On the Optimization of User Allocation in Heterogeneous 5G Networks Using DUDe Techniques

Konstantinos Tsachrelias
Computer Engineering and Informatics Department
University of Patras
Patras, Greece
up1096511@upatras.gr

Apostolos Gkamas
University Ecclesiastical Academy of Athens
Athens, Greece
gkamas@aeavellas.gr

Chrysostomos-Athanasios Katsigiannis
Computer Engineering and Informatics Department
University of Patras
Patras, Greece
up1072490@upnet.gr

Christos Bouras
Computer Engineering and Informatics Department
University of Patras
Patras, Greece
bouras@upatras.gr

Vasileios Kokkinos
Computer Engineering and Informatics Department
University of Patras
Patras, Greece
kokkinos@upatras.gr

Philippos Pouyioutas
Computer Science Department
University of Nicosia
Nicosia, Cyprus
pouyioutas.p@unic.ac.cy

***Abstract*—In previous years, 3G and 4G cellular homogeneous networks configured with macro Base Stations (BSs) relied only on the downlink signal, even though transmission power and interference levels differ significantly between uplink and downlink. In 5G Heterogeneous Networks (HetNet), a new generation which have multiple BSs of different types such as Femto BS and Macro BS, there is the possibility of choosing to receive the data from one BS and transmit them to a different BS, and therefore decoupling the uplink and downlink. Especially, the increasing demand for faster, more reliable, and efficient connectivity has made the optimization of User Equipment (UE) allocation in 5G networks a crucial task. To tackle the challenges posed by heterogeneous 5G networks, this study compares and evaluates the performance of Downlink/Uplink Decoupling (DUDe) and traditional Downlink/Uplink Coupled (DUCo) user allocation approaches. Simulation results show that DUDe UE allocation outperforms DUCo by providing improved network performance and more efficient utilization of network resources in diverse network conditions. These findings have important implications for the design and optimization of 5G networks and provide valuable insights for researchers and practitioners in the field.

Keywords—Downlink/Uplink Decoupling (DUDe), Resource Allocation, Users Allocation, Heterogeneous Networks

I. Introduction

One of the main research areas of research in the field of 5G heterogeneous networks [1] is the efficient redesign of network Base Stations (BSs). More specifically, a heterogeneous mobile telecommunication network consists of high-cost BS with large size and power overlapping called macro cell, and one or more low-power and size BS called femtocells, picocells and microcells. The main advantages of this heterogeneous structure are initially the successful coverage of a larger geographical area compared to the homogeneous 3G and 4G networks, as well as the greater capacity of the network in combination with the reduction of infrastructure costs and the saving of the battery drain of mobile devices and in general it achieves optimal energy consumption of the network. Especially in the context of green development and always keeping in mind the impact of the network on biodiversity and the environment in general, the selection of the base station is made by the network, based on the number of User Equipment (UE) in the station, to work efficiently without consuming large amounts of energy.

Also, the advent of 5G technology has brought forth a new era of communication networks that are expected to provide faster, more reliable, and more efficient connectivity. As a result, the optimization of resource allocation in these networks has become a crucial task. In particular, the design of 5G networks must consider the heterogeneity of the network, including differences in traffic demands, network capacity, and user mobility patterns.

However, the association of cells in such a multi-layered cellular infrastructure poses multiple challenges in multiple areas of the heterogeneous network, the most important of which are finding ways to deal with inter-cell interference, and Multicast and Broadcast Services (MBS) with high transmission power which interferes UE. Moreover, issue occur related to Low Power Stations (LBS) or relay or Device to Device (D2D) technology, as well as finding an efficient solution for mobile devices with low Signal-to-Noise Ratio (SNR) located at the edges of the cell and receiving the base station signal from a relay device.

Some researchers in various research works, such as[2][3], and [4], tried to solve the above problems by considering Uplink (UL) and Downlink (DL) as two separate data flow channels by dividing their cell correlation. A direct result of this, is the fact that the user can associate with different BSs to transfer and receive his data independent of each other. This technique is called Decoupling UL /DL access.

