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# Simulation of Massive MIMO Antennas for Improved Link Throughput

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**ABSTRACT**
Massive MIMO technology involves deploying multiple antennas on both ends of a communication link, which boosts spatial diversity and signal-to-noise ratio. By using multi-user MIMO transmission and techniques like spatial multiplexing and beamforming, it increases capacity, spectral efficiency, and data rates. Simulations conducted with tools like Octave software help engineers to optimize designs, predict system behavior, and assess the impact of antenna quantity on downlink throughput. This study addresses the increasing demand for high downlink data rates within modern communication networks. It explores the performance of Massive MIMO systems through simulations using Octave software, focusing on the quantity of antenna elements (M), and considering both spectral efficiency (SE) and data throughput. Results show higher M enhances both spectral efficiency and data rates. Efficiency dips at M=10, surges at M=40, and slowly, but steadily grows from M=50 to 100. Similar trends in data rates indicate M's impact on transmission performance. SE values range from 5.8442 bps/Hz (M = 10) to 24.1608 bps/Hz (M = 100), while data rates range from 116.8834 Mbps (M = 10) to 483.2158 Mbps (M = 100). These insights offer practical guidance for engineers and could facilitate the optimization of wireless communication setups and addressing the imperative for improved data rates. The study advances the understanding of Massive MIMO's potential, providing a roadmap for effectively leveraging its capabilities across diverse communication network scenarios.

## INTRODUCTION

Antenna arrays with massive MIMO technology have become increasingly popular in the wireless communication industry due to their ability to improve downlink throughput. This technology involves the implementation of multiple antennas on both ends of a communication link, allowing for increased spatial diversity and improving the signal-to-noise ratio. By simulating an antenna array using massive MIMO technology, it is possible to predict the performance and capabilities of a communication system before it is implemented. This helps engineers to optimize the design and reduce the risk of costly mistakes or inefficiencies. The simulation procedures will show how the MIMO antenna array technology can be used to improve network accessibility on downlinks and downlinks in wireless communication systems.. When a large number of antennas are deployed at each base station, the multi-user MIMO (MU-MIMO) transmission is used to serve a smaller group of users (Marzetta, 2010; Rusek et al. 2013).

Massive multiple-input multiple-output (MIMO) is an innovative communication technique that has gained significant attention in recent years Several theoretical studies and preliminary simulations carried out by researchers (such as Ashikhmin et al., 2012; Fernandes et al., 2012; Ngo et al., 2011) have demonstrated the potential of massive MIMO systems. (Rusek et al., 2013). They noted that previous researchers focused primarily on the impact of channel estimation errors caused by noise or pilot contamination. However, further investigation under realistic conditions was necessary to assess the practical implications and capabilities of the Massive MIMO technology, (Ashikhmin et al., 2012; Fernandes et al., 2012; Ngo et al., 2011).

Some researchers (Hoydis et al., in 2011 and 2013) have also observed that pilot contamination imposes deterministic limits on the signal-to-interference-plusnoise ratio (SINR) and the achievable rates in massive MIMO systems. The main focus of this study is to simulate the downlink of massive MIMO systems. The study examines the impact of different parameters or their equivalents in developing simulations for cellular networks with a large number of antennas at each base station, as discussed by Hoydis et al., in 2011 and also 2013.

Also, Abdo et al., 2018 introduced a novel power iterative precoding technique to enhance the system's average capacity. They minimized channel interference by iteratively identifying dominant eigenvectors, Comparative results revealed that the proposed power iterative method performed better than the singular value decomposition (SVD) technique. The achievable sum-rate capacity was higher in the power iterative technique, which shows its potential for MU-MIMO systems with massive antennas , Abdo et al., 2018.

