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Bandwidth Optimization Techniques in Heterogeneous 5G Networks Using DUDe

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***Abstract*— The deployment of 5G networks has led to a significant increase in demand for high-speed data rates and improved overall network performance. HetNets are a promising solution for providing coverage and capacity enhancements for 5G networks. However, one of the key challenges in HetNets is the optimization of bandwidth allocation. Traditional resource allocation techniques are limited in their ability to provide efficient and effective solutions for 5G networks. To address this challenge, a novel technology called DUDe (Downlink/Uplink Decoupling) has been proposed. DUDe optimizes bandwidth allocation in HetNets by dynamically adjusting the allocation of network resources to user demand and network conditions. The motivation of this paper is to highlight the importance of DUDe technology in macro cell offloading in 5G HetNets. The paper evaluates the performance of DUDe in comparison to traditional resource allocation techniques and provides insights into the key factors that influence its effectiveness. Moreover, this paper presents a detailed analysis of simulations results and provides recommendations for future research. The findings of this study will be useful for network operators and researchers in developing more efficient and effective resource allocation strategies for 5G networks.**

Keywords—Downlink/Uplink Decoupling (DUDe), 5G Networks, Resource Allocation, Bandwidth Allocation, Heterogeneous Networks

I. INTRODUCTION

The deployment of 5G networks has led to a significant increase in the demand for high-speed data rates, ultra-low latency, and improved overall network performance. The rise of new applications, such as autonomous vehicles, virtual reality, requires the deployment of a robust and efficient 5G infrastructure. In this regard, HetNets are a promising solution for providing coverage and capacity enhancements for 5G networks. HetNets are characterized by the deployment of different types of base stations, such as macro cells, small cells, and femtocells, to cover different geographic areas and user densities [1], [2], [3]. One of the key challenges in HetNets is the optimization of resources allocation. Traditional resource allocation techniques, such as centralized and distributed resource allocation, are limited in their ability to provide efficient and effective solutions for 5G networks. These techniques do not take into account user preferences and network conditions, which can result in suboptimal resource allocation.

To address this challenge, a novel technology called DUDe (Downlink/Uplink Decoupling) has been proposed. DUDe is a solution that optimizes bandwidth allocation in HetNets by dynamically adjusting the allocation of network resources to user demand and network conditions. DUDe considers various parameters, such as user location, traffic demand, signal strength, and network load, to determine the optimal allocation of resources. DUDe may utilize machine learning algorithms and other advanced techniques to make real-time decisions on resource allocation. The DUDe technology offers several advantages over traditional resource allocation techniques. It can adapt to changing network conditions in real-time and allocate resources based on user preferences and network conditions. Moreover, DUDe can improve the overall network performance by reducing latency, increasing data rates, and improving the user experience.

In addition, there is a significant amount of scientific research being conducted in the field of optimizing 5G networks via DUDe technology. Authors in [4] propose a method, which considers both user throughput and energy consumption to allocate resources efficiently. This method uses a novel cell association scheme that considers the energy consumption of each cell and the Quality of Services (QoS) requirements of the users. The scheme aims to minimize the total energy consumption of the network while ensuring that each user receives the required QoS. The results show that the proposed method achieves better energy efficiency while maintaining a comparable user throughput.

Another paper [5] proposes the implementation of millimeter-wave (mmWave) Small Cell Base Stations (SCBSs) in the upcoming 5G cellular network's standard, which is expected to increase the data rate and network capacity. To address the transmit power imbalance between macro-base stations and SCBSs, DUDe has also been proposed in 5G. The authors of this paper formulate the joint uplink and downlink scheduling and resource allocation in a dynamic Time Division Duplex (TDD) system as an optimization problem. The problem is solved by deriving the dynamic TDD and the user scheduling time fractions for a generalized α-fair scheduler.