5G networks are characterized by their ability to support a wide range of devices and services, leading to a high degree of heterogeneity in terms of traffic demands and network resources. DL/UL Decoupling (DUDe) techniques aim to separate the control and data plane for DL and UL transmissions in order to improve the overall network performance. In this paper, we discuss the differences between the wireless connection through a merged channel (DUCo-DL/UL Coupled) and through separate channels (DUDe–DL/UL Decoupling) for the transmission and reception of information in modern mobile networks. We focus on the optimization of resource allocation – and more specific in UE allocations – in heterogeneous 5G networks using DL/UL Decoupling techniques. Our motivation is the fact that many researchers during DUDe evaluation ignore the fact that macro and small cell BSs (micro BS and pico BS) have a limited user capacity which may affect the performance of the DUDe implementation. In this research, we firstly evaluate the DUDe approach without taking into account the small cell BS limited user capacity and after that we evaluate DUDe implementation taking into account also the macro and small cell BS limited user capacity.

Our findings will be relevant for both researchers and practitioners in the field of 5G network design, as well as for companies and organizations that are developing 5G technology and applications. Through our comparison of DUDe and DUCo resource allocation approaches, we aim to provide valuable insights and recommendations for the optimization of resource allocation in heterogeneous 5G networks.

The rest of this paper continues as stated bellow: in section II we compare DUDe with previous technique, which is DUCo and in section III we present the simulation environment which we used for the evaluation. Section IV presents the user allocation algorithms which we have used during our evaluation. After that, in section V we present simulation results that demonstrate the performance of each approach under different number of UE and in section VI we conclude by summarizing the key findings of our study and discussing their implications for the design and optimization of 5G networks.

II. DUDE TECHNOLOGY OVERVIEW

DUDe is a key technology that has been proposed for improving the energy efficiency and capacity of 5G wireless networks [5][6][7][8][9][10]. It involves the separation of the control plane (signalling) and the user plane (data) in the UL and DL channels, allowing for more flexible resource allocation and improved energy efficiency.

In traditional cellular systems, the UL and DL channels are typically coupled, meaning that resources such as frequency bands and time slots are allocated to both channels together. This can lead to inefficient resource allocation, as the traffic demands and conditions on the UL and DL channels may vary significantly at different times. DUDe decouples the UL and DL channels, allowing for more efficient resource allocation and better utilization of network resources.

In addition, to improving the energy efficiency and capacity of the system, DUDe also offers other benefits, such as increased flexibility and scalability, improved coverage, and reduced latency. These benefits make DUDe a promising technology for 5G and beyond, and it is expected to play a key role in the evolution of future wireless networks.

Furthermore, one key advantage of DUDe is its ability to optimize resource allocation and improve the utilization of network resources. By decoupling the UL and DL channels, DUDe allows for more flexible resource allocation and UE allocation and the ability to adapt to changing traffic demands and conditions. This can lead to higher capacity and improved spectral efficiency, as well as reduced energy consumption.

DUDe also offers improved coverage and reduced latency, as the decoupling of the UL and DL channels allows for more efficient resource allocation and the ability to adapt to changing conditions. This can lead to higher Quality of Service (QoS) and a better user experience.

Despite these benefits, there are also some challenges and limitations to consider when implementing DUDe. One key challenge is the need for a robust control plane signalling mechanism to support the coordination between the DUDe controller and the BSs and UEs. This signalling mechanism must be able to support the fast and reliable exchange of information, while also being able to handle the large scale and complexity of the 5G network. Another challenge is the potential for increased complexity and cost, as DUDe may require the deployment of additional infrastructure and the implementation of advanced signal processing techniques. This may increase the complexity and cost of the system, as well as the latency of the system.

Overall, DUDe is a promising technology for improving the energy efficiency and capacity of 5G wireless networks. Its ability to decouple the UL and DL channels and optimize resource allocation, combined with advanced signal processing techniques, make it a key technology for the future of wireless communications. However, it is important to consider the trade-offs and challenges associated with DUDe when designing and implementing 5G and beyond systems.

