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Enhancement of Cooperative NOMA Performance via Integration with m-MIMO and Caching

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Abstract

The demand for data and the spectrum utilization together with interference issues and energy use requirements and sustainability objectives and reduced latency needs have become the main driving forces behind developing 6G mobile networks. High-definition videos along with augmented reality and virtual reality and connected devices in the Internet of Things (IoT) are main factors behind the network growth. This research aims to examine the strategic combination of C-NOMA cooperative access and massive MIMO antennas with caching data entities to boost the operational qualities of these networks. The combined system seeks to manage escalating data volumes better. This research proposed a combination of C-NOMA with massive MIMO along with caching functions to boost 6G network operations in dynamic form. NYSIM along with MATLAB simulations are used to evaluate the performance of this system against different setups that implement massive MIMO technology in 6G communication networks. The results demonstrated that integrating C-NOMA with caching and m-MIMO leads to better performance in sum rate, latency reduction, and throughput for different file sizes, different networks traffic, different users and stations numbers and different power allocation levels. The results also show improvement gained in sum rate, throughput, latency reduction when compared with other recent studies too. Finally, integration results lead to higher-level performance improvement in the 6G mobile networks.

Keywords: *6G mobile communication, C-NOMA, caching, m-MIMO, dynamic resource allocation.*

1 Introduction

The exponential rise in data demands in 6G mobile communication networks rises the problems latency, spectrum constraints, interference reduction and energy efficiency. Thus, research should be conducted in these challenges to solve these problems. One approaches that can be considered is the combination of C-NOMA with massive MIMO together with caching. This approach is used to maximizes spectrum efficiency, reduces interference, and improves user experience by enabling simultaneous transmissions and spatial multiplexing, which results in higher data rates and lower latency [1]. Moreover, caching reduces latency even more and improves content delivery by making frequently accessed content close to users and avoiding the need to bring such contents from distant sources with assurance of efficient spectrum use, low-latency communication, and a flawless user experience. This integration has laid the foundation for a robust and sustainable 6G mobile communication ecosystem [2].

Caching reduces the need to retrieve content from distant servers, increasing spectral efficiency by optimizing available spectrum resources [3]. By utilizing C-NOMA's power domain multiplexing capabilities and Massive MIMO's ability to serve many users with spatially multiplexed streams, the integration increases the system's total throughput [4]. For the reduction of average latency, C-NOMA and Massive MIMO synergistically collaborate to facilitate effective resource allocation and interference management, culminating in diminished transmission delays and reduced latency. This mechanism proves particularly advantageous for latency-sensitive applications such as gaming, real-time communication, and Internet of Things applications that necessitate rapid response times [5]. Caching additionally diminishes the requirement for frequent long-distance data transmissions, which further conserves energy consumption in data delivery [6].

While accepting changes in user traffic and content popularity, the ability to dynamically adjust resource allocation, power levels, and caching techniques ensures the effective use of network resources [7]. Reduced waiting times for content retrieval led to increased user satisfaction and network service engagement [8]. This C-NOMA Massive MIMO with caching integrated framework is inherently scalable and flexible enough to accommodate changing network conditions and user needs [9, 10].

The research problem is how to overcome the challenges brought on by the exponential growth in data demand, spectrum constraints, and the requirement for low-latency communication, C-NOMA, Massive MIMO, and caching must be included into 6G mobile communication networks. The research problem can be defined as the ability to adapt power levels, caching tactics, and resource allocation dynamically ensures effective network resource use while taking user traffic and content popularity fluctuations into account. This suggests the research objectives through the investigation of how well C-NOMA with and without massive MIMO and caching enhances the performance and efficiency of 6G networks.

The rest of this study is in the following order. In section 2, C-NOMA with caching integrated with massive MIMO in 6G mobile communication networks, together with detailed related works concerning C-NOMA with caching and massive MIMO, has been presented. In section 3, proposed C-NOMA massive MIMO with caching in 6G mobile communication is presented. Section 4 presents the system simulation and analysis. Section 5 presents the proposed integration of m-MIMO NOMA with the caching technique. Finally, the conclusion and future work are presented in section 6.

2 Methods and Materials

Two advanced techniques, C-NOMA and Massive MIMO, are greatly improving how 6G mobile networks work. Massive MIMO makes better use of radio spectrum, allowing for faster data speeds, wider coverage, more capacity, and lower energy use. They also make networks more reliable and flexible. Mathematically, C-NOMA with Massive MIMO in 6G can be represented by [11]:

$$y_{k,n} = \sqrt{P_n} \cdot h_{k,n} \cdot x_n + \sum_{\substack{j=1 \\ j \neq n}}^{N} \sqrt{P_j} \cdot h_{k,j} \cdot x_j + n_k \tag{1}$$

where:

- (P_n) represents the transmitted power for user (n) is.
- $(h_{k,n})$ represents channel gain nth user with the kth antenna.
- (x_n) represents transmitted symbol by user (n)
- (n_k) represents the AWGN The AWGN at the (K_{th}) antenna of the BS.

