IRAQI Academic Scientific Journals
Al-Rafidain Engineering Journal (AREJ) Vol. 30, No. 1, March 2025, pp. 135-149

6G Mobile Communication Performance Enhancement Using Cooperative NOMA and Caching

Salar I. Ahmed* salar.ahmed@epu.edu.iq
Siddeeq Y. Ameen ** siddeeq.ameen@dpu.edu.krd

* Information System Engineering Department, Erbil Technical Collage, Erbil Polytechnic University, Erbil, Iraq
** Energy Engineering Department, Duhok Polytechnic University, Duhok, Iraq

Received: August 1st, 2024 Received in revised form: September 19th, 2024 Accepted: September 28th, 2024

ABSTRACT

Mobile communication networks in 6G with emerging applications and standards introduce demands for an increasingly intelligent network, smart services based on the Internet of Everything (IoE), extremely low latency, fast network connection, lower power, and support for a large number of different communication services. These demands require advanced techniques to improve and enhance the performance and efficiency in the 6G mobile communication network systems. The paper proposed a technique that combines C-NOMA with caching as a dynamic resource allocation among users and relay nodes is used to enhance and optimize performance and efficiency of 6G mobile communication networks. The results have shown promise in maximizing throughput, minimizing latency, and optimizing resource efficiency. Caching reduces access latency and network congestion by making use of the idea of keeping frequently requested content closer to users. Through dynamic adjustments to user clustering and resource distribution within clusters, the system may maximize utilization of resources and reduce interference, resulting in enhanced system efficiency and performance. The simulation results with the aid of MATLAB (V 2022a) demonstrate the enhancements of 6G mobile communication networks achieved by C-NOMA with caching compared to all systems through the improvement in latency, sum rate, and throughput the investigation of different cases of 6G mobile communication networks environments and compared with the same cases in traditional NOMA.

Keywords:

6G, C-NOMA, caching, dynamic resource allocation, D2D.

===

1. INTRODUCTION

The demand for faster, more reliable, and more efficient networks to support a wide range of applications and services has increased due to the quick advancement of wireless communication technology. Emerging use cases such as the Internet of Things (IoT), augmented reality (AR), virtual reality (VR), ultra-high-definition video streaming, and autonomous vehicles require novel approaches to be explored in order to improve performance and efficiency as we proceed closer to the era of 6G mobile communication networks. [1]. Globally rapid communication is the feature that the upcoming sixth-generation (6G) communications technologies and networks aim to provide, with extremely low latency and large data rates. In its Release 13 (R13), the Third Generation Partnership Project (3GPP) identified three primary use cases for 5G: massive machine type communication (m-MTC), ultra-reliable and low latency communication (u-RLLC), and enhanced mobile broadband (e-MBB) [2]. Algorithms are being developed concurrently for the next generation of communication systems, which will perform better than the current 5G networks. To be more precise, in order to achieve massive access in communication systems that go beyond 5G (B5G)/6G, a more robust network needs to be developed [3].

Caching makes use of the idea of keeping frequently requested content closer to users in order to minimize network congestion and access delay. Utilizing the diversity gains and increasing spectral efficiency, C-NOMA allows simultaneous transmission to numerous users on the same resource [4]. The combination of C-NOMA with caching appears to be an effective combination that has the potential to completely change the wireless communication scenario as 6G mobile communication networks are navigated [5].

Using the cooperative diversity and spectral efficiency advantages made possible by NOMA, 6G mobile communication networks will be able to achieve previously unreachable levels of performance and efficiency by utilizing caching to reduce network congestion and reduce latency [6]. C-NOMA with caching technique helps in fast content placement and delivery, maintaining fairness in 6G mobile communication networks due to the dynamic behaviors of the wireless channel and movement of the user content placement and delivery that become challenges in wireless caching networks [7]. While there are many benefits of C-NOMA with caching, their effectiveness needs to be further investigated and evaluated in conjunction with other state-of-the-art techniques in order to fully solve the complex issues that 6G networks confront [8].

The purpose of this study is to develop 6G network technologies by clarifying the relative performance of C-NOMA with caching with other systems and to help make educated decisions regarding network design, optimization, and deployment. Furthermore, investigate whether combining C-NOMA with caching and dynamic resource allocation techniques will improve the performance and efficiency of the 6G mobile communication network system. In this proposed algorithm, various factors need to be considered, such as resource allocation, interference management, and caching strategies.

The rest of the paper is in the following order: In Section 2, C-NOMA with caching in 6G mobile communication networks are represented. In Section 3, detailed related works concerning C-NOMA with caching have been presented and discussed. In Section 4 the proposed C-NOMA with caching in 6G mobile communication is presented. Section 5 presents the system simulation and analysis. Finally, the conclusion and future work are presented in Section 6.

2. C-NOMA AND CACHING IN 6G MOBILE COMMUNICATION NETWORKS

2.1. C-NOMA in 6G Mobile Communication Networks

With the introduction of 6G mobile communication networks, wireless communication anticipates going through a paradigm shift that will require innovative solutions to meet the increasing demands for high throughput, low latency, and ubiquitous connection [9]. C-NOMA is a cutting-edge technology in 6G mobile communication networks that has the power to fundamentally alter how users share and utilize wireless resources [10]. C-NOMA utilizes the concept of users collaborating to share the same time-frequency resources, which leads to enhanced spectral efficiency and reliability over traditional orthogonal multiple access systems. C-NOMA enables cooperative resource optimization and aids users in mitigating the impact of fading channels and interference by dynamically adjusting transmit power levels and utilizing diversity improvements offered by cooperative transmission [11]. For C-NOMA deployment in 6G mobile networks, resource management, algorithmic optimization, infrastructure enhancement, and user-centered design are all necessary components of a diverse approach. Details on the main functions that are involved in implementing C-NOMA can be found in [12].

In C-NOMA, power allocation aims to distribute transmit power between users within a NOMA cluster to enhance and increase system throughput while satisfying power limits [13].

The power allocation (PA) factor, denoted by (α_i) for the (i_{th}) user. The ratio of (PA) is:

$$\sum_{i=1}^{N} \alpha_i = 1 \tag{1}$$

To maximize the (PA), where (R_i) represents the achievable rate of the (i_{th}) user:

$$\text{Maximize (PA)} \sum_{i=1}^{N} \alpha_i R_i \tag{2}$$

The achievable rate (R_i) of users in C-NOMA depends on the power allocation, channel conditions, and interference from other users. Assuming (P_i) is the transmit power of the (i_{th}) user, (h_{ii}) represents the channel gain of the direct link between the (i_{th}) user and the base station, (h_{ji}) represents the channel gain of the interference from the (j_{th}) user to the (i_{th}) user, and (σ^2) is the noise power, the achievable rate for the (i_{th}) user, the achievable rate (R_i) is expressed as follows:

$$R_i = \log_2\left(1 + \frac{P_i|h_{ii}|^2}{\sum_{j=1,j\neq i}^{N} P_j\left|h_{ji}\right|^2 + \sigma^2}\right) \tag{3}$$

The (R_i) of each user is impacted by the interference that other users in the NOMA cluster cause. The interference (I_i) for the (i_{th}) user expressed as:

$$I_i = \sum_{j=1,j\neq i}^{N} P_j\left|h_{ji}\right|^2 \tag{4}$$

To maximize the sum-rate of all users within the NOMA cluster, power and interference limits should be considered. The objective function for maximize sum rate (SR) formulated as:

$$\text{Maximize (SR)} \sum_{i=1}^{N} R_i \tag{5}$$

subject to power constraints:

$$\sum_{i=1}^{N} P_i \leq P_{\text{total}} \tag{6}$$

and interference limits:

$$I_i \leq I_{max} \text{ for all users } i \tag{7}$$

These formulas are used to assess and optimize C-NOMA in 6G mobile communication networks and to create efficient resource allocation algorithms that ensure fairness and quality of service while improving network performance and efficiency.