III. SIMULATIONS ENVIRONMENT

The HetNet implemented in our simulations includes macro cell BSs (MBs), small cell BS (micro BS and pico BS) and UE. More specific the topology which we used in our simulations includes a set of MBs (M = 1,2,3,4.......| M|), a set of small cells (micro => Mi = 1,2,3,4.... |Mi|, pico => P= 1,2,3,4 |P||) and a set of UE (U = 1,2,3,4.......|U|). We assume that macro BS are placed at high levels to provide continuous uninterrupted coverage to large cells. In addition, we assume that the stations with the least sensitivity are placed at lower levels within an area, and as a result, the coverage of the Non-Line-Of-Sight locations is as wide as possible in the entire area, even in the most remote/obstructed points in order to efficiently serve static UE or UE who are constantly in motion within the area. The main advantage of this network is the efficient coverage in densely populated areas, where we have a lot of indoor activity (homes, companies etc.).

More particularly, we consider a 5G Heterogeneous network consisting of 2 macro BSs, 4 micro BSs, and 8 pico BSs (all the BSs are located in fixed positions), each equipped with specific transmit power in dBm. Furthermore, it should be noted that the maximum capacity of the macro cells is 2000 UE, the capacity of the micro cells is 200 UE, and the capacity of the pico cells is 46 UE as mentioned in [11]. This information is crucial in determining the optimal number of UE that can be allocated to each type of BS. A total number of N UE is distributed within the network, each with their own transmit power in dBm. The gain from all BSs, including bandwidth and noise in the network, is also considered. The UE is assigned in random locations (with 1- or 2-meter distance between each user) and the algorithm presented in allocates them to a BS with the best Signal to Noise Ratio (SNR). Table I shows the simulation parameters.

In order to determine the path loss between a UE and a BS, we utilize the Matlab [12] function nrPathLoss, which takes into account the transmit power and gain from the antennas in the three BS categories (macro, micro, and pico) respectively. This function allows us to identify the path loss of each UE in relation to the different types of BSs. Furthermore, nrPathLoss in Matlab is a tool designed to calculate the path loss of a signal transmitted over a wireless communication channel. The function takes inputs such as the frequency of the signal, the distance between the transmitter and receiver, and the properties of the environment through which the signal is propagating, and it can be used to generate graphical representation of the path loss. it can be used to optimize resource allocation, link budget and interference analysis, and other system-level evaluations.

Once the path loss has been calculated, we proceed to calculate the SNR. Utilizing the highest SNR, we connect each UE to the best BS choice from the three categories. We calculate SNR by considering the transmit power of the UE, the gains of all BSs and the UE, and the path loss experienced by the signal. via the following mathematical types:

$$prm = ptue + Gm + Gue - PLm \qquad (1)$$

$$SNR = prm - NOISE; \qquad (2)$$

The variable "prm" represents the received power from a BS for a given transmit power. The variable "ptue" represents the transmit power of the UE. The variable "Gm" represents the gain of the BS. The variable "Gue" represents the gain of the UE. The variable "PLm" represents the path loss experienced by the signal transmitted from the BSs to the UEs.

In addition, this study demonstrates the importance of utilizing the nrPathLoss function and the SNR in determining the best path loss and user allocation in a 5G DUDe network. The results indicate that DUDe approach achieves better user allocation compared to DUCo. The results of this study can serve as a valuable reference for future research in the field of 5G networks. It is important to note that this scenario, apart from being a theoretical representation, has the potential to be applied to a real-world scenario since it considers real factors such as the specific location of the BSs, their type, height difference between them and the heights of the buildings in which they will be placed.

TABLE I. SIMULATION PARAMETERS

Parameter	Value
Transmit power(dbm)	UE=20 Macro cell = 45 Micro cell = 33 Pico cell = 24
BS height (m)	Macro height = 25 Micro height =15 Pico height = 10
Antenna gain (dbi)	Macro cell = 17.8 Micro cell = 12 Pico cell = 4
bandwidth (MHz)	20
Environmental parameters	UE1=100/UE2=500/UE3=1000 Position=random
Power Noise	Pnoise= -74+10log(Bandwidth(hz))

IV. User Allocation Algorithms

The proposed algorithms assign UE to BSs in our 5G cellular network. The simulation starts by initializing network parameters such as the number of macro, micro and pico cells, and their respective capacities as has been described in the previous section.