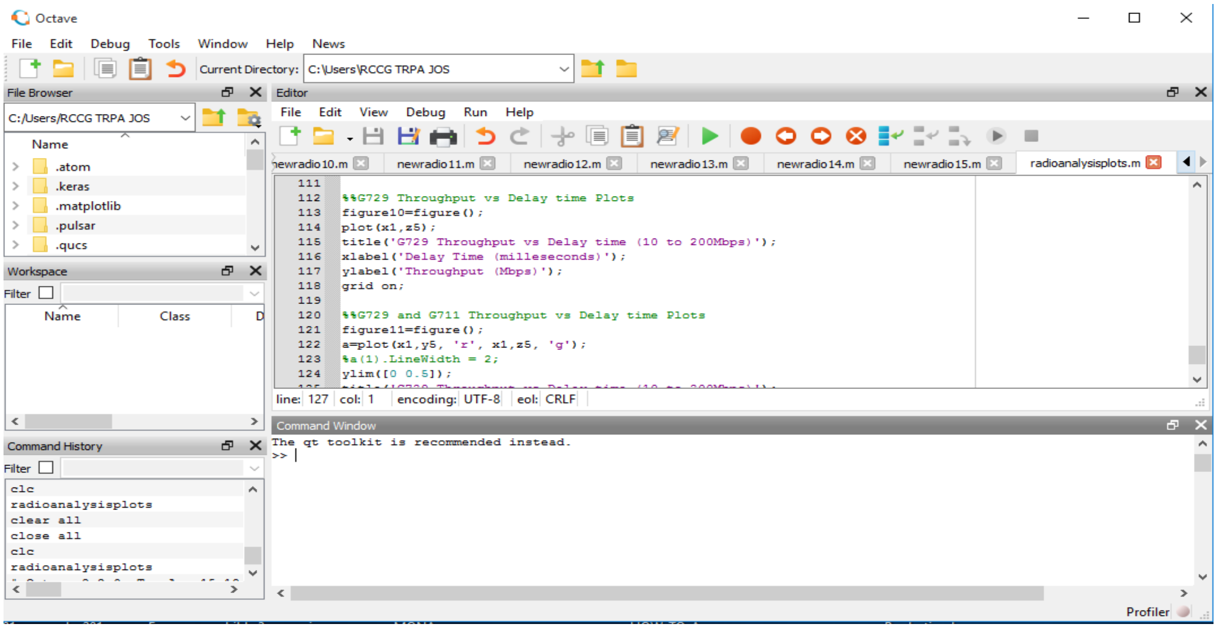
Lim et al., (2015) and Selvam & Vishvaksenan, (2019) adopted another method by incorporating time variation into the framework. The study conducted an asymptotic analysis of the achievable rates in both the uplink and downlink of massive MIMO systems using maximal ratio combining (MRC) receivers or matched filtering (MF) precoders. The findings indicate that the desired signal power for user depends primarily on channel aging and introduces inter-cell interference caused by pilot noise/disruptions. Again, total transmitter power consumption is minimized when optimal power allocation is combined with antenna selection; while the sum rate capacity is maximized (Lim et al., 2015; Selvam & Vishvaksenan, 2019).

In a different approach, Aslam et al., (2019) concluded that linear arrays prove superior, and offers a useful result for optimization of modern-day LTE and 5G-network deployments (Aslam et al., 2019). Their paper compared various antenna designs, unveiling limitations like fabrication costs and interference issues. The paper suggests improvements, highlighting the importance of accurate channel estimation, robust precoding, and signal detection methods. Singh et al., (2023) opined that massive MIMO will continue to expand in its crucial role in communication systems, despite the numerous challenges.

## MATERIALS AND METHODS

### Materials

This research was carried on with an Intel corei5 with a RAM of 4 GB memory and 500 GB hard drive. OCTAVE, the preferred software for simulation, offers a versatile environment for numerical computation, data analysis, and visualization. With its comprehensive range of built-in functions, OCTAVE enables seamless mathematical modeling, algorithm development, and simulation execution. It has a user-friendly interface to explore complex scenarios, perform statistical analyses, and generate insightful visual representations, enhancing the process of data-driven decision-making. The display interface is shown in figure 1.



```
%%G729 Throughput vs Delay time Plots
figure10=figure();
plot(x1,z5);
title('G729 Throughput vs Delay time (10 to 200Mbps)');
xlabel('Delay Time (milleseconds)');
ylabel('Throughput (Mbps)');
grid on;

%%G729 and G711 Throughput vs Delay time Plots
figure11=figure();
a=plot(x1,y5, 'r', x1,z5, 'g');
%a(1).LineWidth = 2;
ylim([0 0.5]);
```

```
The qt toolkit is recommended instead.
>>
```

```
clc
radioanalysisplots
clear all
close all
clc
radioanalysisplots
```

Figure 1: Display interface of OCTAVE software

## Method

### *Downlink Data Throughput*

To derive the downlink data throughput in terms of the number of user equipment (UEs) and base station antennas (BS) using zero forcing (ZF) beamforming, the spectral efficiency (SE) for each user was considered, and the total throughput for all users was calculated.