Usually, users are divided into multiple power domains in NOMA. The power allocation problem for NOMA can be described mathematically as [12]:

$$\max_{P_n} \sum_{n=1}^{N} \log_2\left(1 + \frac{P_n \cdot |h_{k,n}|^2}{\sum_{\substack{j=1 \\ j \neq n}}^{N} P_j \cdot |h_{k,j}|^2 + \sigma^2}\right) \tag{2}$$

subject to: $0 \leq P_n \leq P_{max}$,

where the noise power denoted (σ^2), the maximum transmit power denoted (P_{max}), and the power allocation denoted (P_n) to user (n). The base station is assumed to utilize beamforming to simultaneously serve numerous consumers in the context of massive MIMO. The signal vector obtained at the base station can be described as [13]:

$$\mathrm{y}_k = \sum_{n=1}^{N} \sqrt{P_n} \cdot h_{k,n} \cdot x_n + \mathrm{n}_k \tag{3}$$

where:

- The received signal vector denotes as (Y_k) at the (K_{th}) antenna of the BS.
- The AWGN vector denotes as (n_k) at the (K_{th}) antenna of the BS.

The mathematical method serves as a core component for C-NOMA Massive MIMO applications in 6G networks. The system combines NOMA which distributes power with Massive MIMO which distributes space through beamforming. The network receives performance and efficiency enhancements because of their combined effort. The implementation of caching for C-NOMA Massive MIMO in 6G networks demands well-planned operations on air transmission data and in-network data storage. The goal focuses on developing a system that operates at better speeds. The addition of caching introduces m which represents local file storage while $(x_{m,n})$ depicts the requested file of user (*n*) for file (*m*). Caching optimization presents itself as a mathematical problem requiring optimal file placement to enhance network efficiency as per [14].

$$\max_{x_{m,n}} \sum_{m=1}^{M} \sum_{n=1}^{N} \mathrm{hit}_{m,n} \cdot \log_2\left(1 + \alpha_{m,n}\right) \tag{4}$$

subject to:

$$\sum_{n=1}^{N} x_{m,n} \leq C_m$$

where $(hit_{m,n})$ is a variable indicating whether user (n) requests content (m) from the cache, $(\alpha_{m,n})$ is the achieved SINR by user (n) when requesting content (m) and (C_m) is the cache capacity. The integration system aims to boost performance through strategic management of transmission and caching operations under power and storage constraints. The combined optimization method for resource allocation at this point maximizes 6G mobile network efficiency through C-NOMA Massive MIMO and caching.

A range of studies exists to optimize and boost the operational capabilities and effectiveness of 6G mobile network communication methods beyond regular transmission procedures.

In a study by [15], four new system models that mix NOMA, D2D, and caching were created and tested. They found that the total time to deliver files is a good way to measure how well the system is performing. When all files are sent at once, delivery times are shorter. Another study by Hassan and colleagues in 2023 showed that NOMA is a very effective way to improve spectrum efficiency in 6G networks. They explained how multiple access techniques can boost the spectrum efficiency of NOMA's downlink power domain.

Researcher in [16] provided a detailed review of current trends and new patterns. They explained that 6G will deliver faster speeds and better connections. It will reach a level where telling the difference between the real world and the virtual one becomes nearly impossible.

In another study [17], the authors introduced a new clustering method. They also proposed a model called Massive MIMO NOMA double mode to improve network performance.

The authors in [18] created a novel clustering approach as part of their study. The authors designed the Massive MIMO NOMA double mode model as a solution to improve network efficiency. Researchers aim to achieve multiple objectives including the enhancement of average sum rate, maximum energy efficiency for edge user areas and reduced power battery consumption. The outcome of the study proved that this model both maximizes energy efficiency and facilitates environmentally-friendly wireless network development. Numerical investigations from the researchers established improved average rate and energy efficiency marks superior to traditional network designs.

3 Proposed Dynamic C-NOMA Massive MIMO with Caching Technique

6G mobile communication networks implementing C-NOMA Massive MIMO require a system algorithm to address multiple operating elements such as resource allocation and interference management together with caching strategies. The proposed design aims to improve system performance and efficiency by optimizing resource sharing, beamforming, and caching at the same time. The proposed dynamic C-NOMA Massive MIMO with caching system works according to the diagram presented in Figure 1.