Regarding the user allocation to the various BSs (Macro, Micro, Pico), we investigate the following scenarios:

- 1st Scenario, comparison of DUCo and DUDe: The user allocation in this scenario is based on the best DL SNR for DUCo and the best UL SNR for DUDe among the various BSs (either Macro or Micro or Pico). In this scenario we are not taking into account the capacity of each BS.
- 2nd Scenario, comparison of DUCo and DUDe with user allocation: This scenario is the same with the previous but we are taking into consideration the user capacity of each BS.

In the following paragraphs we present in pseudocode the algorithm for the implementation of the above describe scenarios.

In the first DUCo scenario, the calculation of SNR for all UE is based on the DL channel for DUCo and UL channel for DUDe and is performed for 1000 snapshots. By considering the SNR values for each user and for each snapshot, the UE is connected to the BS with the highest value. This approach maximizes the performance and user experience by ensuring that the user is always connected to the best possible BS. In addition, to UE allocation and network behavior control ensures that each user is connected to the type of BS (macro, micro, or pico) that provides the best performance and is closest to them. The algorithm of the first scenario in the case of DUCo is presented in Fig 1 and the algorithm of the first scenario in the case of DUDe is presented in Fig 2.

The first scenario does not take into account he capacity of each BS and can lead to an infeasible situation, when the number of the UE connected to a BS is higher that the BS UE capacity. For the above reason, in the second scenario with user allocation, the SNR for all UE is calculated for 1000 snapshots based on the on the DL channel for DUCo and UL channel for DUDe. The limited capacity of Bs is taken into account, and when a user selects the best (in term of downlink channel SNR) one of the 14 BSs, two actions are performed simultaneously. Firstly, a unit of capacity is removed for each UE that enters the BS, and secondly, the number of UEs entering the BS is counted. This control of capacity combined with counting of UEs in each BS ensures that no BS reaches the maximum capacity, resulting in a more even distribution of UE within the network. As we present in the next section, the uneven and insufficient service of UE is avoided by this approach, even this case which DUCo technique achieve much worse user allocation in compare with DUDe.

```
for each snapshot:
  for each UE:
    calculate SNR based on downlink channel
  end for
  determine the type of antenna (macro, micro, pico) with the highest SNR value
  connect UE to the determined antenna
end for
```

Fig. 1. First Scenario DUCo

```
for each instance:
  for each UE:
    calculate SNR based on uplink channel
  end for
  determine the type of antenna (macro, micro, pico) with the highest SNR value
  connect UE to the determined antenna
end for
```

Fig. 2. First Scenario DUDe.

The algorithm of the second scenario in the case of DUCo is presented in Fig 3 and algorithm of the second scenario in the case of DUDe is presented in Fig 4.

```
For each user:
    SNR_values = []
    For each antenna in [macro, micro, pico]:
        Calculate the SNR for the antenna for 1000 snapshots based on the downlink channel
        Add the calculated SNR value to the SNR_values list

   Return the index of the antenna with the highest SNR value in the SNR_values list
    best_antenna = select_best_antenna(SNR_values)

    Select the kind of antenna with highest SNR value from list above  [macro, micro, pico]
            If capacity_check_best_antenna has not reached the maximum
               Remove one unit of capacity from the antenna
               Increment the count of users in the antenna

            Else:
                Repeat the process of calculating SNR values for all antennas [macro, micro, pico]

                Select the best antenna and check its capacity
                            If the capacity of the best antenna is not at maximum:
                                allocate_user(user, best_antenna)
                                update_capacity(best_antenna)
                                update_user_count(best_antenna)
                            Else:
                                Repeat the process until find the best antenna with capacity and highest SNR.
```

Fig. 3 Second Scenario DUCo

```
For each user:
    SNR_values = []
    For each antenna in [macro, micro, pico]:
        Calculate the SNR for the antenna for 1000 snapshots based on the Uplink channel
        Add the calculated SNR value to the SNR_values list

   Return the index of the antenna with the highest SNR value in the SNR_values list
    best_antenna = select_best_antenna(SNR_values)

    Select the kind of antenna with highest SNR value from list above  [macro, micro, pico]
            If capacity_check_best_antenna has not reached the maximum
               Remove one unit of capacity from the antenna
               Increment the count of users in the antenna

            Else:
                Repeat the process of calculating SNR values for all antennas [macro, micro, pico]

                Select the best antenna and check its capacity
                            If the capacity of the best antenna is not at maximum:
                                allocate_user(user, best_antenna)
                                update_capacity(best_antenna)
                                update_user_count(best_antenna)
                            Else:
                                Repeat the process until find the best antenna with capacity and highest SNR.
```