Another important contribution in this scientific field which highlights the efficiency of DUDe technology is the paper [6] which addresses the issue of computational-intensive mobile applications conflicting with resource-limited Mobile Devices (MDs) in Mobile Edge Computing (MEC) scenarios. While research in multi-user single-server and homogeneous multi-server scenarios has been extensive researched, the authors note that the research in the heterogeneous multi-server scenario, where servers are located at Small Base Stations (SBSs), Macro Base Stations (MBSs), or the cloud with different computing and communication capabilities, is limited. Furthermore, while previous research has focused on offloading the MD's computational tasks to the MEC servers/cloudlets at its

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serving BS, the authors propose a joint BS association and subchannel allocation algorithm based on a Student Project Allocation (SPA) matching approach to minimize the network sum-latency.

The motivation of this paper is to highlight the importance of DUDe technology in macro cell offloading in a 5G HetNets. While high capacity 5G macro cells offer advantages in terms of improved network performance, they also face several challenges and issues related to interference, coverage, power consumption, and cost concerns. The deployment of high-capacity 5G macro cells should be carefully considered, taking into account the specific requirements of the network operator and the deployment scenario, as well as the potential benefits and challenges of the technology. In s 5G HetNets network, the offloading of traffic from macro cells to smaller cells (such as small cells or micro cells) is an important technique to improve network performance and increase capacity. By offloading traffic to smaller cells, the load on macro cells can be reduced, leading to less congestion and better coverage in areas where macro cells are less effective. This can improve the quality of service for end-users and ensure that the network can handle the increasing demand for high-bandwidth services such as video streaming and online gaming. Furthermore, offloading can reduce the power consumption of macro cells, which is important for operators seeking to optimize their network efficiency and reduce operating costs. Overall, the offloading of macro cells in heterogeneous 5G networks is a key strategy for ensuring optimal network performance and delivering a high-quality user experience.

In conclusion, the primary objective of this research paper is to demonstrate the evident superiority of DUDe technology over DUCo technology in terms of efficient and seamless bandwidth distribution, regardless of the number of users in the network. A key outcome of this comparison is the reduced bandwidth consumption by macro cell antennas, resulting in improved service for both existing users and potential new users. The significance of this contribution to the scientific community lies in its emphasis on the imperative adoption of DUDe technology in 5th generation networks. By optimizing resource allocation, the network's performance, capacity, and latency can be substantially enhanced.

What sets this paper apart from other related works in this scientific field is its comprehensive investigation into the specific benefits of DUDe technology. The study offers a detailed analysis of bandwidth distribution efficiency, independent of the number of users, providing valuable insights for network optimization. Furthermore, it highlights the direct impact on macro cell antennas, ultimately leading to enhanced user experience and resource availability. By emphasizing the importance of implementing DUDe technology in 5G networks, the paper goes beyond simply comparing two technologies and delves into the potential for transformative advancements in network performance and capacity.

The rest of the paper is organized as follows. Section II presents the DUDe technology and its key features. Section III presents the mathematical model which we used in our simulation environment. Section IV presents the simulation setup and methodology used to evaluate the performance of DUDe. Section V presents the results of the simulation and provides a detailed analysis of the findings. Finally, Section VI concludes the paper and provides suggestions for future research.

II. DUDE REVIEW AND FEATURES

In a traditional cellular network, the downlink and uplink are tightly coupled, meaning that the same amount of bandwidth is allocated for both directions of communication. The decoupling of downlink and uplink in 5G networks allows for a more flexible allocation of resources, where different amounts of bandwidth can be assigned for each direction of communication based on the traffic demand. In other words, the network can allocate more resources to the downlink direction when there is high demand for data-intensive applications, such as streaming video or gaming, while still providing sufficient uplink bandwidth for activities such as video conferencing or uploading files [7], [8], [9].

The decoupling of downlink and uplink also enables the network to dynamically allocate resources based on the specific needs of each user. For example, if a user is streaming video, the network can allocate more bandwidth to the downlink direction, while still providing sufficient uplink bandwidth for other activities such as browsing the web or checking email. This approach can lead to significant improvements in network efficiency and user experience, as it ensures that the network is able to provide the necessary resources to each user based on their specific needs.

