distance and PLE=3.75

Technique	SNR at distance (100) and PLE (n)=3.75			
	10 User	20 User	30 User	50 User
8 MIMO	14.385	11.768	10.282	8.460
64 mMIMO	17.439	15.339	14.296	12.959
Improvement %	21.23%	30.35%	39.04%	53.17%

5 Conclusions

A model is proposed that represents the integration of two key technologies—(mMIMO) and millimeter-wave (mmWave)—under realistic fifth-generation (5G) conditions, particularly focusing on commonly encountered NLOS environments. Several comparative simulations were conducted to evaluate the combined performance and to benchmark mMIMO against conventional MIMO systems. The findings confirm that mMIMO significantly enhances signal quality, measured by signal-to-noise ratio (SNR), especially in NLOS scenarios where conventional MIMO suffers larger degradations. Increasing the number of antenna elements reduces the adverse effects of interference, reflections, and path loss and contributes to more robust link reliability across various distances. Quantitatively, the SNR optimization achieved with mMIMO over a 100-meter link serving ten users reached 85.5%, while the average enhancement across 50, 70, and 100 meters was 56.39%. When the number of users increased to twenty, the average optimization decreased to 48.33%, indicating a clear trade-off between user density and per-user performance. These results suggest that deploying mMIMO can effectively extend the practical transmission range of base stations compared to traditional MIMO deployments, improving coverage in dense urban and indoor environments. From an application perspective, the demonstrated gains support the use of mMIMO in capacity-constrained and interference-prone scenarios common to 5G networks, including hotspots and crowded venues. However, this study is limited by its reliance on simulation-based evaluation under controlled channel models and assumptions about perfect or near-perfect channel state information. Future research should validate these findings through measured experiments, explore the effects of imperfect CSI, evaluate multi-reconfigurable intelligent surface (multi-RIS) configurations, and investigate scheduling and beam management strategies to balance capacity and fairness in larger user populations and energy efficiency trade-offs.

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Authors contribution

Rosin contributed 50% to the work by formulating the main idea, supervising the research process, and structuring the theoretical framework. Saad contributed 40% by developing the system model, conducting simulations, and performing detailed performance analysis. Omer contributed 10% through data organization, result interpretation, and proofreading of the final manuscript. All authors read and approved the final version of the paper.

Conflict of interests

The authors declare no conflicts of interest. The research was conducted independently, without any financial or personal relationships that could have influenced the results or conclusions of this work. No external funding agencies had any role in the study design, data collection, analysis, or decision to publish.

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