Scalability in 6G is a significant concern, as 6G aims to support massive connectivity, ultra-low latency, high data rates, and increased energy efficiency. As the number of connected users increases, managing the interference and decoding complexity becomes more challenging. The cooperative nature of C-NOMA, where users share resources, adds to this complexity. Effective power allocation, user pairing, and decoding mechanisms are needed to ensure scalability. Interference must be managed efficiently as the network scales. Advanced interference cancellation techniques such as Successive Interference Cancellation (SIC) can become computationally expensive as the number of users increases. For C-NOMA to scale, more efficient and lower-complexity SIC algorithms are required to reduce latency and processing power in large-scale 6G networks. The overhead of dynamic resource allocation and optimal user pairing for C-NOMA may increase significantly, impacting the scalability of the system. C-NOMA relies heavily on accurate Channel State Information (CSI) to differentiate between users' channel conditions for proper power allocation.

As the number of connected devices grows, ensuring energy-efficient communication becomes critical. Maintaining energy efficiency in a large-scale C-NOMA network is challenging, especially when balancing between performance and power consumption for the increasing number of users. Scaling the network while maintaining high throughput and low latency in a C-NOMA environment requires advanced scheduling and protocol designs to handle the larger number of devices efficiently. Thus, the following can be used to address scalability: advanced machine learning algorithms, enhanced SIC techniques, distributed and decentralized architectures, and beamforming with MIMO. By addressing these scalability concerns, C-NOMA can be made more suitable for large-scale 6G applications and networks [14].

2.2. Caching in 6G Mobile Communication Networks

Caching is used by 6G mobile communication networks to guarantee faultless user experiences in a range of applications, from ultra-high-quality video streaming to immersive virtual and augmented reality. These user experiences can be achieved by employing cutting-edge algorithms and edge computing infrastructure. To successfully implement caching in 6G mobile networks, an integrated approach comprising infrastructure deployment, algorithmic optimization, and user-centered design is required. The key ideas behind caching in 6G system networks are [15]:

1) Careful positioning of nodes to be close to the network edge for lower latency and to enhance content delivery supported by backhaul networks ensure seamless content distribution and synchronization.
2) Optimization involves anticipating user demand and proactively storing content at edge nodes through the use of sophisticated predictive caching algorithms.
(3) Effective content placement strategies can be created by accounting for factors such as popularity dynamics, user spatial dispersion, and content characteristics.
4) Optimizing cache replacement algorithms is necessary to cache the most relevant content and maximize hit rates while minimizing cache contamination.
5) Quality of Experience (QoE) optimization and user-centric design are required to emphasize user experience by providing lower-latency access to popular information and personalized services.
6) Secure caching techniques and robust security measures should be used to guard against unwanted access, modification, and data breaches involving cached content.
7) Creating a caching infrastructure that can grow with the volume of data and users in 6G mobile communication networks is the idea of scalable architecture.

A complete approach that considers user-centric design, algorithmic optimization, infrastructure deployment, security and privacy concerns, scalability, and interoperability is required for the successful implementation of caching in 6G mobile communication networks [16]. In the context of 6G mobile communication networks, mathematical expressions are widely utilized to mimic various aspects of caching techniques, resource allocation, and optimization algorithms. The following mathematical formulas are used to study and examine caching in 6G mobile communication networks. The probability that an item of content will be found in the cache when it is requested is known as the Cache Hit Probability (P_{hit}) [17]:

$$P_{\text{hit}} = \frac{\text{Quantity of demand provided by cache}}{\text{Total quantity of demand}} \quad (8)$$

For the (P_{miss}) Probability of Cache Miss, the probability that, should the requested information not be fetched in the cache, it will need to be fetched from the origin server:

$$P_{\text{miss}} = 1 - P_{\text{hit}} \quad (9)$$

For the Cache Hit Rate: The ratio of cache hits to total requests, often used as a performance metric for caching technique:

$$\text{Cache Hit Rate} = \frac{\text{Number of cache hits}}{\text{Total number of requests}} \quad (10)$$

3. RELATED WORKS

To enhance the performance of 6G mobile network communication over traditional communications, three combination techniques NOMA, D2D communications, and wireless caching have been investigated in the related works.

In [14], the the authors created and assessed four novel system models that combine NOMA, D2D communications, and wireless caching. The total delivery time, according to academics, is a useful metric for assessing the level of expertise and the deductions made in order to solve the optimization problem. In order to illustrate key performance metrics such as delivery times and sum rate, scientists devoted resources to model optimization, which was subsequently tested using numerical simulations. They claimed that the total delivery time is shortened when all files are delivered simultaneously.

In [18], Non-orthogonal Multiple Access (NOMA) is considered by authors to be one of the essential enabling multiple access techniques for the next six-generation (6G) networks because of its capacity to accommodate a large number of connected devices and improve network spectral efficiency. The fundamentally difficult issues of integrating NOMA with other B5G/6G enabling technologies in upcoming wireless networks were tackled to maximize the number of linked devices and achieve high spectrum efficiency and energy-efficient communications.

Non-orthogonal multiple-access (NOMA) schemes, in contrast to orthogonal multiple-access (OMA), can serve a pool of users without utilizing the limited frequency or time domain resources, thereby meeting the 6G network requirements, which include low latency, massive connectivity, users' fairness, and high spectral efficiency. However, content caching limits the transmission of duplicate data by pre-archiving popular contents at the network edge, hence decreasing 6G data traffic [19].

Various aspects of 6G wireless networks with different perspectives are covered in [20]. In order to set the standard for the upcoming generation of communication systems, they presented a vision for B5G/6G communications, 6G network design, KPI criteria, important enabling technologies, their use-cases, and network dimensions. The authors discussed how these possible technologies could fulfill the systems' key performance indicator (KPI) needs and obstacles related to next-generation communication network commercialization, including hardware complexity, variable radio resource allocation, preemptive scheduling, power efficiency, coexistence of multiple RATs, and issues with security, privacy, and trust issues for these technologies.

Researchers in [21] offered a thorough analysis of current developments and emerging patterns. They clarified that 6G, which has more technological needs than 5G, will allow for faster and more connectivity, to the point where it will be impossible to distinguish between the real world and the virtual world.

The paper [22] investigated the performance of NOMA and OMA techniques in a unique cell environment, where the cellular users are dispersed randomly and cooperative relays are taken into consideration for improved system reliability. The dominance of the NOMA scheme over the OMA scheme was demonstrated through numerical data.

User clustering and resource allocation techniques ensure efficient spectrum utilization, improve user fairness, and maximize system throughput. User clustering in C-NOMA is a technique used to group users with complementary characteristics (such as different channel conditions) into clusters for non-orthogonal transmission. It’s essential in C-NOMA since multiple users share the same frequency resources, relying on power domain multiplexing to differentiate signals. Clustering decisions are based on several criteria, such as channel conditions, Quality of Service (QoS) requirements, proximity or mobility, and fairness. Techniques used for user clustering can be channel gain-based clustering, distance-based clustering, graph-based clustering, or machine learning techniques [23]. Combined user clustering and resource allocation algorithms are used to optimize the overall performance of C-NOMA systems. Many algorithms simultaneously consider user clustering and resource allocation, such as heuristic and metaheuristic approaches, convex and non-convex optimization, and machine learning-based joint optimization. Therefore, in C-NOMA, effective user clustering and resource allocation are critical to improving system performance. Techniques like power domain multiplexing, machine learning, and optimization algorithms help ensure that spectrum is used efficiently and users' quality of experience is maximized. These techniques will be essential in future 5G and 6G networks, where ultra-reliable and low-latency communication is required [23].