One of the key benefits of downlink/uplink decoupling is that it can help reduce network congestion, particularly during peak usage times. By allocating more bandwidth to the downlink direction when there is high demand for data-intensive applications, the network can ensure a smoother and more reliable experience for users. This can lead to increased customer satisfaction and retention, as well as improved revenue for network operators. Another advantage of DUDe is that it allows for more efficient use of resources in areas with high traffic asymmetry, where there is a significant difference between the amount of downlink and uplink traffic. For example, in a residential area where most users are streaming video, the network can allocate more bandwidth to the downlink direction, while still providing sufficient uplink bandwidth for activities such as video conferencing or uploading files. This can help reduce network congestion and improve overall network performance.

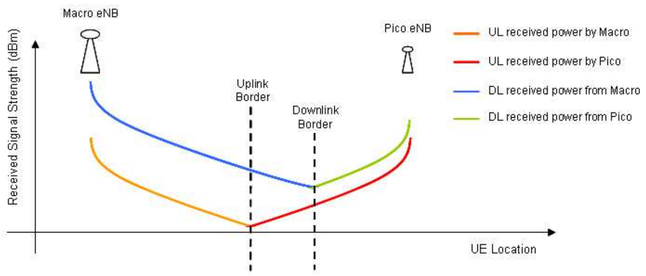

Fig.1 graphical representation of DUDe technology.

As depicted in Fig.1, when a user moves from a macro cell to a pico cell, there can be a distance between the uplink and downlink borders, which causes the user to receive a stronger signal for the uplink channel from the pico antenna and for the downlink channel from the macro cell antenna. This scenario creates an opportunity for the DUDe technology to be leveraged, enabling a separate connection for the uplink and downlink channels. This can free up resources and traffic from the macro cell antenna, reducing its load and increasing its efficiency. By distributing users more evenly across the network, the DUDe technology can improve network efficiency and energy efficiency, resulting in a positive impact on the environment and to the battery efficiency of the mobile end devices. This is achieved by offloading traffic from the macro cell antenna and using the pico cell antenna for the uplink channel, which reduces interference and improves the overall quality of service for users. The benefits of the DUDe technology are highlighted in the 3GPP technical report [10], which provides a more detailed overview of the technology and its implementation. Overall, the DUDe technology offers a promising solution for optimizing the use of network resources and improving network efficiency, while also reducing the environmental impact of wireless networks. In conclusion, DUDe is an important technique for optimizing bandwidth usage in 5G networks. By enabling more flexible allocation of resources based on traffic demand, significant improvements in network efficiency, user experience, and overall network performance can be achieved.

III. Mathematical Model

We calculate the maximum ends Users Equipment (UE) bandwidth limit for each antenna type, using the Shannon-Hartley theorem [11]. The Shannon-Hartley theorem is a principle that determines the theoretical highest rate at which information can be transmitted over a communication channel of a given bandwidth in the presence of noise. It is a practical application of the noisy-channel coding theorem, applied to a standard scenario of a continuous analog communication channel with Gaussian noise. The theorem establishes the channel capacity, which is the maximum amount of error-free information that can be transmitted per unit time with a specified bandwidth in the presence of noise, assuming the signal power is limited, and that the properties of the Gaussian noise process are known. The theorem is named after Claude Shannon and Ralph Hartley, and it is a crucial concept in information theory that is widely used in the design and analysis of communication systems. The theorem expresses the maximum theoretical limit of information that can be reliably transmitted through an analog communication channel subject to Additive White Gaussian Noise (AWGN) of power N, given a specific average received signal power S and an arbitrarily low error rate. The channel capacity, denoted by C, is a measure of the channel's ability to convey information and represents the tightest upper bound on the rate of data transmission. The theorem provides a mathematical relationship between C, S, N, and the channel's bandwidth, enabling designers to optimize communication systems for maximum information transfer while minimizing errors.

$$C = Blog_2(1 + S/N) \tag{3}$$

Where the channel capacity C in bits per second represents the upper limit of the net bit rate that can be achieved without using error-correction codes. The channel's bandwidth B is measured in hertz, and for a bandpass signal, it is the passband bandwidth. The average received signal power S is the average power of the signal over the bandwidth, measured in watts (or volts squared). In a carrier-modulated passband transmission, it is often denoted as C. The average power of the noise and interference over the bandwidth is denoted by N and measured in watts (or volts squared). The Signal-to-Noise Ratio (SNR) or Carrier-to-Noise Ratio (CNR) is expressed as a linear power ratio of the communication signal to the noise and interference at the receiver, not in logarithmic decibels.

