Enhancing Millimeter-Wave Wireless Networks with BAT Algorithm for Dynamic User Position and Application Priority

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Abstract— **With the advancement in the development of wireless network transmission technologies, there has been a significant investment in research in the field of mobile networks, especially in 5G and 6G technologies. This investment is driven by the exponential increase in the number of mobile network users who utilize a wide variety of services with this technology. However, one challenge in planning wireless networks is optimizing the allocation of user positions to maximize network efficiency. This paper will conduct wireless network simulations with millimeter waves, using the bat algorithm to determine new user positions based on their current positions and the type of application used. The goal is to improve coverage and efficiency of next-generation networks, especially in areas with difficult access.**

Keywords— 5G Networks, 6G Networks, millimeter waves, user's position.

I. Introduction

5G networks represent a significant advancement over previous generations of mobile technology, offering much higher download and upload speeds, reduced latency, and greater capacity to connect devices simultaneously. This technological advancement will enable the development of applications such as augmented and virtual reality, telemedicine, and autonomous vehicles. Additionally, 5G networks are fundamental for the expansion of the Internet of Things (IoT), allowing the connection of billions of devices, from smart home appliances to industrial sensors, promoting a digital transformation across various industries[6].

The development of 6G networks promises to take these capabilities even further. Expected to be implemented starting in the next decade, 6G networks aim to provide even higher data transmission speeds, near-zero latencies, and greater energy efficiency. Additionally, 6G networks are designed to integrate emerging technologies such as artificial intelligence, distributed cloud computing, and holographic communications. These advancements will enable new possibilities for advanced services, such as real-time communication between machines and the creation of hyper-realistic virtual environments, providing completely new experiences for users and facilitating technological advances in areas such as healthcare, education, and entertainment [7].

Millimeter waves play a crucial role in realizing the benefits of 5G and 6G networks. These waves operate at much higher frequencies than traditional mobile networks, allowing for the transmission of large amounts of data quickly and efficiently. However, millimeter waves have a shorter range and are more susceptible to physical interference, requiring a denser network infrastructure with a greater number of antennas. Despite these challenges, the use of millimeter waves is essential to meet the growing demand for bandwidth and to support applications that require extremely high data rates and low latency [1].

5G and 6G networks, along with the use of millimeter waves, have the potential to transform regions where connectivity is often limited due to vast distances and infrastructure challenges. The implementation of these technologies can significantly improve communication in remote areas, facilitating access to education and healthcare, for example, through telemedicine, enabling remote medical consultations and diagnoses. Furthermore, enhanced connectivity can support environmental monitoring initiatives, which are essential for forest conservation, providing real-time data on deforestation and climate change [2].

This paper aims to simulate wireless networks using millimeter waves with the objective of reallocating users to achieve better network performance. The reallocation of users is done using the bat algorithm, taking into account the users' positions and the priority of the application type. The benefits of the proposal were analyzed by evaluating the signal quality and transmission delay, comparing the initial positions with the optimized positions of the users.

The sections of this article are organized as follows: Section 2 discusses the benefits of 5G networks. Section 3 describes millimeter waves. Section 4 covers the methodology addressed in the article. Section 5 presents the results obtained from the simulations. Section 6 concludes the article.

II. 5G Networks

In recent years, technological development has promoted a true revolution in the way we connect and share information. The fifth generation of mobile networks, known as 5G, emerges as the protagonist of this transformation, promising faster, more reliable, and more efficient connectivity than ever before. One of the most remarkable features of 5G is the use of millimeter waves at high frequencies, paving the way for a new paradigm of wireless communication.

The advancement of automation and technology in the industrial sector is also remarkable. The adoption of 5G in the industry aims to provide substantial improvements in the versatility, flexibility, efficiency, and usability of future smart factories. Thus, Industry 4.0 incorporates 5G technologies, promoting continuous integration throughout the entire value chain and across all layers of automation.

The features of 5G have raised great expectations, especially compared to 4G, due to the significant advancements this technology promises to bring. Notable improvements include mobile broadband speed and low latency, which are essential for critical applications such as virtual reality, artificial intelligence, autonomous vehicles, and robotics. Additionally, technologies like network slicing offer personalized service levels, optimizing the infrastructure for different use cases and enabling an enhanced user experience [4].

This technological evolution can also play a crucial role in environmental preservation, especially in areas like the Amazon, where deforestation is a global concern. The implementation of 5G networks can enable more effective remote monitoring of forests, helping to detect illegal deforestation activities and wildfires with greater precision and speed. Additionally, the use of technologies such as the Internet of Things (IoT) and real-time data analysis can contribute to the sustainable management of natural resources, reducing the human impact on these vital ecosystems.