From the related works presented, it is clear that C-NOMA is an approach method to meet the various needs of improved user fairness, high reliability, high spectrum efficiency, SE, extensive connectivity, raising data rates, high flexibility, low transmission latency, massive connectivity, low delay, higher cell-edge throughput, and superior performance. Moreover, cooperative communications might reduce fading and solve the challenge of installing multiple antennas on small wireless connections, such as physical variety; it has been highly recommended for implementation during the deployment of 5G. Cooperative communications, when implemented with NOMA, can enhance and increase the coverage capacity and reliability of the system. The NOMA systems technique, along with earlier information, is utilized by the C-NOMA technique. As a result, these users serve as relays to increase the dependability of users' reception for users with weaker connections to the BS. The C-NOMA technique in the 5G is considered to maximize the potential of NOMA in multiuser environments where one of the users acts as the relay role for another user. These abilities of C-NOMA and PD-NOMA need to be improved to meet the requirements of new applications and the growth in demands. Thus, this can be a major problem to be investigated in this research, which is to look for ways to improve C-NOMA to meet the 6G and demands requirements.

4. PROPOSED DYNAMIC C-NOMA CACHING TECHNIQUE

This research offers a proposed system that combines C-NOMA with caching and dynamic resource allocation to improve the performance of the 6G mobile communication networks.

An extensive overview of the algorithm that combines C-NOMA with caching in 6G mobile networks is as shown in Figure 1.

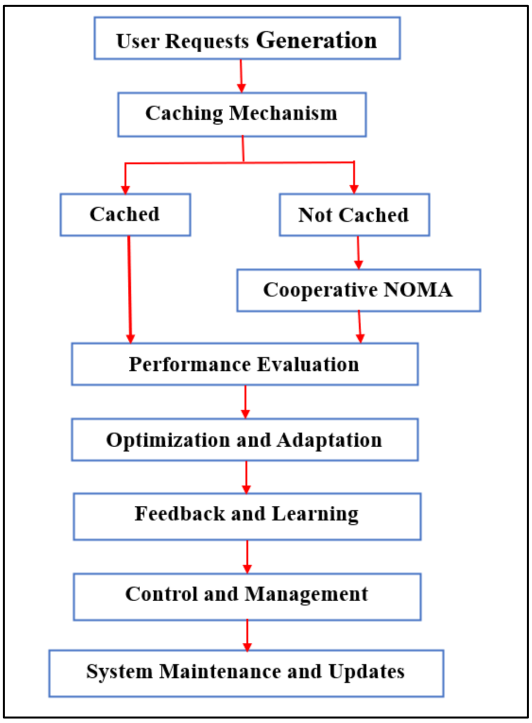

Fig. 1 Proposed Algorithm for C-NOMA with Caching

Each block represents a significant step or process in the algorithm. The following are the algorithm's primary steps:

1) Generate user requests to provide content requests from all users in the system.

2) Check the cache to see if the requested content is available. Serve content straight from the cache if it is cached. Proceed to C-NOMA if not cached.

3) Determine which users are taking part in NOMA transmission and setting power allocation for transmission in tandem with sending data by utilizing NOMA methods and signal decoding at the receiving end.

4) Optimizing NOMA transmission power allocation techniques and adjusting system settings to reflect evolving network requirements.

5) To guarantee effective resource allocation, establish control systems in a desired place, and adapt system resources dynamically to network and demand conditions.

.

6) Updating the system and performing routine maintenance, such as cache updates and system upgrades, are important, and implement new standards and technology to maintain the system current.

The proposed algorithm has been modeled to work with the 6G network communication as shown in Figure 2.

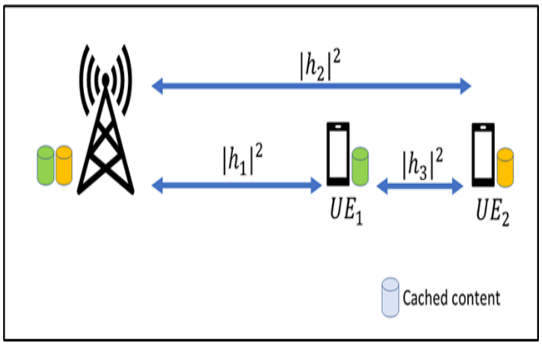

Fig. 2 The System model for C-NOMA with caching

It is clear from Fig. 2, that the network architecture consists of base stations (BSs), edge computing nodes, and user equipment (UE). Base stations serve as access points for user communication. Edge computing nodes host caching functionalities and facilitate C-NOMA transmission. Each edge computing node is equipped with a cache to store popular content items. The cache employs predictive caching algorithms to proactively store content based on user behavior and content popularity. For the catching mechanism, each base station (BS) caches popular content items. (C_i) denote the content cached at (BS_i). The cache capacity (M) represents the maximum number of content items that can be stored at each (BS). Each (BS_i) caches a set of content items (C_i) with a cache capacity (M): $C_i = \{c_{i,1}, c_{i,2}, \dots, c_{i,M}\}$. The cache content (C_i) is determined based on popularity profiles, user demands, or other caching policies.

The proposed system model involves the following steps;

1) User requests arrive at edge computing nodes, requesting specific content items from the cache. Requests follow a certain distribution, which may vary over time and geographical locations. Each user is associated with a nearby (BS) based on signal strength or other association criteria. (U_i) denote the set of users associated with (BS_i). Each user (j) is associated with a nearby (BS_i) based on signal strength or other association criteria: $U_i = \{u_{i,1}, u_{i,2}, \dots, u_{i,N}\}$. (N) is the total number of users, and (U_i) is the set of users associated with (BS_i).

2) In C-NOMA transmission, users requesting un-cached content items form NOMA clusters with nearby relay nodes. Then, relay nodes assist in cooperative transmission by relaying signals between users and base stations. Power allocation and resource allocation schemes are employed to optimize system throughput and mitigate interference. Beamforming and precoding techniques are utilized to enhance signal quality and minimize interference among users.

3) The channel between each user and base station, as well as between users and relay nodes, is assumed to be frequency-selective and time-varying, necessitating dynamic adaptation of transmission parameters.

4) C-NOMA enables multiple users to share the same resource block by exploiting power domain NOMA. $(P_{i,j})$ represent the power allocated to user j at (BS_i) for NOMA transmission, that is subject to power constraints and interference management;

- $(h_{i,j})$ is the channel gain between (BS i) and user (j).
- (x_i) is the transmitted signal from (BS i).
- $(n_{i,j})$ is the additive white Gaussian noise (AWGN) at user (j).

The received signal $(y_{i,j})$ at user (j) from (BS_i) can be expressed as:

$$y_{i,j} = \sqrt{P_{i,j}} h_{i,j} x_i + \sum_{k \neq j} \sqrt{P_{i,k}} h_{i,k} x_i + n_{i,j} \quad (11)$$

where:

$\mathbb{E}[\mathrm{R}_{\mathrm{i,j}}]$ is the expected data rate for user (j) at $(\mathrm{BS_i})$. The latency $(\mathrm{L_i})$ experienced by users at $(\mathrm{BS_i})$ depends on the content retrieval time and transmission delay. The throughput (T_i) at (BS_i) as seen is determined by the caching hit rate, user association, and NOMA transmission:

$$T_i = \sum_{j \in U_i} \mathbb{E}[R_{i,j}] \quad (12)$$

5) For the system optimization, user association, power allocation, and resource scheduling to maximize throughput and minimize latency:

$$\text{Maximize/Minimize} \sum_i \text{Throughput/Latency} \quad (13)$$

This involves solving optimization problems subject to constraints such as cache capacity, power constraints, and quality-of-service (QoS) requirements. The system constrains are:

- Caching capacity constraints: $|C_i| \leq (M)$.
- Power constraints: $P_{i,j} \leq P_{max}$ for all (i,j).
- Quality-of-Service (QoS) requirements: $T_i \geq T_{min}$ or $L_i \leq L_{max}$.