The next step involves determining the variable B for each user, which will be used to reserve a specific frequency range from the antenna to perform UE services efficiently without any interference. This is done by using the modified formula above that takes into account the SNR value and a pre-set threshold value for the variable C. The phrase "pre-set" refers to randomly assigned bandwidth value for users of a certain service. The services available are described earlier in the text and can be found in a table.1 The new modified type is:

$$B = C/log_2(1 + S/N) \tag{4}$$

IV. Algorithm Analysis

The algorithm in Alogirthm.1 compares the performance of two different technologies for bandwidth allocation in a 5G network scenario. The two technologies are DUCo and DUDe. The algorithm assumes that there are a number of macro cell antennas, a number of micro cell antennas, and a number of pico cell antennas in the network. It also generates random bandwidth values for each UE in the network. Based on the mathematical model discussed earlier, it is possible to determine the theoretical maximum amount of bandwidth (in hertz) that an antenna can provide for each user, given their Signal-to-Noise Ratio (SNR) and the specific service they require. This calculation enables efficient and effective service provision for each user.

Then the algorithm calculates the total bandwidth available in the network by summing up the bandwidth values generated for UE. Each UE randomly selects a service from Table I. Then, it calculates the available bandwidth per antenna for both coupling and decoupling technologies. To calculate the bandwidth in both scenarios (DUDe/DUCo) we use the upload and download values for the services mentioned in Table I. Users are selected based on the best SNR value while maintaining the principle of DUDe technology that no user will connect for the downlink to a small cell antenna and for the uplink to a macro cell antenna. Knowing this distribution of users on the network antennas, we initially define a bandwidth amount for the two macro cell antennas. Every time a user connects to one of the two macro cell antennas, resources are removed from the macro cell antenna. This process is performed for both scenarios, and the final conclusion that follows from their execution is which of the two technologies results in larger amounts of bandwidth remaining in the macro cell antennas. This is more efficient since it achieves a more efficient distribution of users and their requirements within the network, with the direct consequence of increasing the throughput on the network as a whole. Next, the algorithm calculates the total bandwidth allocated to all users for both technologies. For the DUCo scenario, the algorithm loops through each user and distributes their bandwidth to the antenna they are connected to, ensuring that the allocated bandwidth does not exceed the available bandwidth per antenna. For the DUDe scenario, the algorithm loops through each user and allocates their bandwidth to both the uplink and downlink antennas they are connected to, ensuring that the allocated bandwidth does not exceed the available bandwidth per antenna for either the uplink or downlink. Finally, the algorithm compares the total bandwidth distributed to all users for both scenarios (DUDe and DUCo). If the total bandwidth allocated using DUDe technology is greater than the total bandwidth allocated using DUCo technology, the algorithm prints a message indicating that DUDe technology achieves better bandwidth allocation on a number of antennas and therefore offers a more efficient solution for 5G networks. Otherwise, the algorithm prints a message indicating that DUCo technology achieves better bandwidth allocation on a number of antennas and therefore offers a more efficient solution for 5G networks.

Algorithm 1 Algorithm for calculating bandwidth for DUCo and DUDe scenarios.

```
// Initialize variables
decoupling_total_bandwidth_macro = 0
coupling_total_bandwidth_macro = 0
num_ues = N
occurrences_for_scenarios = 1000
// Generate random bandwidth for each UE
for i in range(num_ues):
   bandwidth_values = randomly_select_bandwidth ()
   total bandwidth += bandwidth
// generate bandwidth from mathematical type above
   for i in range(num_ues):
       C = bandwidth_values.
       Bandwidth_for_Macro_UE = C/log2(1+SNR)
   end_for
end_for
// Calculate bandwidth allocation for downlink/uplink decoupling and
Downlink/uplink coupling
//DUCo Since the macro antenna is in closer proximity, it is likely to provide
a stronger SNR compared to other types of antennas, so the user should
connect to it.
for i in range(num_ues):
for j in range(occurrences_for_scenarios):
If (snrMacro_UE>snrMicro_UE) && (snrMacro_UE>snrPico_UE)
    coupling_total_bandwidth_macro = coupling_total_bandwidth_macro -
Bandwidth_for_Macro_UE
end_for
end_for
//DUDe Since the macro antenna is in closer proximity, it is likely to provide
a stronger SNR compared to other types of antennas, so the user should
connect to it.
for i in range(num_ues):
for j in range(occurrences_for_scenarios):
If (snrMacro_UE>snrMicro_UE) && (snrMacro_UE>snrPico_UE)
   decoupling_total_bandwidth_macro =
decoupling_total_bandwidth_macro - Bandwidth_for_Macro_UE
end_for
end_for
if decoupling_total_bandwidth_macro > coupling_total_bandwidth_macro:
   output("Downlink/uplink decoupling achieves better bandwidth allocation
and lower bandwidth consumption.")
else:
   output("Downlink/uplink coupling does not achieve as good bandwidth
allocation as downlink/uplink decoupling and results in higher bandwidth
consumption.")
```