*Step 1: Spectral Efficiency (SE) with Zero Forcing Beamforming*

The already derived the spectral efficiency (SE) for the j-th user with zero forcing beamforming is given by eqn. (1):

$$SE_j = log_2 \frac{(1+w_j^H.h_j|^2)}{N\ 0} \qquad (1)$$

Where: $SE_j$ is the spectral efficiency for the j-th user; $(W_j)$ represents the j-th column vector of the zero forcing beamforming matrix W; $(w_j^H)$ is the Hermitian transpose (conjugate transpose) of the j-th column vector of W; $h_j$ is the j-th column vector of the channel matrix H, representing the channel gains between the antennas at the base station and the j-th user; N0 is the power spectral density of the noise.

*Step 2: Total Throughput with Zero Forcing Beamforming*

The total throughput $(R_{total})$ in a massive MIMO system with zero forcing beamforming is the sum of the spectral efficiencies of all users represented as eqn. (2):

$$R_{total} = \sum(SE_j)_J \qquad (2)$$

Where: j ranges from 1 to L; L is the total number of users served by the base station. Substituting the expression for $SE_j$ in equation (1) into the total throughput equation yields eqn. (3):

$$R_{total} = \sum\left(\frac{(log_2|(1+w_j)^H.\,H_j|^2)}{N0}\right)_J \qquad (3)$$

*Step 3: Final Result*

The derived expression for the downlink data throughput $(R_{downlink})$ in terms of the number of user equipment (UEs) and base station antennas (BS) using zero forcing (ZF) beamforming is:

$$R_{downlink} = R_{total} = \sum\left(\frac{(log_2|(1+w_j)^H.\,H_J|^2)}{N0}\right)_J (4)$$

In equation (3.8), the summation is performed over all L users served by the base station. Each user's spectral efficiency $(SE_j)$ depends on the individual channel vector $(h_j)$ and the corresponding zero forcing beamforming vector $(w_j)$ for that user.

The downlink data throughput $(R_{downlink})$ is the total data rate transmitted over the downlink channel per unit time and is obtained by summing up the spectral efficiencies of all users in the massive MIMO system using zero forcing beamforming. This expression provides insights into the total system capacity and performance in terms of the number of UEs and BS antennas in the network.

### *Spectral Efficiency (SE)*

The spectral efficiency for the j-th user $(SE_j)$ is given by the Shannon capacity formula:

$$SE_j = log_2(1 + SNR_j) \qquad (5)$$

### *Total Throughput*

The total data rate $(R_{total})$ transmitted over the downlink channel is the sum of the spectral efficiencies of all users:

$$R_{total} = \sum(SE_j)_j = \qquad (6)$$

### *Downlink Data Throughput*

The downlink data throughput $(R_{downlink})$ is the total data rate transmitted over the downlink channel per unit time:

$$R_{downlink} = R_{total} = \sum(log_2(1 + SNR_j))_{\mathrm{j}} \quad (7)$$

In this system model, the noise power ($N_0$) was considered explicitly, as it affects the signal-to-noise ratio (SNR) and, consequently, the spectral efficiency and downlink data throughput of each user in the massive MIMO system using zero forcing beamforming. beamforming vectors, and noise level in the system.

### *Simulation Parameters and Flow-Chart*

The network simulation parameters used are shown in Table 1, while Table 2 are the channel coding parameters, and Figure 2 is the simulation flowchart.

**Table 1: Network Simulation Parameters**

| **Parameter** | **Value** |
|---|---|
| Network layout (L) | 25 |
| Inter-BS distance | 200 m |
| UE dropping (K) | 10 UEs in 200m x 200m area per BS |
| Minimum UE distance | 35m |
| Channel model | AWGN |
| BS antenna height | 25m |
| UE antenna height | 1.5m |
| Carrier frequency | 4 GHz |
| Transmission Bw (B | 20 MHz |
| Max UE transmit power | 23dBm |
| Max BS transmit power | 44dBm |