The proposed system model can be represented mathematically by using various optimization formulations, such as mixed-integer linear programming (MILP) as a powerful mathematical programming technique, non-linear programming (NLP), or convex optimization. The MILP is used to model and solve optimization problems where some variables are required to be discrete integers and others continuous values. In this dynamic proposed model, MILP formulations are used to optimize:

- Integer variables (0 or 1 decision), representing binary decisions, such as whether to cache a particular content item or not.
- Continuous variables represent resource allocation parameters, such as power levels, bandwidth allocation, user grouping, and content placement.
- Objective functions that capture system goals, such as minimizing latency, maximizing throughput, optimizing energy efficiency, or balancing resource utilization.

The (NLP), deals with optimizing continuous variables subject to constraints, where the objective function or constraints be nonlinear. In the context of dynamic resource allocation, NLP formulations can capture more complex relationships and optimizations, such as:

- Nonlinear power allocation schemes in C NOMA to maximize sum rate or minimize interference while meeting quality of service constraints.
- Nonlinear content placement strategies in caching systems to minimize latency based on content popularity dynamics and user demands.
- Nonlinear objective functions that consider trade-offs between different performance metrics, such as throughput, latency, fairness, and energy consumption.

Convex optimization is a subset of mathematical optimization where the objective function and constraints are convex, allowing for efficient and globally optimal solutions. In the context of dynamic resource allocation for C-NOMA with caching, convex optimization techniques can be employed to:

- Optimize convex objective functions such as minimizing the weighted sum of latencies or maximizing the minimum achievable rate among users.
- Formulate convex constraints representing power constraints, bandwidth constraints, QoS requirements, and system capacity limits.
- Apply convex relaxation techniques to linearize non-convex problems or approximate optimal solutions efficiently.

By customizing and combining these optimization formulations (MILP, NLP, and convex optimization), one can capture the specific requirements and constraints of the C-NOMA with caching techniques for sum rate, average latency reduction, and throughput in 6G networks. Power allocation among users within NOMA clusters is optimized to maximize system throughput while satisfying power constraints and quality-of-service requirements. Each user is allocated a certain portion of transmit power, determined based on channel conditions and cooperation strategies. For esource allocation, spectrum resources, time slots, and transmission durations are allocated dynamically among users and relay nodes to maximize spectral efficiency and throughput.

Resource allocation decisions consider channel conditions, interference levels, and traffic demands. In the model for Cache Hit/Miss process, upon receiving a user request, the edge computing node checks the cache for the requested content item. The user receives the content with the least amount of latency possible if it is cache-hit. If the content cannot be located in the cache, a request for C-NOMA transmission (cache miss) is made. Performance metrics such as cache sum rate, average latency reduction, system throughput, and user satisfaction are evaluated to see how well C-NOMA with caching enhances network performance and efficiency.

5. SYSTEM SIMULATION AND PERFORMANCE EVALUATION

The main parameters used to simulate compression the C-NOMA with caching proposed technique and C-NOMA mentioned in Table 1.

Table 1. The main parameters used for simulate the proposed dynamic system

Parameters	Data
SNR in dB	SNRdB = -20:5:20
SNR in Linear Scale	$10^{(SNR\_dB/5,\ 10,\ or\ 20)}$
Number of SNR Points	N = length (SNR)
Number of Users Compression	[2, 5, and 10]
Number of Monte Carlo Simulations	M = 10000
Number of Stations Compression	[5, 10, 15, and 20]
File size Compression	[1, 10, and 100 MB]
Cache hit ratio for 10 MB File Size	1 - exp (-file size)
Different numbers of Stations	[5, 10, 15, and 20]
Traffic Levels Compression	[high, medium, and low]
Channel Gain Type	[Rayleigh fading]

The simulation results are achieved via the implementation of systems using MATLAB (V 2022a). The systems performance is measured by the values of sum rate, average latency reduction, and throughput. Sum rate refers to the total data rate or capacity achieved by the system over a given time interval or bandwidth. It is calculated as the sum of the individual data rates of all users or channels in the system. Given N is the number of users, and (Data Rate $_i$) represents the data rate of the (i_{th}) user, then the sum rate expressed as [23]:

$$Sum\ Rate = \sum_{i=1}^{N} \text{Data Rate}_{\ i} \qquad (14)$$

While throughput, on the other hand, specifically measures the rate at which data is successfully transmitted from source to destination. It considers the actual amount of useful data delivered per unit of time, accounting for factors like retransmissions, errors, system overhead, and resource allocation strategies. For these reasons, the sum rate is higher than the throughput. The mathematical expressions for sum throughput in the context of a communication system for C-NOMA with caching in 6G networks are as follows [22]:

$$Throughput = \frac{\text{Useful Data Transmitted}}{\text{Time Interval}} \qquad (15)$$

Due to the system overhead (protocol headers reduces, control signaling, and error correction codes):

$$\text{Throughput} = \text{Sum Rate} - \text{Overhead} \qquad (16)$$

As well as, due to the packet loss and channel conditions (packet loss, interference, noise, and channel conditions):

$$\text{Throughput} = \text{Sum Rate} \times \text{Channel Efficiency} \qquad (17)$$

In this study, the proposed system simulation performance evaluation compares the values of sum rate, average latency reduction, and throughput of C-NOMA and C-NOMA with caching technique in a wireless communication to investigate enhancements in the performance and efficiency in 6G mobile communication networks under different scenarios.

5.1. Sum Rate Evaluation

The results of the simulation showing the sum rate for the comparison between the proposed dynamic system C-NOMA with caching versus traditional C-NOMA are as shown in Figure 3.