V. Simulations Parameters and Results

We randomly generate a number of UE and assign each UE one of the services described in Table 1. According to Table 1, the speeds range from 1 to 25 Mbps for downstream and 0.5 to 2 Mbps for upstream.

Then in order to conduct our simulations, we developed a 5G heterogeneous network. This network consisted of 2 Macro Cell antennas, 4 Micro Cell antennas, and 8 Pico Cell antennas. Antennas are positioned in a 2 x 2 km urban square area. The macro cell antennas are placed at a height of 30 meters, the micro cell antennas at a height of 10 meters, and the pico cell antennas at a height of 5 meters. It is worth noting that the macro cell antennas are placed in the area mentioned above, and within that area, the remaining 12 antennas are positioned at suitable points. Each type of antenna has a different transmission power, with the macro cells having the highest power at 45 dbm, the micro cells having a power of 33 dbm, and the pico cells having the lowest power at 24 dbm. The gain of each antenna also varies, with the macro cells having a gain of 21 dbi, the micro cells having a gain of 10 dbi, and the pico cells having a gain of 5 dbi. The macro cells have a bandwidth of 400 MHz. The purpose of creating a heterogeneous network is to provide a more efficient distribution of resources within the network, allowing for more effective communication between users. To ensure the success of the simulations, we allocated users to random positions within the network. However, we maintained a minimum distance of 1 to 2 meters between each user to prevent overlapping and ensure reliable communication. The network was designed to allow for dynamic allocation of resources, meaning that the bandwidth and frequency range could be adjusted depending on the number and location of users in the network. The graphic representation in Fig.2 shows the layout of our network with the two macro cell antennas in the center and the small cells distributed around them.

TABLE I. Type of Services

Services	Downstream	Upsteam
Browsing/Email	5 Mbps	2 Mbps
HDTV	16 Mbps	0.5 Mbps
Video Streaming	25 Mbps	1 Mbps
Podcasts	2 Mbps	0.5 Mbps
VoIP	1 Mbps	1 Mbps

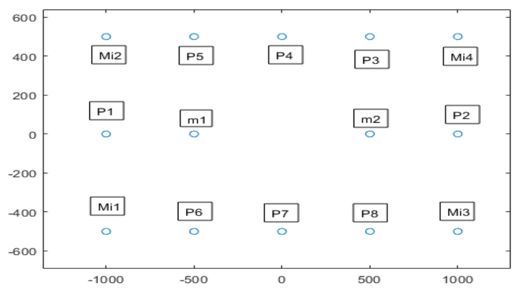

Fig.2. topology of our network. (m) for macro (mi) for micro and (p) for pico

We evaluated two scenarios: one using DUCo and the other using DUDe. The simulations were conducted with 100, 200, and 400 UEs respectively to simulate various levels of network congestion. The purpose of the simulations was to demonstrate that DUDe technology leads to a better distribution of users and bandwidth within the network. This results in the release of resources from Macro Cell antennas, allowing them to serve new users or those with greater needs. This ultimately increases the capacity and performance of the network. The simulations were critical in highlighting the usefulness and importance of DUDe technology. This technology is designed to optimize the performance of the network and free up resources from Macro Cell antennas. By doing so, it ensures a more efficient distribution of resources within the network, leading to more reliable and effective communication between users. It's worth noting that in order to obtain highly precise results, we conducted our simulations for a total of 1000 snapshots and we present the sum values.