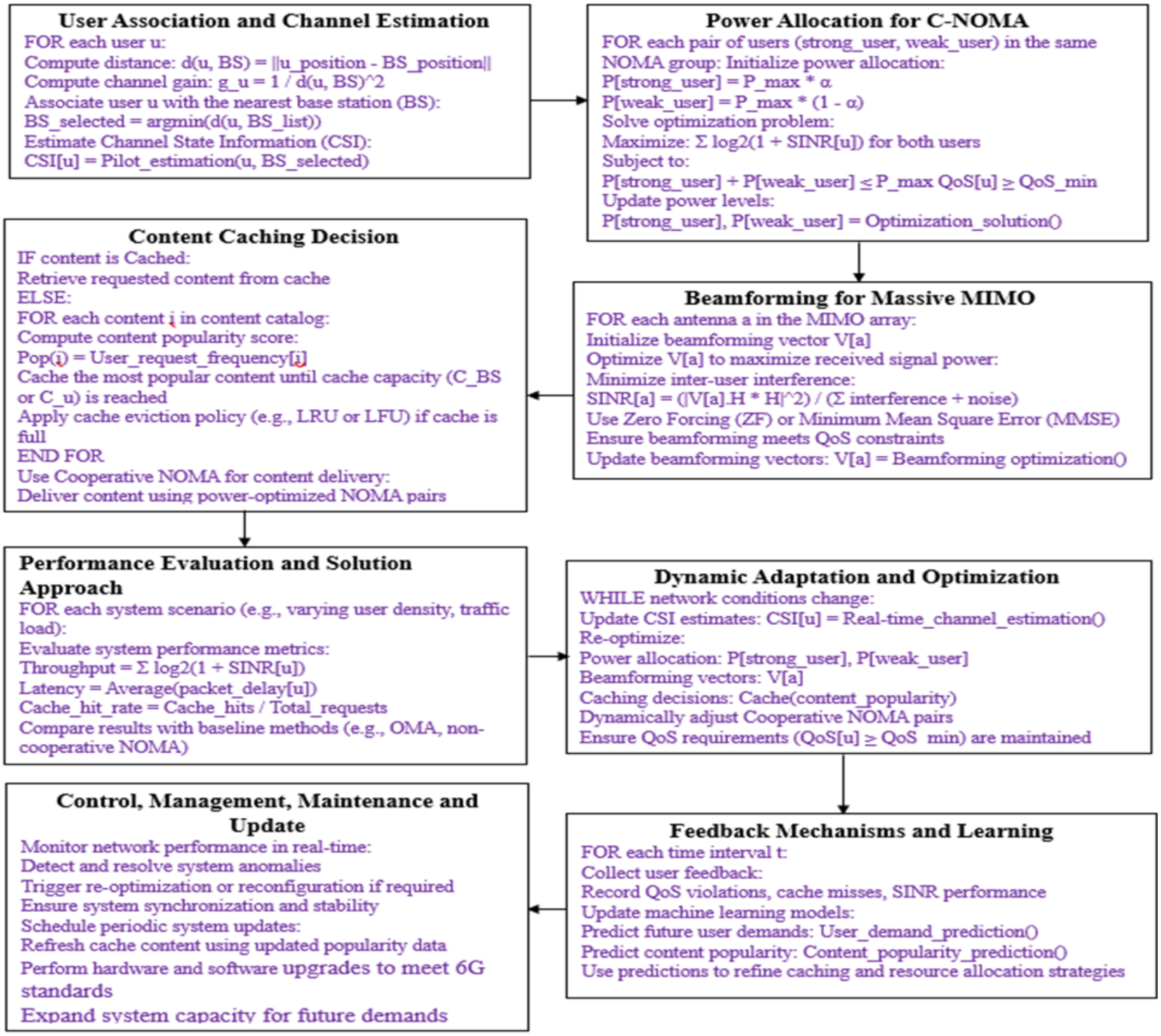


Figure 1: The Flow Chart Diagram of C-NOMA Massive MIMO with Caching

The diagram outlines the essential procedures which direct C-NOMA Massive MIMO with caching administration in 6G mobile networks. Following step-by-step process allows C-NOMA Massive MIMO with caching to work better. The main steps include:

a. At the beginning the system identifies channel conditions for individual users. The system retrieves channel state information through methods that combine distance between users and their link quality.

b. The system defines redistribution of power among users when performing C-NOMA transmission. The system controls these power distributions in order to achieve higher sum rates while maintaining equal user service levels below their power thresholds.

c. The system proceeds to generate beamforming vectors for every antenna.

d. The system takes responsibility for selecting which content needs to be stored either at base stations or user devices. The system selects its method by considering both content popularity and user preferences as well as disk space availability. The system implements three caching policies: Least Recently Used (LRU), Least Frequently Used (LFU) and probabilistic approaches to determine when and what content to store for removal.

e. An optimization problem appears after system setup. The combination of power distribution and beamforming and caching functions together to enhance the system performance.

f. Anton Soft uses automated algorithms to address this issue. The optimization system applies iterative or heuristic methods through continuous updates to power distribution and beamforming along with caching to discover the optimal configuration.

g. The system must also adapt in real-time to changes in network conditions and user needs. Feedback mechanisms help update channel info, power levels, and cache content continuously.

h. Test to check if the system is working well and meets the performance goals.

i. Finally, the system is maintained regularly. This includes updating caches and making system improvements.