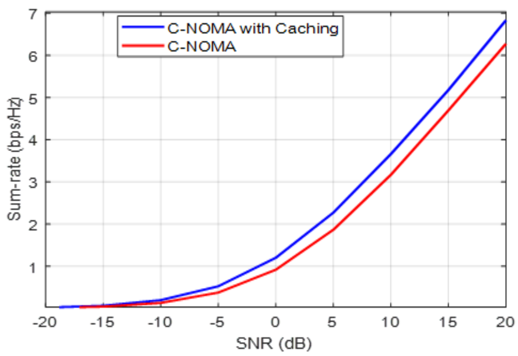

Fig. 3a

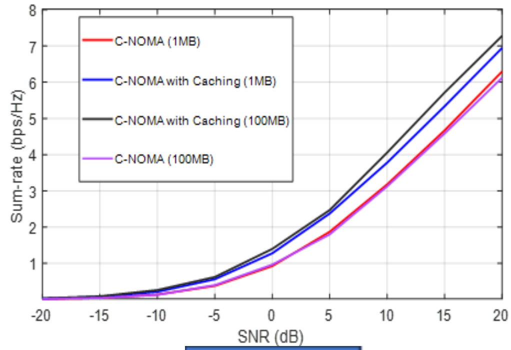

Fig. 3b

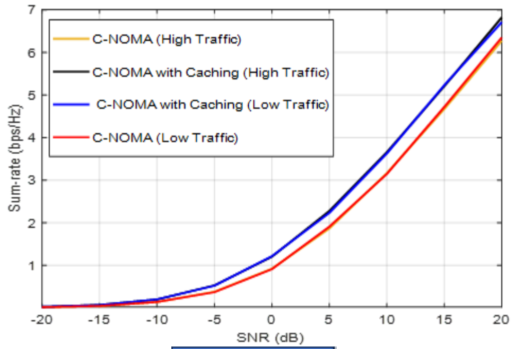

Fig. 3c

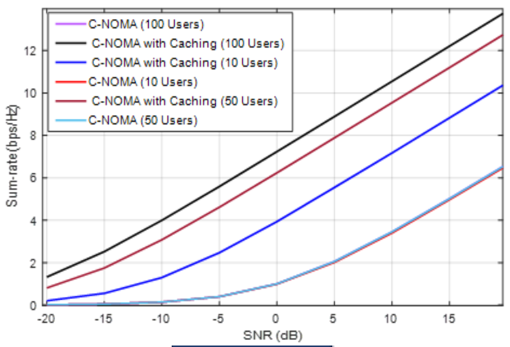

Fig. 3d

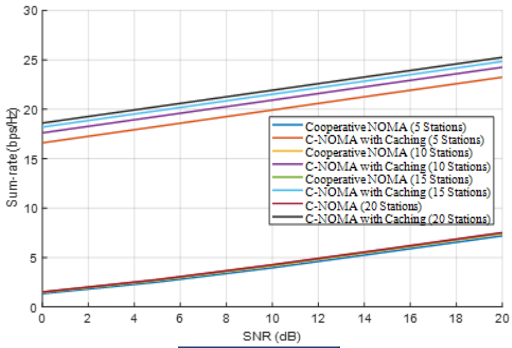

Fig. 3e

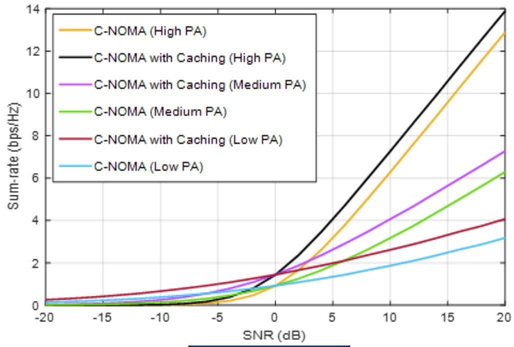

Fig. 3f

Fig. 3 Sum rate comparison between the C-NOMA with caching versus traditional C-NOMA for different cases

Figure 3a, shows that the sum-rate increases with (SNR) due to the improved signal quality. In caching NOMA incorporates caching at the users' end, this can enhance the system's throughput. At lower power allocation (PA) value, C-NOMA tends to outperform C-NOMA with caching. This is likely because, at lower (PA), the benefits of cooperation outweigh the gains from caching.

The impact of the file size on the sum rate is shown in Figure 3b for different file sizes for both cases C-NOMA and C-NOMA with caching. It is clear that when the file size increase from (1MB) to (100MB), the sum rate decreases (6.298 bps/Hz) to (6.125 bps/Hz). While, for C-NOMA with caching the sum rate increase (6.947 bps/Hz) to (7.279 bps/Hz). From these results, one can observe the advantage roll of the proposed system when caching combined with C-NOMA.

The network traffics impact on the sum rate of the system results is as shown in Figure 3c. For the high network traffic scenario, the sum rate value is increase to (6.827 bps/Hz) due to the advantages use of caching than the case without caching. This result confirms the roll of caching when combined with C-NOMA technique.

Figure 3d shows the simulation results for the sum rate with (10, 50, and 100) users for C-NOMA and C-NOMA with the catching technique. The results show that the proposed system C-NOMA with caching has significant advantages leading to achieve higher sum rate than the C-NOMA when the number of users increases in the 6G network systems compared to NOMA without caching.

The simulation results in Figure 3e, shows the impacts of station numbers (5, 10, 15, and 20) on sum rate in the proposed system. The sum rate for C-NOMA with caching increase with increases as the number numbers increases. These results, shows the advantage of C-NOMA with caching in improving the performance and efficiency in 6G network mobile communication for the cases of increase in number of users.

Figure 3f shows the power allocation (PA) with different level rate (high, medium, and low) impacts on sum rate. From these results with all three (PA) levels, C-NOMA combined with caching has higher value than the sum rates for C-NOMA due to the advantage rolls of caching in the system.

5.2. Average Latency Reduction Evaluation

The other measure of performance is the average latency reduction for the proposed dynamic system C-NOMA with caching versus traditional C-NOMA as shown in Figure 4.

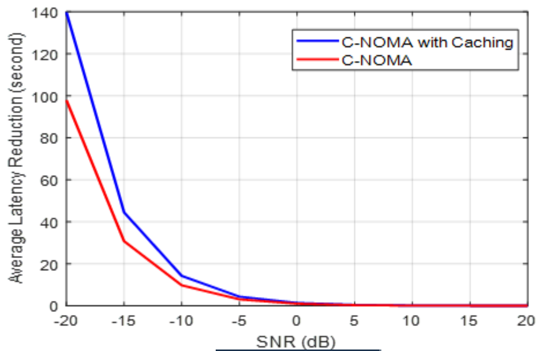

Fig. 4a

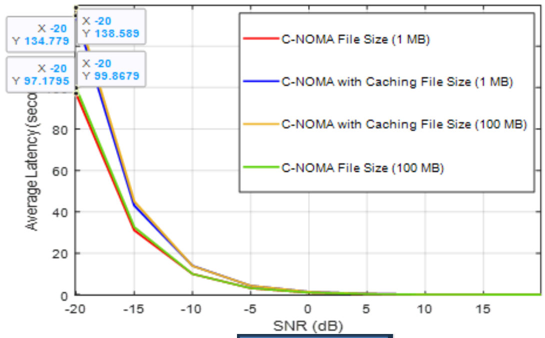

Fig. 4b

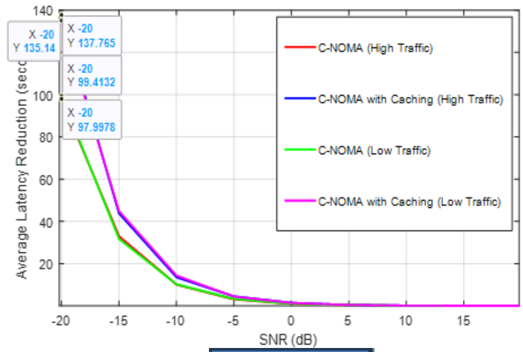

Fig. 4c

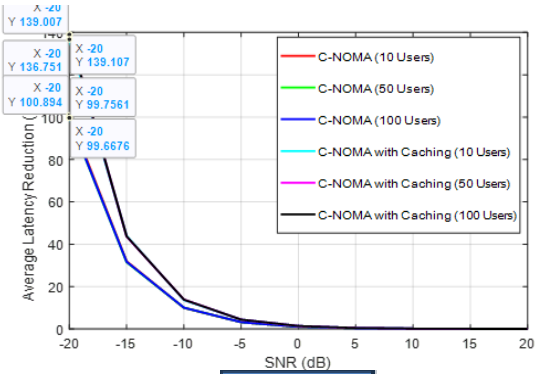

Fig. 4d

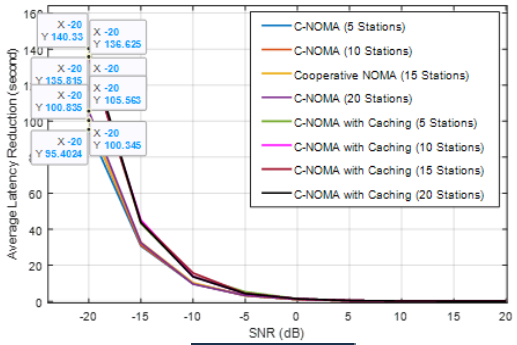

Fig. 4e

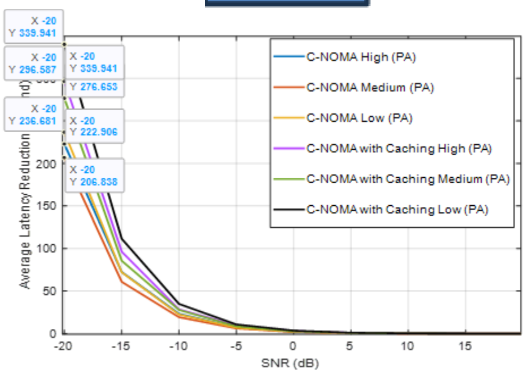

Fig. 4f

Fig. 4 Average Latency Reduction comparison between the C-NOMA with caching versus traditional C-NOMA for different cases

It is clear from Figure 4a, that the average latency reduction for the proposed dynamic C-NOMA with caching has higher value than the traditional C-NOMA at different environment aspects. The file size impacts on the performance of the system have been investigated as shown in Figure 4b, for both file sizes1 MB and 100 MB). For the proposed C-NOMA with caching the average latency reduction is (138.589s and 99.867s) respectively for 1 and 100MB, while for traditional C-NOMA, the average latency reduction is (134.779s and 97.179s), respectively.