These technologies and associated advancements in 5G represent a significant evolution in the field of wireless communications, offering transformation opportunities across various sectors, from industry to environmental preservation, contributing to global-scale connectivity, efficiency, and innovation [3].

III. User-Assist Enhancement

In 5G networks, enhancing connectivity to deliver a superior user experience is essential. User-Assist Enhancement stands out by implementing advanced technologies that not only improve the connection but also make it more robust and adaptable to the dynamic needs of users.

In an environment where data demand and connectivity are increasingly critical, technologies such as Artificial Intelligence (AI) and Machine Learning (ML) play a crucial role. These technologies enable advanced customization of connectivity, dynamically adjusting to individual user needs and predicting bandwidth demands to ensure stable, high-quality connections at all times[8][9].

Furthermore, 5G networks benefit from advancements in adaptive antennas and beamforming techniques, optimizing spectral efficiency and significantly enhancing coverage and network capacity. This results in a more stable and high-speed connection, especially in dense urban areas and locations with high traffic demand.

The capability for dynamic spectrum sharing is also a crucial feature of 5G networks, ensuring intelligent bandwidth allocation according to variable demands, further improving connection quality for all users.

In summary, User-Assist Enhancement in 5G networks not only delivers higher speeds but also ensures reliable connectivity that adapts to the specific needs of each user. With these advanced technologies and efficient management practices, 5G networks are poised to transform how we connect and interact digitally, promoting a significantly enhanced user experience and paving the way for new innovations in the era of mobile connectivity [10][11].

IV. Millimeter-waves

Millimeter waves, compared to lower frequencies, offer substantially greater bandwidth, enabling much faster data transmission speeds, essential for exceptional user experiences such as high-definition video streaming and online gaming without latency. However, they have limited range and difficulty penetrating solid obstacles, requiring denser infrastructure with small cell base stations and antennas to ensure effective coverage.

These high frequencies of millimeter waves are ideal for applications in densely populated urban areas with high data density. Additionally, they are crucial for supporting emerging technologies such as virtual reality (VR), augmented reality (AR), and ultra-reliable communications in autonomous vehicles and intelligent transportation systems. The successful implementation of 5G networks with millimeter waves creates business opportunities across various sectors, fostering innovative technological ecosystems and transforming interaction with the digital world [5].

The use of millimeter waves at high frequencies is a central and innovative feature of 5G technology, representing a significant advancement in wireless communication networks. Millimeter waves, with frequencies ranging from 30 GHz to 300 GHz, offer various advantages and challenges that shape how connectivity is delivered and the applications that become viable.

One of the primary advantages of millimeter waves is their ability to transmit an extraordinary amount of data, thanks to substantially greater bandwidth compared to the lower frequencies used in 4G and earlier networks. This results in exceptionally fast data transmission speeds, enabling the delivery of high-quality user experiences. This characteristic is crucial for bandwidth-demanding applications such as high-definition video streaming, latency-free online gaming, and instant content transfer.

However, the use of millimeter waves also presents significant challenges as they have a more limited range and difficulty penetrating solid obstacles such as building walls. This necessitates the implementation of denser infrastructure, with base stations and small-sized antennas, known as Small Cells, positioned closer to each other to ensure effective coverage. These limitations make millimeter waves more suitable for densely populated urban areas and high-density data applications.

V. Related Works

In this section on related works, several studies aligned with the current article's research focus will be discussed. The analysis will cover recent advancements and significant contributions in the optimization of 5G networks, including energy efficiency, resource allocation, and signal quality improvement. Each study will be compared to the current article's approach, highlighting similarities and differences in methodologies and outcomes. This will provide a comprehensive overview of the state-of-the-art in communication network optimization.

[14] reviewed scheduling algorithms that maximize the efficiency and fairness of network resource use. These algorithms allocate network resources fairly among users, while the Bat Algorithm optimizes user positions to improve received signal strength. Both techniques aim to enhance user experience, addressing different aspects of network resource management.

[15] investigated techniques to improve indoor connectivity, focusing on indoor-outdoor communication. While the current technique focuses on reconfiguring user positions outdoors to optimize signal strength, [15] study focuses on indoor communication, complementing the approach by improving different connectivity scenarios.