The proposed dynamic system has been implemented in 6G mobile communication networks shown in Figure 2.

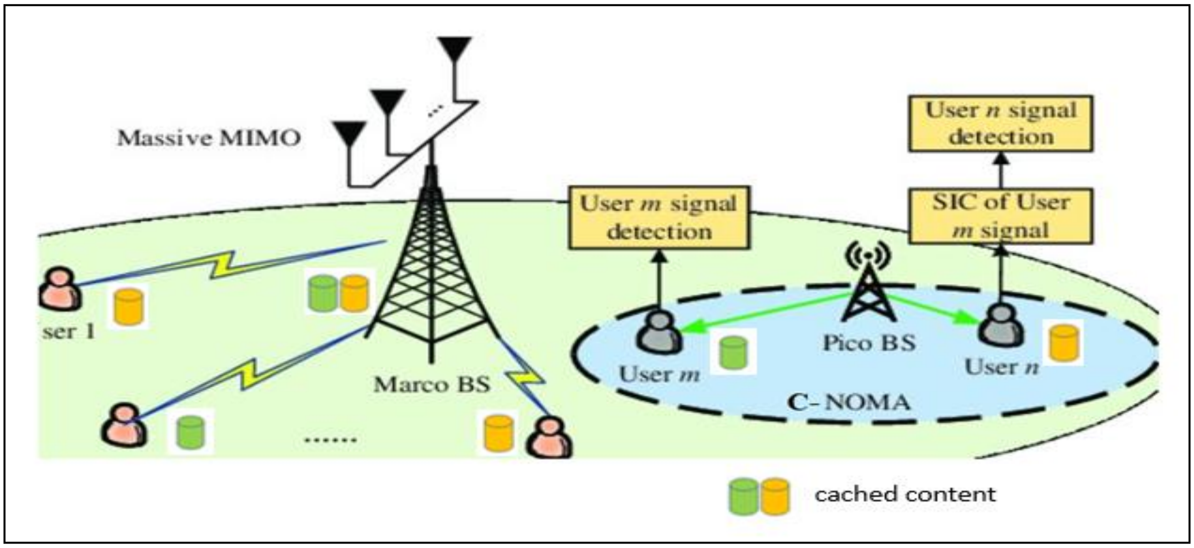


Figure 2: The C-NOMA m-MIMO with caching system layout for 6G

Within the 6G implementation layout, the proposed system has several key parts;

a. First, assume the network includes base stations (BSs) with K antennas that support Massive MIMO technology and features edge computing nodes. The number of users served by each BS is N, and each user has an ID labeled n.

b. The connection between user n and each antenna of the BS is described by a channel gain, labeled H. These channels follow a Rayleigh fading model, which includes small-scale fading effects.

c. For power sharing, the NOMA system allocates power to user n, shown as P. This allocation considers both the quality of the channel and fairness rules to ensure everyone gets a fair share.

d. Massive MIMO allows the BS to connect with many users at the same time through beamforming. The beamforming vector for each antenna is represented by a specific symbol. Content caching takes place either at the BS or the users' devices. The total number of files that can be stored is M. Whether a user has a particular file cached is shown by a binary indicator, where 1 means the file is cached for user n, and 0 means it is not.

e. Base stations act as access points for user connections. Edge computing nodes store content and help manage C-NOMA transmissions. Each edge node has its own cache to hold popular files. Caching is done using algorithms that predict what users will want, based on their behavior and the popularity of content. For the BS caches, the cached files are represented by a set, with a maximum capacity of M items. The content stored depends on how popular it is, user demands, or other caching rules.

f. The connection channels between each user and BS or relay nodes are affected by factors like distance, shadowing, and fading. These channels are often frequency-selective and change over time. This means transmission parameters must be adjusted regularly to keep the system running well.

4 System Simulation and Analysis

To achieve the system implementation and to evaluate the proposed system, the proposed system was using MATLAB and NYUSIM simulations. The main parameters used in the simulation of proposed system integration with are illustrated in Table 1.

Table 1: The main parameters used in the simulation of 6G networks mobile communication.