Our research aimed to compare the performance of two different technologies, DUCo and DUDe, on two macro cell antennas in these different scenarios. The goal was to investigate which technology is more efficient in terms of bandwidth usage and distribution when multiple UEs are connected to a network. In our study, we conducted simulations with varying numbers of users and compared the bandwidth consumption of DUCo and DUDe technologies. The results showed that DUCo technology consumed significantly more bandwidth on the macro cell antennas, regardless of the number of users connected.

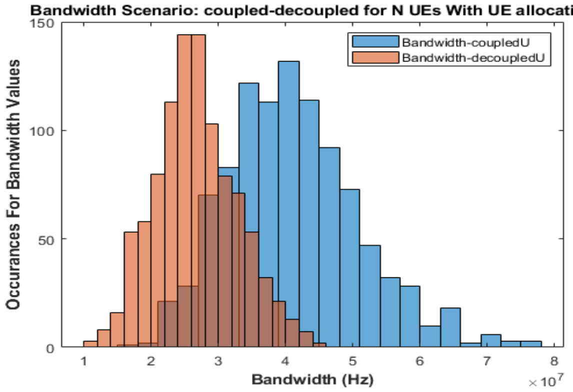

Fig.3.Bandwidth Consumption Comparison for 100 UEs in Macro cell one.

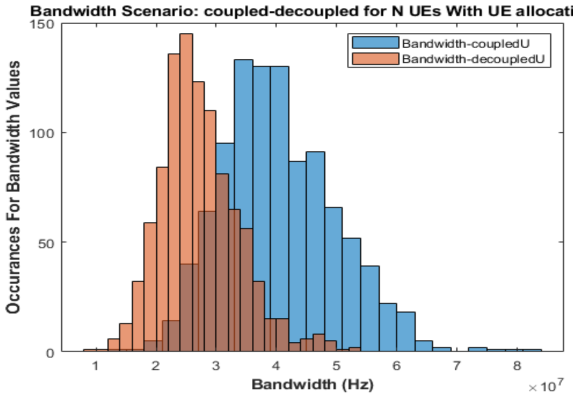

Fig.4. Comparison Bandwidth Consumption For 100 UEs in Macro cell two.

To analyze the data, we presented charts from Fig.3 to Fig.8, which showed that the amounts of bandwidth consumed to the DUDe scenario were significantly lower than those consumed to the DUCo scenario. This indicates that DUDe technology allows for a more even distribution of users and their bandwidth, resulting in more available bandwidth in the macro cell antennas. To provide clarity also, we would like to highlight some important details regarding our graphs.

The x-axis represents the remaining bandwidth (measured in Hz) after the experiments were conducted, while the y-axis shows the number of consecutive experiments that resulted in a specific bandwidth value for our antennas. The color scheme of the graphs distinguishes the coupling scenario in blue and the decoupling scenario in orange. Our study confirmed our initial hypothesis that the application of DUDe technology is more efficient in terms of bandwidth usage and distribution when multiple UEs are connected to a network. This excess bandwidth can be utilized to improve the quality of service for existing users or accommodate more users on the network. The findings of our study add a new perspective to existing bandwidth research in the 5G research area. Our research highlights the potential benefits of DUDe technology for bandwidth optimization and its practical application in macro cell antennas. This is particularly important as it can lead to significant improvements in the performance of cellular networks, particularly in crowded or high-density areas.

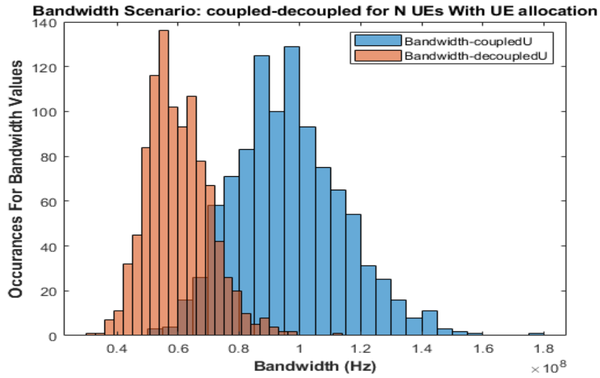

Fig.5.Comparison Bandwidth Consumption For 200 UEs in Macro cell one.