[16] discusses the importance of ultra-reliable and low-latency communications (URLLC) in the context of the Internet of Vehicles (IoV) supported by 5G technology. The authors explore advanced cooperative localization methods that leverage 5G resources to improve the accuracy and reliability of vehicle localization. The research emphasizes the integration of machine learning techniques to optimize communication and coordination between vehicles, addressing challenges such as latency and scalability. The findings suggest that 5G URLLC can significantly enhance transportation safety and efficiency, highlighting the transformative potential of this technology in the automotive sector.

[17] presents a comprehensive review of resource allocation in 5G networks, examining various techniques and algorithms developed to optimize network resource usage. The authors provide a detailed overview of spectrum allocation strategies, interference management, and load balancing, emphasizing how these techniques are crucial for achieving the expected efficiency and quality of service in 5G networks. The research also analyzes the challenges associated with implementing these strategies in real-world scenarios, including computational complexity and the dynamic nature of the network environment. The findings highlight the ongoing importance of innovation in resource allocation to meet the growing demands of users and emerging applications in the 5G ecosystem.

VI. Methodology

The Network Simulator (NS-3) is one of the main open source tools for modeling network scenarios, aiming to simulate an environment that closely approximates real-world conditions. NS-3 allows the use of Python and C++ languages for project development, with the latter being used in this study. To develop a simulated 5G channel, the millimeter-wave module MmWave, developed by New York University, was used. This module allows the simulation of channels with frequencies up to 100 GHz, ideal for data collection and analysis of 5G networks.

In the simulations, the developed scenario had a base station and ten users positioned randomly in an area of 500m x 500m. The users were classified into three priority categories depending on the type of application: High, Medium, and Low. The Base Station will calculate the new positions of the users considering the signal strength and the priority of each user. Table I below shows the simulation parameters used in NS-3.

TABLE I. SIMULATION PARAMETERS

Parameter	**Value**
Scenario	Urban
Frequency	100 GHz
Bandwith	200 MHz
Enviroment	LoS
Mobility	Randow
Antenna	Omnidirecional
Users	10
Base Station	1
Simulation Time	100 s

The Base Station calculates the new position of the users using the Bat Algorithm. The Bat Algorithm is an optimization technique that uses a population of "bats," where each bat adjusts its position based on the frequency of emission and rate of pulse, while the volume of the received echoes indicates the quality of the solution. The process involves updating the positions of the bats in each iteration. The fitness function, which evaluates the quality of each solution, is crucial for the algorithm, as it is defined according to the specific objectives of the problem, such as user allocation, incorporating variables like signal intensity and traffic priority (Table II).

TABLE II. BAT ALGORITHM PARAMETERS

Parameter	Value
Number Users	10
Bat Population	30
Maximum Interections	100
F_Min	0
F_Max	2
Separation Factor	0,8
Application Priority	video: 1.0;voice: 0.8;data: 0.5

VII. RESULTS

The solution aims to offer a better quality of user experience by relocating the user to an optimized position relative to the base station, providing better signal strength and consequently a better connection. The following Figure 1 shows the simulated scenario, where it is possible to observe the base station and the 10 users in their initial positions as well as in the new positions according to the Bat Algorithm. In the new positions, the users are closer to the base station, enjoying enhanced connectivity service.

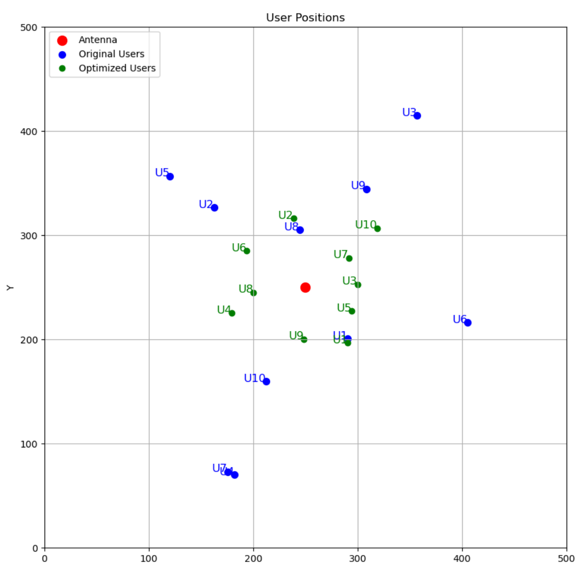

Fig. 1. User Positions

Table III below shows the initial and final positions of each user, as well as the displacement each one had to make. After the displacement, all users are closer to the antenna, thus obtaining a better connectivity experience. Among the high-priority users, User 9 had a displacement of 156.06m. Among the medium-priority users, User 7 moved 235.88m. Among the low-priority users, User 6 had a displacement of 222.11m.