Parameters	**Values**
Base Stations Numbers	5
Users Equipment Numbers	100
Antennas at the Base Station Numbers	64*64
Range of SNR dB	-20 to 20 dB
Operating BW	20 MHz
Maximum Content Items no.	100
Content Items total no.	1000
Caching Policy	Least Recently Used (LRU)
Content Popularity distribution with exponent	$\alpha = 0.8$
Simulation Period	1000 s
Simulation Runs Number	10
Interval for Performance Metrics Collection	Every 10s
The Gain of Cooperative-NOMA Transmission	2
Average request rate (requests per user per second)	0.1
Number of simulation iterations	100
User Requests	Rand (num-users, 1) < request-rate
Channal Gain Type	[Rayleigh fading]

The simulation results are shown in Figures 3a, 3b, and 3c. These figures demonstrate that integrating C-NOMA with caching and Massive MIMO leads to better performance in sum rate, latency reduction, and throughput. This integration results shown a higher-level performance improvement that leads to improve the 6G mobile networks.

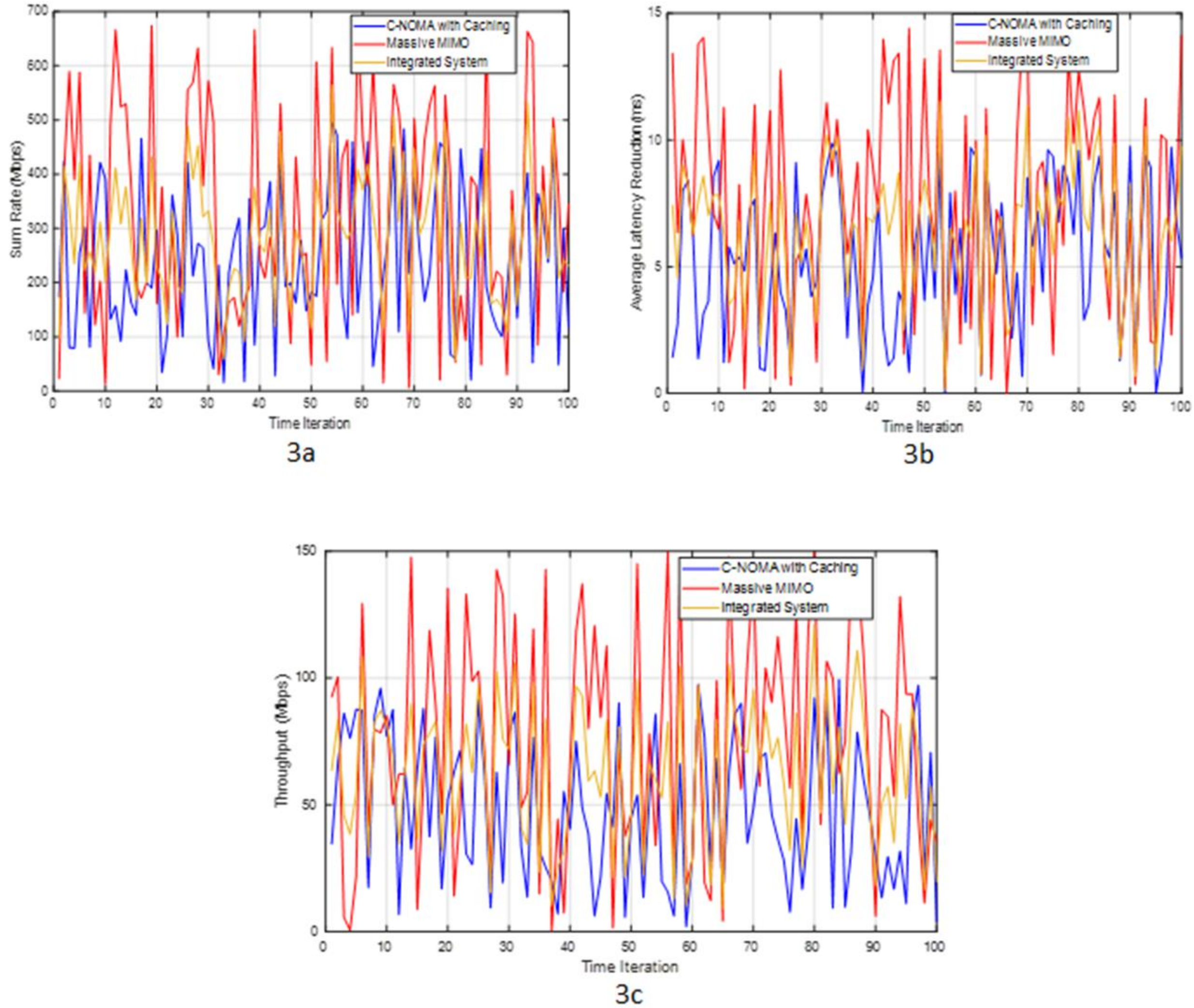
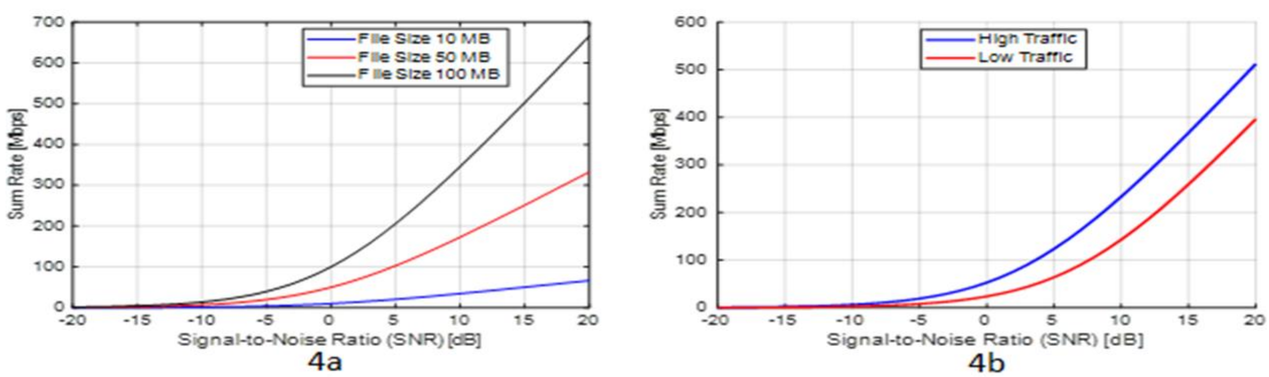