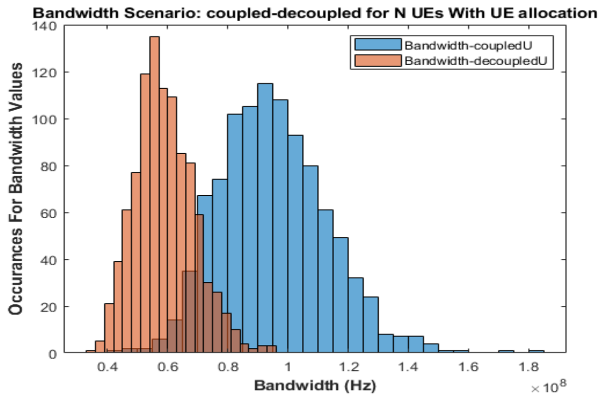

Fig.6. Comparison Bandwidth Consumption For 200 UEs in Macro cell two

Although the graphs may appear identical, they represent experiments conducted with 100, 200, and 400 users to support our hypothesis and demonstrate that our central idea remains valid, even as the number of users increases. The graphs demonstrate that the application of DUDe technology is essential for a smoother distribution of users and bandwidth in the network. Additionally, the coupling scenario shows greater bandwidth consumption, which reduces the resources available in the macro cell antennas. Thus, we present both macro cell antenna distributions to validate our experiments.

Upon analyzing the results of our experiments, it has become evident that the DUDe technology is substantially more effective than the DUCo technology when it comes to utilizing antenna resources for different user numbers. Specifically, for 400 UEs, the DUDe technology demonstrated a 71% improvement over the DUCo technology, while for 200 UEs, it was 73% more efficient and for 100 UEs it is more efficient by 50%. These findings clearly demonstrate the importance of integrating this technology into heterogeneous 5th generation networks and underscore the critical nature of our research in this field.

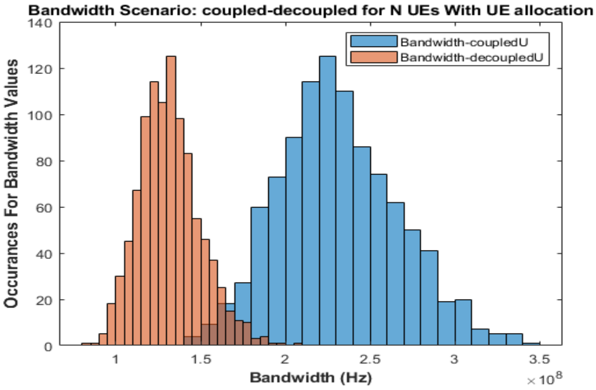

Fig. 7. Comparison Bandwidth Consumption For 400 UEs in Macro cell one.

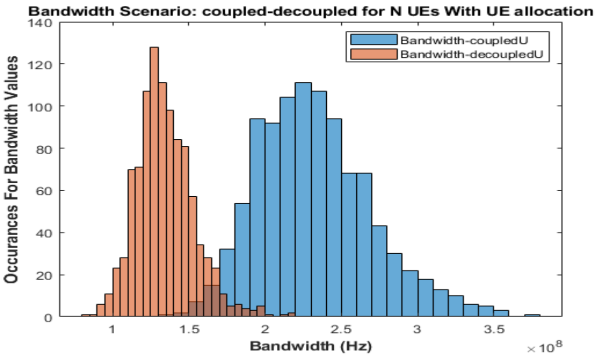

Fig.8. Comparison Bandwidth Consumption For 400 UEs in Macro cell two

It is worth noting that in some cases, the DUCo technology's antennas came close to depleting their resources for 400 users, resulting in subpar service for current users and leaving no capacity for new users to join. This highlights the importance of finding more efficient technologies for accommodating a large number of users in modern networks. Overall, our study provides valuable insights into the efficiency of different technologies for network optimization and highlights the importance of developing innovative technologies to address the challenges of modern wireless networks.