TABLE III.USERS POSITION

User	Initial Distance	Final Distance	Priority	Movement
1	64.10	67.11	High	3.77
2	116.08	66.90	Low	76.82
3	196.32	50.00	Low	171.78
4	192.66	74.76	Low	155.45
5	167.92	50.00	Medium	217.11
6	158.82	65.97	Low	222.11
7	192.42	50.00	Medium	235.88
8	55.15	50.00	Medium	74.52
9	110.78	50.00	High	156.06
10	98.05	89.18	High	182.62

Figure 2 illustrates the signal strength of each user in their initial positions. It can be observed that only two users (Users 9 and 10) have a signal strength above 30 dB, indicating excellent connection quality. Another four users (Users 1, 2, 3, and 7) have a signal strength above 20 dB, representing good connection quality. However, four users (Users 4, 5, 6, and 8) have a signal strength below 20 dB, which may result in unsatisfactory connection quality.

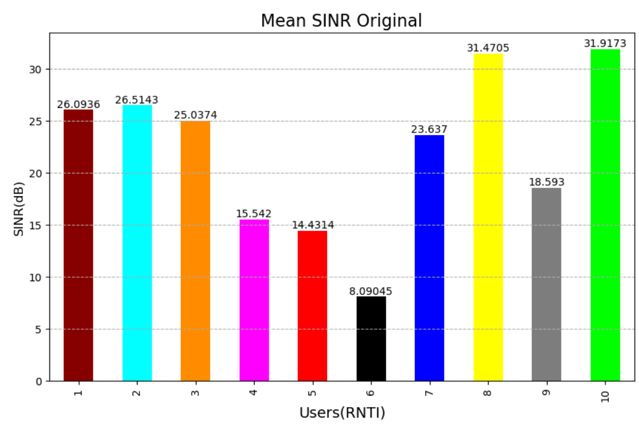

Fig. 2. Original Mean SINR

After optimizing the users' positions, it is possible to observe a significant improvement in signal strength. Five users (Users 2, 3, 7, 8, and 10) now have a signal strength above 30 dB, indicating excellent connection quality. Another four users (Users 1, 4, 5, and 9) have a signal strength above 20 dB, representing good connection quality. Only one user (User 6) has a signal strength above 10 dB, increasing from 8 dB to 13 dB, despite being of low priority. This redistribution of user positions has resulted in a considerable improvement in connectivity experience for the majority of the users (Figure 3).

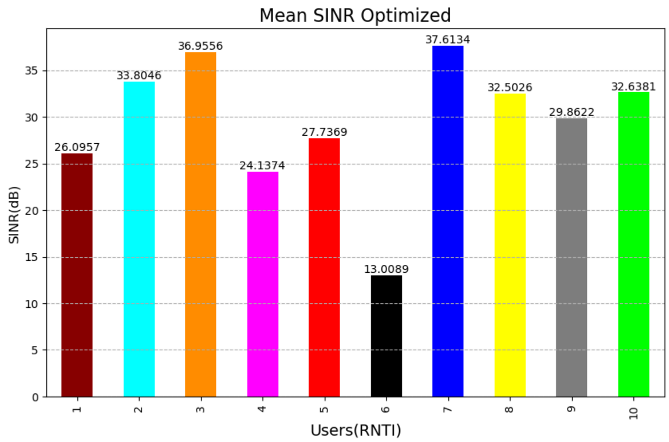

Fig. 3. Optimized Mean SINR

When analyzing the average signal intensity by user priority, significant improvements can be observed for all three groups. The percentage gain was 12.14% for the high priority group, 51.93% for the medium priority group, and 54.01% for the low priority group. These improvements indicate that the optimization algorithm effectively distributed the users, providing better signal quality and, consequently, a superior connectivity experience for all users (Figure 4).

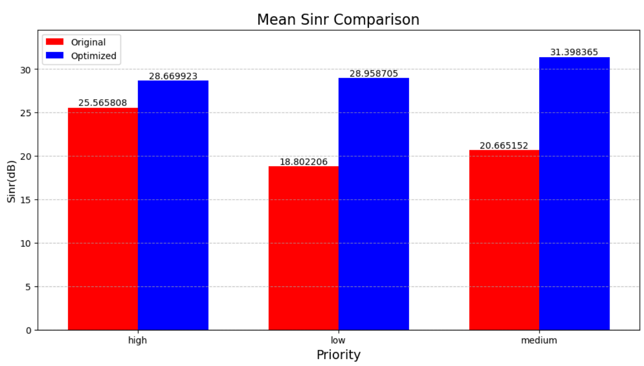

Fig. 4. Mean SINR by Priority

In the graph below, we can see the delay values for each user. It is evident that there is a considerable variation in delay among the different users. This significant variation in delay values can directly impact the quality of the connection, affecting the user experience. It is important to note that a smaller variation in delay values is desirable to ensure a more stable and consistent connection (Figure 5).