The impact of caching and network traffic on the average latency reduction is shown in Figure 4c. For proposed dynamic system C-NOMA with caching at the high network traffic, it has been found the average latency reduction is higher than the traditional C-NOMA. Furthermore, the average latency reduction for traditional C-NOMA at the high network traffic is less than at the low network traffic.

User numbers impact the performance of proposed dynamic system C-NOMA with caching is shown in Figure 4d. The simulation results for average latency reduction for cooperative with caching is higher to average latency reduction for C-NOMA for the same number of user numbers. While, when the number of users increases, the average latency reduction rises. The simulation results shows that the proposed dynamic system C-NOMA with caching has significant advantages leads to achieve higher average latency reduction than the C-NOMA.

The simulation results in Figure 4e, shows the impacts of station numbers (5, 10, 15, and 20) on average latency reduction in the proposed dynamic system. The average latency reduction for C-NOMA with caching increase with increase of station numbers directly. These results, show the advantage of caching when combined with C-NOMA to improve the performance.

Figure 4f shows the power allocation (PA) with different level rate (high, medium, and low) impacts on the average latency reduction. The average latency reduction with low level (PA) is higher for C-NOMA with caching compared with C-NOMA for all level PA. The simulation results confirms that when the (PA) with a low level, resulting in a highe raverage latency reduction.

5.3. Throughput Evaluation

Simulation results showing throughput for the proposed dynamic system C-NOMA with caching versus traditional C-NOMA are shown in Figure 5 for different cases.

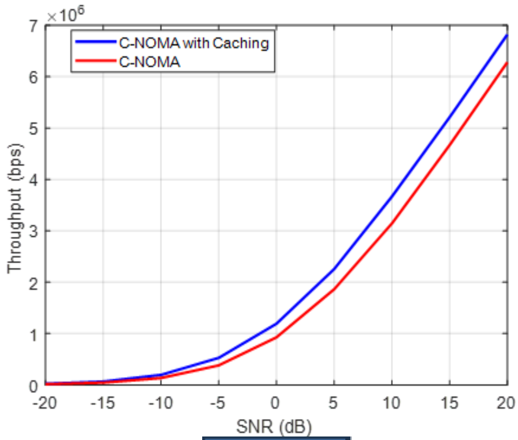

Fig. 5a

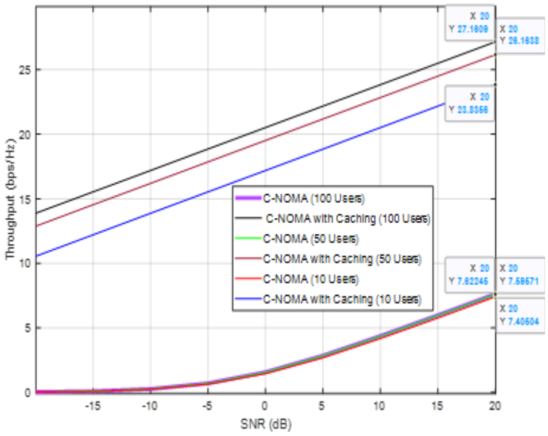

Fig. 5b

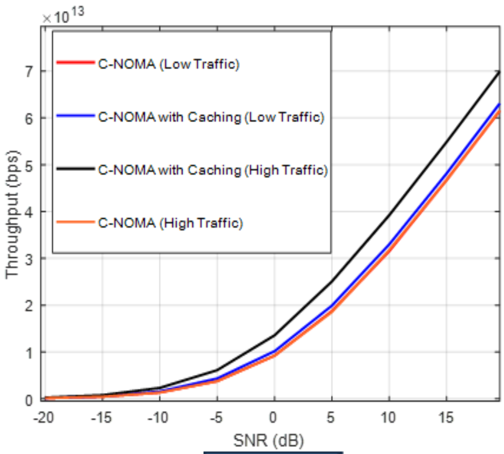

Fig. 5c

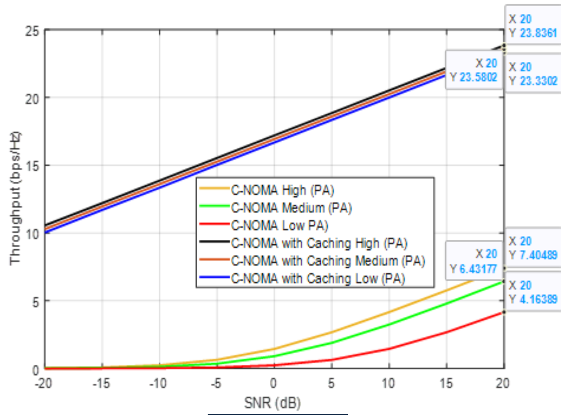

Fig. 5d

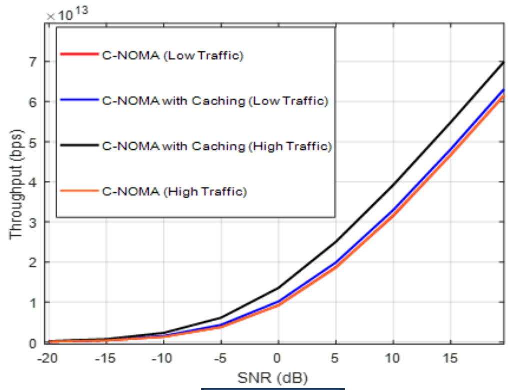

Fig. 5e

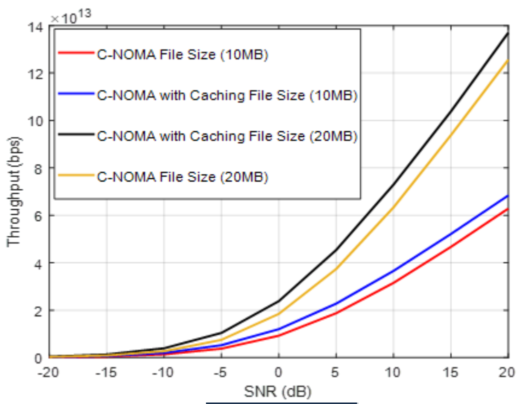

Fig. 5f

Fig. 5 Throughout comparison between the C-NOMA with caching versus traditional C-NOMA for different cases

As seen in the Figure 5a, the throughput for the proposed dynamic C-NOMA with caching is higher than the traditional C-NOMA at different environment aspects. The file size impacts on the throughput have been measured for both C-NOMA and C-NOMA with caching as shown in Figure 5b. The results show that when the file size increases from (10 MB) to (20 MB), the throughput increases (6.28693×10^{13}bps) to

(12.562 $\times 10^{13}$bps). While, for C-NOMA with caching when the file size increases from (10 Mb) to (20 MB), the throughput increases (6.83923 $\times 10^{13}$bps) to (13.7001 $\times 10^{13}$bps). These results confirm the advantage of caching when combined with C-NOMA.

As seen in the Figure 5c, the simulation results for throughput versus SNR (20 dB), have a higher value for proposed dynamic system C-NOMA with caching at the high network traffic and higher than the traditional C-NOMA. Furthermore, the throughput for traditional C-NOMA at the high network traffic is less than at the low network traffic. All the results are due to the caching advantages roll when combining with C-NOMA. These results confirm the advantages roll of caching when combined with C-NOMA.

The impact of user numbers on the throughput of proposed dynamic system C-NOMA with caching is investigated as shown in Figure 5d. The figure shows the throughput for (10, 50, and 100) users in case of C-NOMA and C-NOMA with caching technique. The simulation results show the that proposed dynamic system C-NOMA with caching has significant advantages leads to throughput increase with the user numbers increase, compared to C-NOMA.