Figure 3: C-NOMA with Caching and Massive MIMO techniques Performance. 3a: The Sum Rate, 3b: Average Latency reduction, and 3c: Throughput.

Extra simulation was carried out to show how the sum rate relates to SNR when using the proposed system combined with massive MIMO technology. The results of these extra tests are shown in Figure 4. In Figure 4a, the impact of file size on system performance is displayed. The results show that as the file size gets larger, the sum rate also increases. This growth due to the advantages of integrating the proposed system C-NOMA with massive MIMO technique.



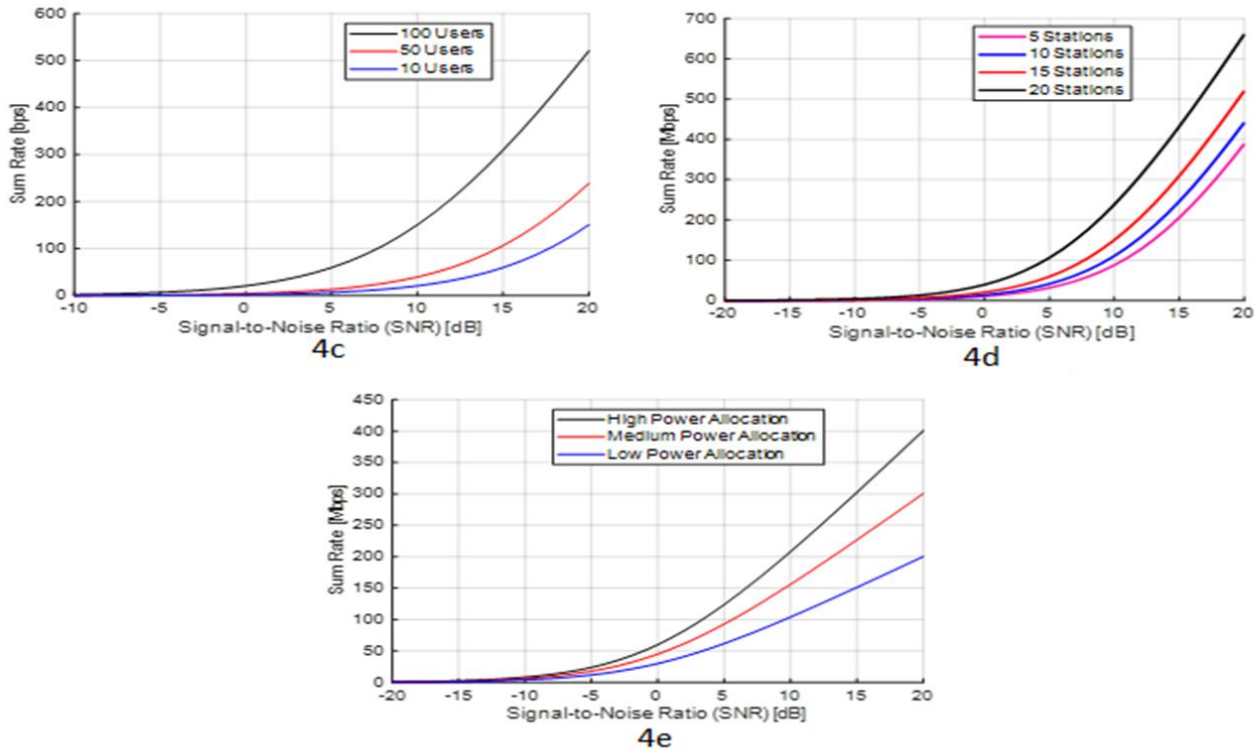


Figure 4: The Proposed System Evaluation for Sum Rate versus SNR (dB) for C-NOMA with Caching and Massive MIMO technique. 4a: Different File Sizes, 4b: Different network traffics, 4c: Different User Numbers, 4d: Different station numbers and 4e: Different Power Allocation levels.

Figure 4b shows the sum rate compared to SNR for high and low network traffic. The results show that the sum rate is 512.271 Mbps when traffic is high and 396.666 Mbps when traffic is low. This demonstrates that combining the proposed system with massive MIMO improves the overall data rate. It also shows that higher network traffic leads to a higher data rate.

Figure 4c presents the results of the proposed C-NOMA system with caching and massive MIMO. It shows the sum rate in Mbps versus SNR in dB. The results indicate that as the number of users grows, the sum rate also rises. This is because the integration of the proposed system with massive MIMO enhances performance in 6G mobile networks.

Figure 4d displays the simulation results for the system with different numbers of stations. It shows how the sum rate in Mbps changes with SNR in dB. As the graph shows, increasing SNR leads to a higher sum rate. It is also clear that adding more stations boosts the overall data rate. These findings highlight that increasing the number of stations improves the system's performance, thanks to the advantages of massive MIMO technology.

Figure 4e shows how the sum rate related to SNR under different power allocation levels. The results show that the sum rate is higher when power allocation is at a high level. Conversely, the sum rate drops when power allocation is low.

The combination leads to maximum speed and minimum delay performance and higher data transfer rates which enhance the power and effectiveness of 6G mobile networks based on Figure 5. The figures in 5a, 5b and 5c show sum rate data, latency and throughput improvements measured with and without caching for massive MIMO NOMA.