Fig. 5. Original Delay

Upon analyzing the delay values after optimizing the positions using the Bat Algorithm, a significant improvement in the values, as well as their stabilization, can be observed. Before optimization, the delay values exhibited great variability, negatively impacting connection quality. With the application of the algorithm, there was not only an overall reduction in delay values but also greater consistency among them, resulting in a more uniform and reliable connectivity experience for all users. These improvements are crucial for delay-sensitive applications, such as video streaming and video conferencing, where maintaining high connection quality is essential (Figure 6).

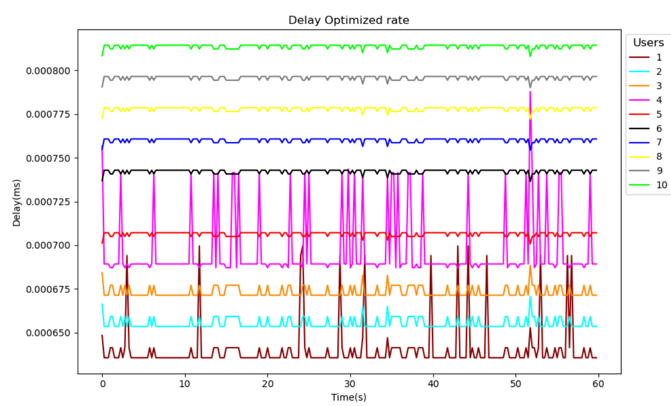

Fig. 6. Optimized Delay

In Figure 7, it is possible to observe the distribution of delay values by groups, similar to the signal-to-noise ratio graph. It is concluded that there was a general decrease in delay across all groups, reflecting a significant improvement in connection quality. However, it is important to highlight that in the low-priority group, there was a slight increase in delay. This increase was caused by the allocation of nodes in the Bat Algorithm. The proximity between the UEnodes resulted in interference in the observed channel, which consequently slightly increased the delay values. Despite this small increase, the overall improvement in delay values demonstrates the effectiveness of the algorithm in optimizing user positions, providing a more stable and efficient connectivity experience.

This analysis is essential to understand the impact of optimization techniques on service quality, especially in scenarios with high user density.

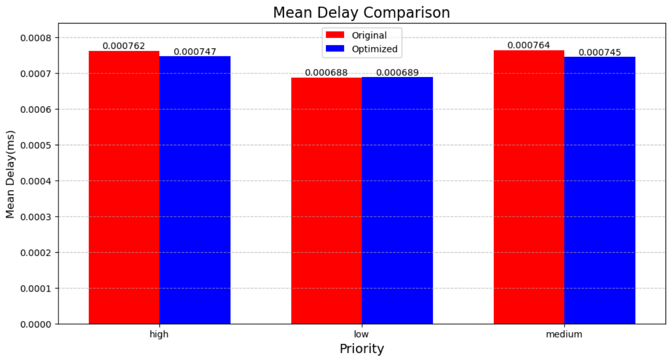

Fig. 7. Delay by Priority

VIII. Conclusions

This paper presented an innovative approach to optimize users' positioning in relation to a base station using the Bat Algorithm. Analyses demonstrated significant improvements in connection quality, reflected in signal strength increases and reductions in delay values. The effective redistribution of users allowed most groups to achieve superior connection quality, with substantial gains observed across all priority levels.

The application of the Bat Algorithm proved efficient not only in increasing signal strength but also in stabilizing delay values, indicating an overall improvement in user connectivity experience. Despite slight interference in the low-priority group due to node proximity, overall performance was largely positive.

The results suggest that optimization techniques based on bio-inspired algorithms, such as the Bat Algorithm, can be extremely effective in enhancing service quality in dense communication networks. This advancement not only benefits end users by providing faster and more stable connections but also offers valuable insights for the future development of more efficient and resilient networks.

Therefore, it is concluded that adopting advanced optimization techniques can play a crucial role in the evolution of communication networks, making them more adaptable and capable of meeting the growing demands of modern connectivity. Future studies could explore the integration of other bio-inspired algorithms and machine learning techniques to further enhance resource allocation and network management.

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