**Table 2: Channel Simulation Parameters**

| Parameter | Value |
|---|---|
| Channel coherence bandwidth ($B_C$) | 180 kHz |
| Channel coherence time ($T_C$) | 10 ms |
| Total noise power ($B\sigma^2$) | -96 dBm |
| Relative pilot lengths ($\tau^{(ul)}$; $\tau^{(ul)}$) | 1 |
| Computed efficiency at BS ($L_{BS}$) | 12.8 Gflops/W |
| Computed efficiency. at UE ($L_{UE}$) | 5 Gflops/W |
| PA efficiency at the BSs ($\eta^{(dl)}$) | 0.39 |
| PA efficiency at the UEs ($\eta^{(ul)}$) | 0.3 |
| Fixed Power consumption ($P_{FIX}$) | 18W |
| Local Osci. Power at BSs ($P_{SYN}$) | 2W |
| Circuit component Pow BS ($P_{BS}$) | 1W |
| Circuit component Pow UE ($P_{UE}$) | 0.1W |
| Coding Pow, data signals ($P_{COD}$) | 0.1 W/(Gbit/s) |
| Decoding Pow, data signals ($P_{DEC}$) | 0.8 W/(Gbit/s) |
| Backhaul Traffic Power ($P_{BT}$) | 0.25 W/Gbit/s) |

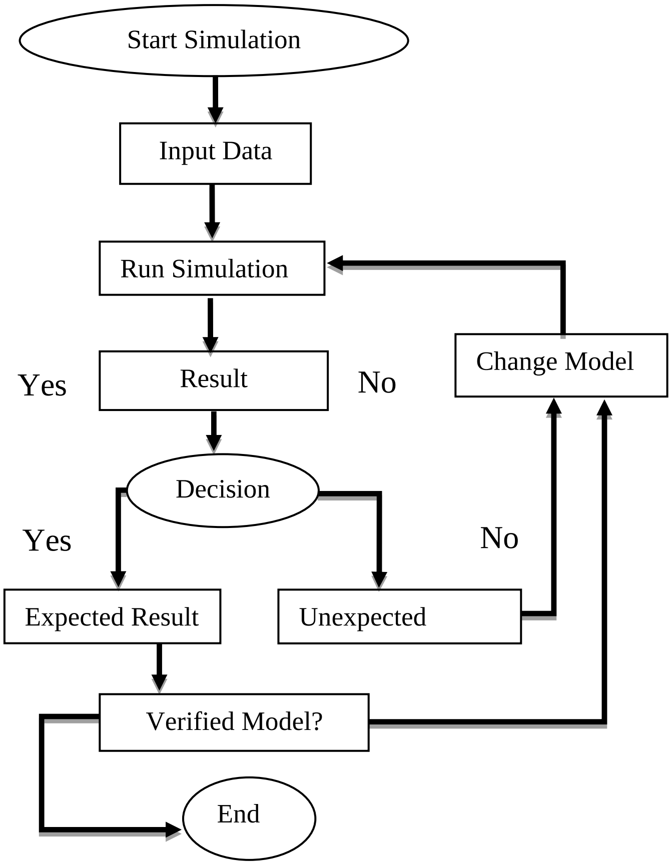


Figure 2: MIMO Simulation flow-chart

## RESULTS AND DISCUSSION

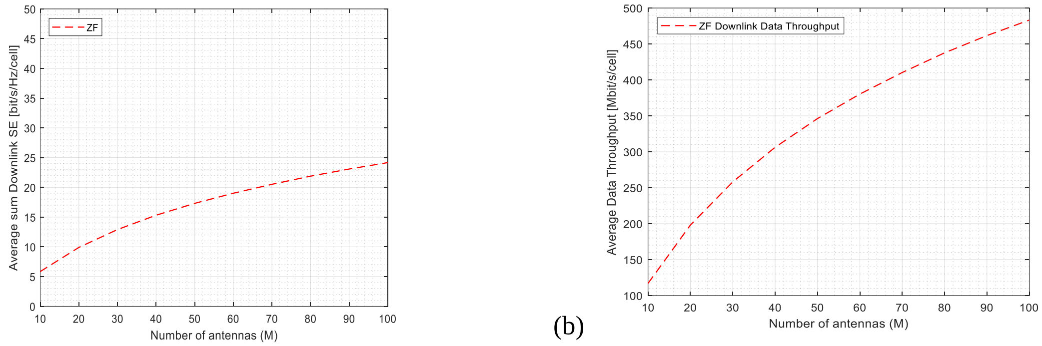
### Spectral Efficiency Simulation Result

The simulation results displayed on Table 3 are the cumulative spectral efficiency across individual cells within synthetic networks. It shows the performance of Massive MIMO during the exchange of data between User Equipment (UE) and the base station in both directions. The spectrum efficiency values range from 5.8442 bps/Hz for a configuration with 10 antenna elements (M) to 24.1608 bps/Hz for that of 100 antenna elements (M). Figure 3 is a visual representation depicting the overall spectral transmission efficiency plotted against varying quantities of antenna elements used in the simulation for data exchange with UEs.