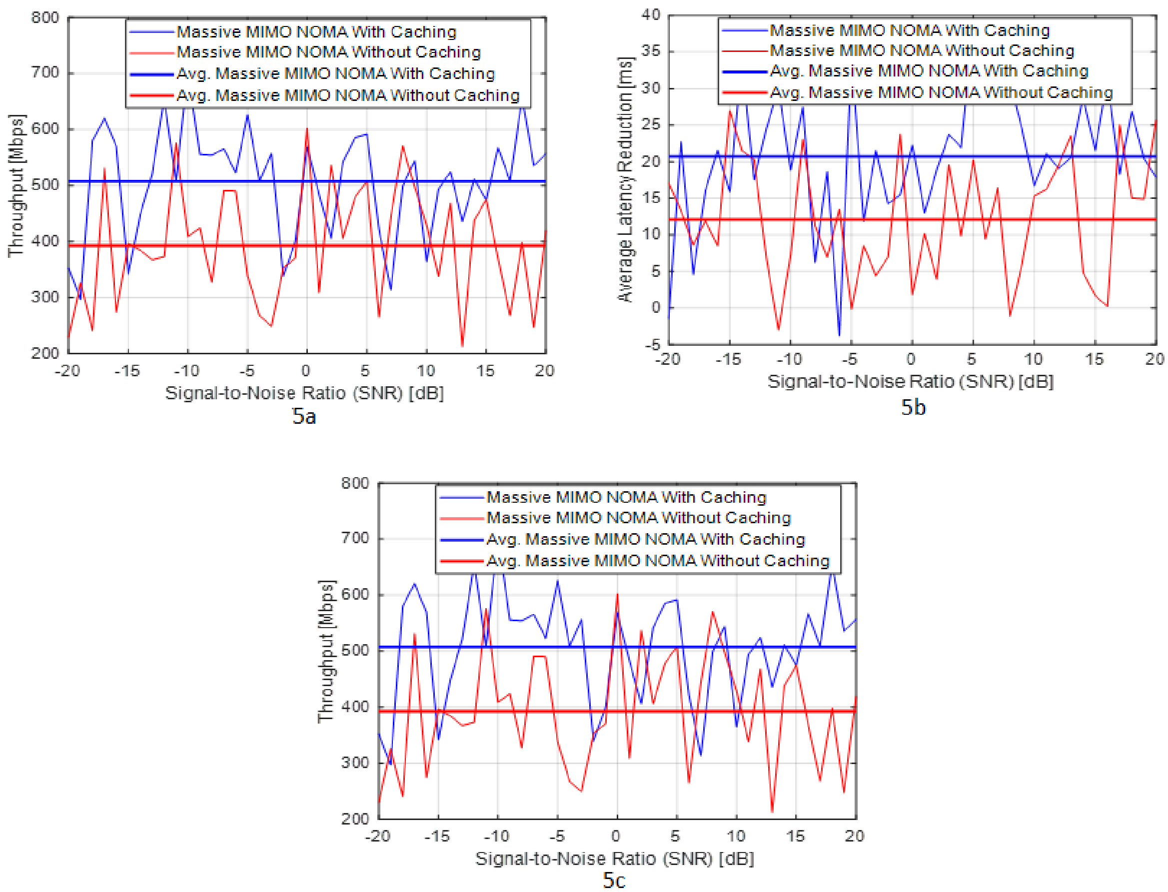


Figure 5: Performance of Integrated Massive MIMO NOMA for with and without Caching Techniques. 5a: Sum Rate vs SNR, 5b: Average Latency reduction vs SNR, and 5c: Throughput vs SNR

A summary of simulation results for all techniques studied is presented in Figure 6.

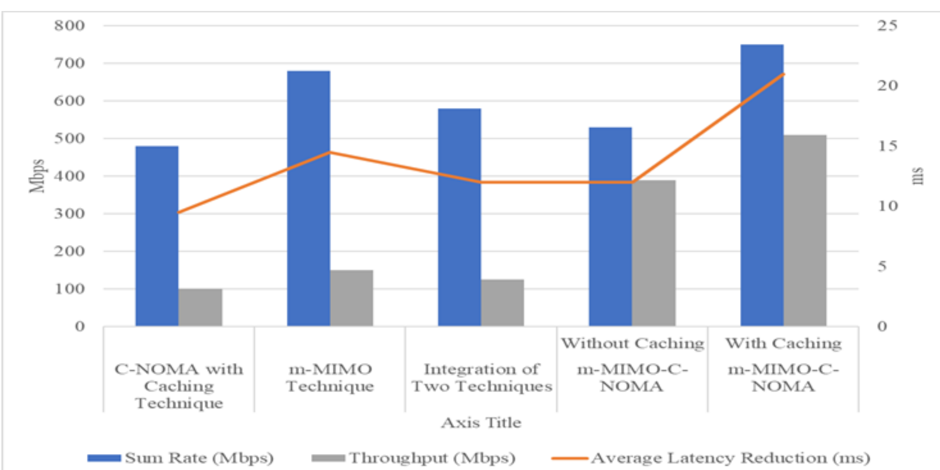


Figure 6: A summary of simulation results for all techniques

Finally, the proposed system investigated has been compared with previous studies in related works. The results of comparison are presented in Table 2.

Table 2: A Comparison for Sum rate, average Latency Reduction and Throughput between related works and proposed system

Reference	Sum rate (Mbps)	Average Latency Reduction (ms)	Throughput (Mbps)
[4]	100	2.5	20
[15]	350	5.3	100
[17]	450	9	150
Proposed	750	21	510

5 Conclusion

The paper investigated the problem continuously raised in communication networks especially in recent generation such as 6G due to the exponential rise in data demands. The demand of 6G for higher throughput, higher sum rate and lower latency with spectrum constraints, interference and energy efficiency is a challenge that for recent research to adopt IoT, smart cities, smart cars and new technologies. The research paper is considered is the combination of C-NOMA with massive MIMO together with caching to resolve such problem. This paper shows that combining C-NOMA Massive MIMO with caching improves the performance of 6G networks. The results of combination show the increases the sum rate, reduction in average latency, and boost throughput. Simulation tests compared the new approach with C-NOMA Massive MIMO without caching for different file sizes, different networks traffic, different users and stations numbers and different power allocation levels. The results showed that the proposed system significantly enhances the sum rate, throughput, and latency for all cases investigated in 6G networks. However, the improvements in sum rate and throughput were less clear when used with massive MIMO alone. Overall, adding caching to Massive MIMO improves network performance, which the simulations confirmed but the complexity defiantly will be increased. This can be proposal for further research. Comparison with other recent studies in 6G networks showed the improvement gained too.

Future research should focus on investigating the impact of inclusion caching in the complexity, combining different technologies, better resource sharing, and solving security and privacy issues. Improving energy use and making standard rules for mass deployment are also important. Using various techniques and algorithms for resource sharing can lead to better results. This will make 6G networks faster and more efficient.

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