VI. Conclusion and Future Work

The application of DUDe in our 5G HetNet showcased promising outcomes. Our experiments demonstrated the technique's effectiveness in dynamically allocating resources, resulting in a more balanced distribution of UEs across antennas. Notably, this approach significantly reduced macro base station bandwidth usage, which translates to enhanced QoS for both existing and new UEs.

Future work in this area could focus on several directions. Firstly, this paper uses simulations to evaluate the performance of the DUDe technique, and more extensive experimental evaluations could be carried out to validate the technique in real-world scenarios. Secondly, the DUDe technique could be extended to support the integration of multiple access technologies, such as Wi-Fi and cellular networks, to further improve the network's bandwidth utilization. Thirdly, the DUDe technique could be integrated with other optimization techniques, such as network slicing and edge computing, to provide a comprehensive framework for optimizing 5G networks.

In conclusion, the paper presents a novel technique for improving the bandwidth utilization in heterogeneous 5G networks. The experimental evaluation shows that the DUDe technique is effective in improving the network's throughput and improving bandwidth distribution among the antennas in the network. The proposed technique has significant contribution for the design and implementation of 5G networks, and future work in this area could focus on extending the DUDe technique to support the integration of multiple access technologies and the integration with other optimization techniques.

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References

[1] S.Ruiza,et al, “5G and beyond networks” in ScienceDirect, Inclusive Radio Communications for 5G and Beyond, 2021, pp. 141-186

[2] H.Elshaer, F.Boccardi, M.Dohler, and R.Irmer “Downlink and Uplink Decoupling: A disruptive architectural design for 5G networks”, 2014 IEEE Global Communications Conference, Austin, TX, USA, 2014, pp. 1798-1803

[3] A. I. Aravanis, O. Muñoz, A. Pascual-Iserte and J. Vidal, “Analysis of downlink and uplink decoupling in dense cellular networks”, 2016 IEEE 21st International Workshop on Computer Aided Modelling and Design of Communication Links and Networks (CAMAD), Toronto, ON, Canada, 2016, pp. 219-224.

[4] H. Z. Khan, M. Ali, I. Rashid, A. Ghafoor and M. Naeem, “Cell Association for Energy Efficient Resource Allocation in Decoupled 5G Heterogeneous Networks”, 2020 IEEE 91st Vehicular Technology Conference (VTC2020-Spring), Antwerp, Belgium, 2020, pp. 1-5

[5] Y. Ramamoorthi and A. Kumar, “Dynamic Time Division Duplexing for Downlink/Uplink Decoupled Millimeter Wave-Based Cellular Networks”, in IEEE Communications Letters, Vol. 23, no. 8, pp. 1441-1445, Aug. 2019

[6] Y.Shi, Emad Alsusa and Mohammed W. Baidas “On the application of uplink/downlink decoupled access in heterogeneous mobile edge computing”, in ScienceDirect, Computer Networks, Volume 223, March 2023, 109593

[7] H. Z. Khan et al., “Resource Allocation and Throughput Maximization in Decoupled 5G”, 2020 IEEE Wireless Communications and Networking Conference (WCNC), Seoul, Korea (South), 2020, pp.1-6

[8] A Khan, et al. “Secure resource management in beyond 5G heterogeneous networks with decoupled access.” Ad Hoc Networks 125 (2022): 102737.

[9] Ali, Sundus, et al. “Uplink Performance of Narrowband Internet-of-Things Devices in Downlink–Uplink Decoupled-Based Heterogeneous Networks”, Iranian Journal of Science and Technology, Transactions of Electrical Engineering (2022): 1-15.

[10] 3GPP, TR 36.842 V12.0.0 “Study on Small Cell enhancements forE-UTRA and E-UTRAN; Higher layer aspects” (Release 12), Dec. 2013-12

[11] “Shannon–Hartley theorem,” Wikipedia, 29-Mar-2023. [Online]. Available:“https://en.wikipedia.org/wiki/Shannon%E2%80%93Hartley_theorem”. [Accessed: 28-Apr-2023]