**Table 3: Spectral Efficiency and Data Throughput**

| Antenna | SE Spectral Efficiency (bits/s/Hz/cell) | Data Throughput (Mbit/s/cell) |
|---|---|---|
| 10 | 5.8442 | 116.8834 |
| 20 | 9.9099 | 198.0189 |
| 30 | 12.9038 | 258.0750 |
| 40 | 15.3114 | 306.2287 |
| 50 | 17.3099 | 346.1975 |
| 60 | 19.0126 | 380.2528 |
| 70 | 20.5127 | 410.2542 |
| 80 | 21.8827 | 437.6549 |
| 90 | 23.0813 | 461.6254 |
| 100 | 24.1608 | 483.2158 |

Analyzing both Figure 3a and the corresponding data in Table 3, a distinct pattern emerges. Specifically, the average efficiency reaches its minimum when the number of transmitting antenna elements (M) is set to 10. Subsequently, there is a notable increase when M is 40, followed by a gradual and consistent growth from when the value of M is 50 to 100.



(a) (b)

Figure 3: (a) Spectral Efficiency and (b) Data Throughput for Downlink

This trend, evident from the visual representation and the tabulated data, yields valuable insights into the intricate relationship between antenna elements and the overall spectral efficiency.

**Data Throughput Simulation Result**

Table 3 also compiled the results derived from simulating the average data rate within individual cells across the synthetic networks, with a specific focus on the performance of Massive MIMO during data transmission. The recorded average data rates range from 116.8834 Mbps for a configuration involving 10 antenna elements (M) to a notable 483.2158 Mbps for scenarios employing 100 antenna elements (M).

Figure 3(b) is the graph of The Average Data Rate against varying quantities of antenna elements utilized within the simulation for data transmission to and from UEs. Figure 3b shows that the lowest average data rates were observed when the transmitting antenna elements (M) are set to 10. This is succeeded by a significant upsurge in the data rate at M is 40, followed by a slower but consistent upward trend from M is 50 to 100. This trend provides valuable insights into the intricate relationship between antenna elements and the resulting average data rate.

**Discussions**

The presented results in Table 3 highlight the critical interplay between the number of antenna elements (M) and both spectral efficiency and data throughput. The column of cumulative spectral efficiency, which accounts for the efficiency of data exchange between UEs and base; and the values vary across different scenarios, ranging from 5.8442 bps/Hz with 10 antenna elements to 24.1608 bps/Hz with 100 antenna elements. This data shows that how the quantity of antenna elements significantly improves spectral efficiency. From the graph in Figure 3, the trend of spectral transmission efficiency increases shows that: spectral efficiency initially dips at M = 10, then experiences a substantial upswing at M = 40, followed by slower, but consistent growth from M = 50 to 100. This trend suggests that optimal performance is expected around 10 to 50 antenna elements. This provides valuable insights into optimizing spectral efficiency and system performance.

Again, Table 3, shows the average data rates across individual cells within networks. The average data rates range from 116.8834 Mbps with 10 antenna elements to an impressive 483.2158 Mbps with 100 antenna elements, which is graphically depicted in Figure 3(b). The pattern in the graph mirrors the spectral efficiency trend, where the average data rate is lowest at M = 10, spikes significantly at M = 40, and experiences a slower but steady growth from M = 50 to 100. The performance trends of data throughput are analogous to that of spectral efficiency. This suggests that the quantity of antenna elements (M) is a critical parameter affecting both spectral efficiency and data rates. The observed initial dip in efficiency and data rate at M = 10 could be attributed to factors such as interference or suboptimal antenna configurations. The subsequent improvements with higher M values underscore the advantages of using more antenna elements, leading to enhanced system performance.

The results when compared with the research by Lim et al., (2015), which worked extensively on various schemes such as maximum ratio transmission (MRT) and maximum ratio combining (MRC); Zero-forcing Scheme of 10 user elements (UE) by 100 antenna element (M) did outperform both schemes visibly well with MRC for 100 M elements at about 9.5 bps/Hz while ZF is at about 24.16 bps/Hz. This improvement achieved is about 254 % increase, hence maximizing the scarce communication channel while delivering more data output.