The simulation results in Figure 5e, shows the impacts of station numbers (5, 10, 15, and 20) on throughput of the proposed C-NOMA with caching. The throughput for C-NOMA with caching increase with increase of station numbers. While, the throughput for traditional C-NOMA is less increased with increase of station numbers. These results, shows the advantage rolls of caching when combined with C-NOMA to improve the throughput performance and efficiency in 6G network mobile communication.

Figure 5f shows the power allocation (PA) with different level allocation (high, medium, and low) impacts on throughput. The throughput with high level (PA) is higher for C-NOMA with caching than that of C-NOMA. The simulation results confirms that when the (PA) with a high level, resulting in higher throughput and the throughput for proposed dynamic system C-NOMA with caching has higher value than the throughput for C-NOMA.

5.4. Comparison with other Systems

Enhancing the performance of 6G mobile communication networks through the use of cooperative Non-Orthogonal Multiple Access NOMA and caching offers significant advantages compared to traditional user clustering and resource allocation techniques. This approach leverages the strengths of NOMA, such as efficient spectrum utilization and power domain multiplexing, while caching increases average latency reduction and backhaul load. A detailed comparison between cooperative NOMA with caching and conventional user clustering and resource allocation methods, including other systems, is shown in Table 2.

Table 2: A Comparison of proposed system with other ralted works systems

Performance Metric	C- NOMA and Caching	NOMA Clustering	OMA Resource Allocation	MIMO Clustering	Proportional Fairness Allocation
SE	Very High	High	Moderate	High	Moderate
Throughput	High	High	Moderate	High	Moderate
Average Latency Reduction	Very high	Moderate	Low	High	Low
EE	High	Moderate	Low	Moderate	Low
Scalability	High	Moderate	Moderate	Moderate	Low
Complexity	Moderate	Low	Low	High	Moderate
QoS and QoE	Very High	Moderate	Low	High	Moderate

It is clear from Table 2 that in cooperative NOMA, users with better channel conditions help relay information to users with weaker channel conditions. This cooperation improves the overall network performance, enhances coverage, and provides robust connectivity for users in poor signal areas. Storing popular content at the network edge, such as base stations or user devices, reduces the need for repeated data retrieval from the core network, leading to lower latency, reduced backhaul congestion, and improved data rates. Combining cooperative NOMA and caching allows efficient delivery of cached content through cooperative relays, optimizing resource usage and reducing the demand on network resources. Thus, cooperative NOMA and caching offer substantial improvements over existing user clustering and resource allocation techniques by providing higher spectral efficiency, lower latency, and better scalability. This makes it a promising approach for enhancing 6G mobile communication networks and meeting the demands of future applications. The simulation and evaluation results proved that the proposed system provides significantly higher performance in terms of data rate, BER, and outage probability and reduces the power consumption to 52.6% and 54.7% compared to NOMA without cooperative and without NOMA, respectively, which is higher than the related works.

6. CONCLUSION

In this paper, C-NOMA with caching has shown promising results in the enhancement of the performance and efficiency of 6G networks. The form of combination that showed promising results is dynamic resource allocation among users and relay nodes in the proposed system through the efficiency for sum rate, latency reduction, and throughput increase in 6G mobile communication networks. Furthermore, in this paper, the simulation results show the impact of file size, number of users, number of stations, traffic levels, and PA on the sum rate, throughput, and average latency reduction. The simulation result showed the significant approach of the proposed system offers improvements in sum rate, throughput, and average latency reduction in 6G networks. Future research should focus on integrating technologies, optimizing resource allocation, addressing security and privacy concerns, improving energy efficiency, and facilitating standardization and deployment.

REFERENCES

[1] A. Nauman et al., "Dynamic resource management in integrated NOMA terrestrial–satellite networks using multi-agent reinforcement learning," Elsevier, vol. 221, p. 103770, 2024. https://doi.org/10.1016/j.jnca.2023.103770

[2] Z. Qadir, K. N. Le, N. Saeed, and H. S. e. Munawar, "Towards 6G Internet of Things: Recent advances, use cases, and open challenges," Elsevier, vol. 9, no. 3, pp. 296-312, 2023. https://doi.org/10.1016/j.icte.2022.06.006

[3] A. ALKandari, M. ALAhmad, N. J o. E. S. ALAwadi, and Technology, "Overview on 5G and 6G WirelessS Communication with IOT Technology," jestec.taylors.edu.my, vol. 17, no. 1, pp. 0095-0105, 2022.

[4] M. W. Akhtar et al., "The shift to 6G communications: vision and requirements," Springer, vol. 10, pp. 1-27, 2020. https://doi.org/10.1186/s13673-020-00258-2

[5] Y.-C. Liang, D. Niyato, E. G. Larsson, and P. J. C. C. Popovski, "Guest editorial: 6G mobile networks: Emerging technologies and applications," ieeexplore.ieee.org, vol. 17, no. 9, pp. 90-91, 2020. DOI: 10.23919/JCC.2020.9205979

[6] D. Bepari et al., "A survey on applications of cache-aided NOMA," ieeexplore.ieee.org, 2023. DOI: 10.1109/COMST.2023.3293231

[7] R. Moreira and F. de Oliveira Silva, "Towards 6g network slicing," in Anais do I Workshop de Redes 6G, 2021, pp. 25-30: SBC, sol.sbc.org. b.

[8] M. Banafaa et al., "6G mobile communication technology: Requirements, targets, applications, challenges, advantages, and opportunities," Elsevier, vol. 64, pp. 245-274, 2023. https://doi.org/10.1016/j.aej.2022.08.017

[9] M. Alsabah et al., "6G wireless communications networks: A comprehensive survey," ieeexplore.ieee.org, vol. 9, pp. 148191-148243, 2021. DOI: 10.1109/ACCESS.2021.3124812

[10] W. Guo, N. M. F. Qureshi, I. F. Siddiqui, D. R. J. o. K. Shin, and I. Sciences, "Cooperative communication resource allocation strategies for 5G and beyond networks: A review of architecture, challenges and opportunities," Elsevier, vol. 34, no. 10, pp. 8054-8078, 2022. https://doi.org/10.1016/j.jksuci.2022.07.019

[11] Y. Shan, Q. Zhu, and Y. J. Wang, "Performance analysis on a cooperative transmission scheme of multicast and NOMA in cache-enabled cellular networks," Wiley Online Library, vol. 15, no. 7, pp. 946-956, 2021. https://doi.org/10.1049/cmu2.12133

[12] M. Z. Asghar, S. A. Memon, and J. J. S. Hämäläinen, "Evolution of wireless communication to 6g: Potential applications and research directions," mdpi.com, vol. 14, no. 10, p. 6356, 2022. https://doi.org/10.3390/su14106356

[13] W. U. Khan, F. Jameel, M. A. Jamshed, H. Pervaiz, S. Khan, and J. J. P. C. Liu, "Efficient power allocation for NOMA-enabled IoT networks in 6G era," Elsevier, vol. 39, p. 101043, 2020. https://doi.org/10.1016/j.phycom.2020.101043

[14] S. Majumdar, et al, "Improving Scalability of 6G Network Automation with Distributed Deep Q-Networks", ICC 2022 - IEEE International Conference on communications, 2022. DOI:10.1109/GLOBECOM48099.2022.10000643

[15] K. Shen, "Non-orthogonal multiple access with wireless caching," University of Manchester, pure.manchester.ac.uk2023 ,.

[16] R. O. Ogundokun et al., "Non-orthogonal multiple access enabled mobile edge computing in 6G communications: A systematic Literature Review *Sustainability* 2023, *15*(9), 7315. https://doi.org/10.3390/su15097315

[17] L. Mastrodicasa, "Caching through aerial platforms for 6G Networks," Politecnico di Torino, webthesis.biblio.polito.it2022 ,. URI: http://webthesis.biblio.polito.it/id/eprint/25536

[18] M. Elhattab, "A Comprehensive Study of Multiple Access Techniques in 6G Networks," Concordia.University, spectrum.library.concordia.ca2022 ,.

[19] D. Bepari et al., "A survey on cache-aided NOMA for 6G networks," dclibrary.mbzuai.ac.ae, 2022. DOI: 10.48550/arXiv.2205.05321

[20] M. W. Akhtar et al., "The shift to 6G communications: vision and requirements," Springer, vol. 10, pp. 1-27, 2020. https://doi.org/10.1186/s13673-020-00258-2

[21] Y.-C. Liang, D. Niyato, E. G. Larsson, and P. J. C. C. Popovski, "Guest editorial: 6G mobile networks: Emerging technologies and applications," ieeexplore.ieee.org, vol. 17, no. 9, pp. 90-91, 2020. DOI: 10.23919/JCC.2020.9205979

[22] P. Jain, A. Gupta, N. Kumar, G. P. Joshi, and W. J. S. Cho, "Performance evaluation of cooperative OMA and NOMA systems in 6G deployment scenarios," mdpi.com, vol. 22, no. 11, p. 3986, 2022.

https://doi.org/10.3390/s22113986
[23] X. Peng, X Yuan and K Zhang, "Clustered NOMA-based downlink adaptive relay coordinatedtransmission scheme for future 6G cell-free edge network", Peer to Peer Networking and Applications, vol. 15, pages 612-625, 2022. DOI: 10.1007/s12083-021-01274-4

MATHEMATICAL NOTATIONS

Symbol	Definition
α	Portion of the Power Resource Allocation
$\boldsymbol{\alpha_i}$	Power allocation factor for the (i_{th}) user
β	Portion of the Total bandwidth
$\boldsymbol{\sigma^2}$	Noise power
$\boldsymbol{C_i}$	The content cached at BS_i
$\mathbb{E}[\boldsymbol{R_{i,j}}]$	The expected data rate for user j at BS_i
$\boldsymbol{h_{i,j}}$	The channel gain between BS_i and user j
$\boldsymbol{h_i}$	Channel Gain for user i
$\boldsymbol{h_{ii}}$	The channel gain of the direct link between the (i_{th}) user and the base station
$\boldsymbol{h_{ji}}$	The channel gain of the interference from the (j_{th}) user to the (i_{th}) user
$\boldsymbol{h_k}$	Channel gain for user K
$\boldsymbol{I_i}$	The interference for the (i_{th}) user
i	User
j	User
$\boldsymbol{K}$	Number of users
$\boldsymbol{L_i}$	The latency experienced by users at BS_i
$\mathbf{log_2}$	Logarithm Base 2
M	The cache capacity
Mc	The number of cached files
N	The total number of users
$\boldsymbol{n_{i,j}}$	The AWGN at user j
$\boldsymbol{n_i}$	The AWGN at the receiver side for the user i
$\boldsymbol{n_{ij}}$	The AWGN on the subcarrier j for user i.
$\boldsymbol{n_k}$	The AWGN from user K
P	Total transmit power
$\boldsymbol{P_{hit}}$	Cache Hit Probability
$\boldsymbol{P_{i,j}}$	The power allocated to user j at BS_i for NOMA transmission
$\boldsymbol{P_i}$	Power Allocated to User i
$\boldsymbol{P_i}$	The transmit power of the (i_{th}) user
$\boldsymbol{P_{ij}}$	Power Allocation on the subcarrier j for user i
$\boldsymbol{P_k}$	Power allocation to user K
$\boldsymbol{P_{max}}$	The maximum transmit power
$\boldsymbol{P_{miss}}$	Cache Miss Probability
$\boldsymbol{P_n}$	The transmit power allocated to user (n)
R	Data Rates
$\boldsymbol{R_i}$	The achievable rate of the (i_{th}) user
$\boldsymbol{T_i}$	The throughput at BS_i
$\boldsymbol{U_i}$	The set of users associated with BS_i
$\boldsymbol{x_i}$	Transmitted Signal by the user i
$\boldsymbol{x_{m,n}}$	The caching content requested by user (n) for file (m)
$\boldsymbol{x_n}$	The information symbol transmitted by user (n)
$\boldsymbol{Y_{Av}}$	The received signal vector at the (A_{th}) antenna of the BS
$\boldsymbol{y_{A,n}}$	The received signal at the (A_{th}) antenna of the BS from the (n_{th}) user
$\boldsymbol{y_{i,j}}$	The received signal at user j from BS_i
$\boldsymbol{y_i}$	Received Signal by the user i
$\boldsymbol{y_{ij}}$	Received signal for the subcarrier j for user i

تحسين أداء اتصالات الموبايل للجيل السادس 6G باستخدام الوصول المتعدد التعاوني غير المتعامد والتخزين المؤقت

***سالار اسماعيل احمد**
salar.ahmed@epu.edu.iq

****صديق يوسف امين**
siddeeq.ameen@dpu.edu.krd

*قسم هندسة نظم المعلومات، الكلية التقنية اربيل، جامعة اربيل التقنية، اربيل، العراق
**قسم هندسة الطاقة، جامعة دهوك التقنية، دهوك، العراق

تاريخ الاستلام: 1 أغسطس 2024 استلم بصيغته المنقحة: 19 سبتمبر 2024 تاريخ القبول: 28 سبتمبر 2024

الملخص

إن شبكات الاتصالات المتنقلة في الجيل السادس مع التطبيقات والمعايير الناشئة تفرض متطلبات لشبكة ذكية بشكل متزايد، وخدمات ذكية تعتمد على إنترنت كل شيء (IoE)، وزمن انتقال منخفض للغاية، واتصال سريع بالشبكة، وطاقة أقل، ودعم لعدد كبير من خدمات الاتصالات المختلفة. تتطلب هذه المتطلبات تقنية متقدمة لتحسين وتعزيز الأداء والكفاءة في أنظمة شبكات الاتصالات المتنقلة في الجيل السادس. اقترحت الورقة تقنية تجمع بين C-NOMA والتخزين المؤقت كتخصيص ديناميكي للموارد بين المستخدمين وعقد التتابع المستخدمة لتعزيز وتحسين الأداء والكفاءة في شبكات الاتصالات المتنقلة في الجيل السادس G6. أظهرت النتائج التأكد في تعظيم الإنتاجية، وتقليل زمن الانتقال، وتحسين كفاءة الموارد. يقلل التخزين المؤقت من زمن انتقال الوصول وازدحام الشبكة من خلال الاستفادة من فكرة إبقاء المحتوى المطلوب بشكل متكرر أقرب إلى المستخدمين. من خلال التعديلات الديناميكية على مجموعات المستخدمين وتوزيع الموارد داخل المجموعات، و يعمل النظام على تعظيم استخدام الموارد وتقليل التداخل، مما يؤدي إلى تحسين كفاءة النظام وأدائه. تظهر نتائج المحاكاة بمساعدة MATLAB (V 2022a) التحسينات التي تم تحقيقها لشبكات الاتصالات المحمولة للجيل السادس G6 بواسطة، الوصول المتعدد غير المتعامد مع التخزين المؤقت C-NOMA مقارنة بجميع الأنظمة من خلال التحسن في زمن الوصول ومعدل المجموع والإنتاجية للتحقيق في حالات مختلفة من بيئات شبكات الاتصالات المحمولة للجيل السادس G6 ومقارنتها بنفس الحالات في ، الوصول المتعدد غير المتعامد NOMA التقليدية.

الكلمات الداله :

الجيل السادس للاتصالات الموبايل G6 ، الوصول المتعدد غير المتعامد التعاوني C-NOMA ، والتخزين المؤقت Caching ، تخصيص الموارد الديناميكي Dynamic Resource Allocation ، من جهاز للجهاز D2D.