## CONCLUSION

This paper investigated the performance of a vast number of multi-user Multiple-input, Multiple output (–MIMO) antenna elements by simulating several hypothetic networks for User Element data exchange. It examined the effects of number of antenna elements (M) on spectral efficiency (SE) and data rates (R). It was observed that the more the number of antennas, M, the higher the value of both spectral efficiency (SE) and data rates (R). Initially, at M=10, Spectral Efficiency drops, rises at M=40, and gradually grows between M=50 up to 100. Data throughput rates exhibited the same trend; showing that increasing the number of antennae (M) increases transmission performance. This study also has established a direct relationship between number of antenna elements M, and spectral efficiency, *SE* as well as data throughput, R . In conclusion, increasing the number of antenna elements leads to visible improvements in both spectral efficiency and data rates as depicted by the direct relationship between antenna elements and system performance. These findings are new practical insights and approaches for systems engineers and network providers; to improve and design their networks. To optimize efficiency and higher data rates in today’s LTE setups, practitioners can modify the network by increasing the number of antenna elements, For improved downlink throughput using massive MIMO technology, Lim et al., (2015), Selvam & Vishvaksenan, (2019) and Singh et al., (2023) identified some typical areas to consider future research namely: estimating Channel and Hybrid Beamforming; optimizing algorithm and managing Interference. These prospective developments in Massive MIMO could mark the direction for the future in optimizing the performance of communication networks across future deployments of LTE applications .

## REFERENCES

Abdo, A. M. A., Zhao, X., Zhang, R., Zhou, Z., Zhang, J., Zhang, Y. and Memon, I. (2018). MU-MIMO downlink capacity analysis and optimum code weight vector design for 5G big data massive antenna millimeter wave communication. *Wireless Communications and Mobile Computing*, *2018*.

Ashikhmin, A., and Marzetta, T. L. (2012). Pilot contamination and precoding in multi-cell large scale antenna systems. In Proceedings of IEEE International Symposium on Information Theory (pp. 1142–1146).

Aslam, M. Z., Corre, Y., Björnson, E., and Larsson, E. G. (2019). Performance of a dense urban massive MIMO network from a simulated ray-based channel. *EURASIP Journal on Wireless Communications and Networking*, *2019*, 1-13.

Björnson E., Hoydis J. and Sanguinetti L. (2017), “Massive MIMO Networks:Spectral, Energy, and Hardware Efficiency”, Foundations and TrendsR in Signal Processing: Vol. 11, No. 3-4, pp 154–655. DOI: 10.1561/2000000093

Fernandes, F., Ashikhmin, A., and Marzetta, T. (2012). Interference reduction on cellular networks with large antenna arrays. In Proceedings of IEEE International Conference on Communications (pp. 5773–5777).

Hoydis, J., Brink, S. T., and Debbah, M. (2011). Massive MIMO: How many antennas do we need? In Proceedings of the Allerton Conference on Communication, Control, and Computing (pp. 545–550).

Hoydis, J., Brink, S. T., and Debbah, M. (2013). Massive MIMO in the UL/DL of Cellular Networks: How Many Antennas Do We Need? IEEE Journal on Selected Areas in

Marzetta, T. L. (2010). Noncooperative cellular wireless with unlimited numbers of base station antennas. IEEE

Transactions on Wireless Communications, 9(11), 3590–3600.

Lim, Y. G., Chae, C. B., and Caire, G. (2015). Performance analysis of massive MIMO Cell-Boundary User. IEEE Transactions on wireless Communications 14(12), 6827 – 6842.

Ngo, H. Q., Marzetta, T. L., and Larsson, E. G. (2011). Analysis of the pilot contamination effect in very large multicell multiuser MIMO systems for physical channel models. In Proceedings of IEEE International Conference on Acoustics, Speech and Signal Processing (pp. 3464–3467).

Rusek, F., Persson, D., Lau, B. K., Larsson, E. G., Marzetta, T. L., Edfors, O., and Tufvesson, F. (2013). Scaling up MIMO: Opportunities and challenges with very large arrays. IEEE Signal Processing Magazine, 30(1), 40–60

Selvam, P. D., and Vishvaksenan, K. S. (2019). Antenna selection and power allocation in massive MIMO. *Radioengineering*, *27*(1), 340-346.

Singh, M. S. J., Saleh, W. S. W., Abed, A. T., and Fauzi, M. A. (2023). A Review on Massive MIMO Antennas for 5G Communication Systems on Challenges and Limitations. *UKM Eng. J*, *35*, 95-103.