Fig. 4. Second Scenario DUDe

V. Results Evaluation and Analysis

In this section, we present the evaluation of the proposed algorithms. For each scenario we calculated the SNR of each UE for 1000 snapshots. Afterwards, the average SNR for every snapshot is calculated and presented.

A. Evaluation and analysis of 1st scenario

We run the simulation of 1st scenario for 100 UE, 1000 UE and 2000 UE (Fig 5 to Fig.7). This simulation shows that lower SNR values result in a higher probability of having efficient coupling due to the high gain of the BS antenna in these cases. On the other hand, higher SNR values lead to a greater likelihood of the DUDe technique being more effective. It is also important to note that the possibility of an efficient coupling technique decreases significantly below SNR 35dB.

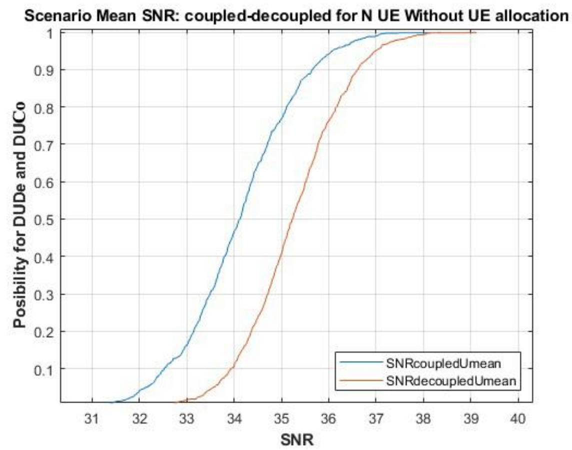

Fig. 5. DUCo/DUDe comparison without UE allocation for N=100.

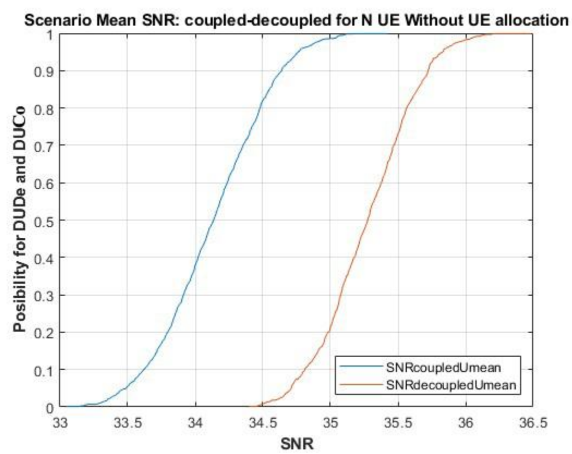

Fig. 6. DUCo/DUDe comparison without UE allocation for N=1000.

As Fig 5-7 suggest, the DUDe approach offers better performance, e.g., for SNR 35dB DUDe is successful for more than 85% of the UE in all case when DUCo is successful for less than 25% of the UE. The choice between DUCo and DUDe techniques for network connection in 5G networks is determined by the signal strength, as measured by the SNR. For weak signals with low SNR values, the DUCo technique is more efficient due to the higher gain of the Macro cell BS antenna. The higher gain of the Macro cell BS antenna results in a stronger signal that can penetrate through obstacles and provide better coverage, making the DUCo technique well suited for weak signals. On the other hand, for strong signals with high SNR values, the DUDe technique is more efficient. In this scenario, the DUDe technique can provide a more stable and higher data rate compared to the DUCo technique.

Hence, for SNR values greater than 36dB, the DUCo technique is not viable as it can result in decreased network performance. It is important to note that the SNR threshold of 36dB is just a rough guideline and may vary depending on specific network conditions and requirements. Hence, regular evaluation and optimization of the network infrastructure is crucial to ensure optimal performance for all UE in a 5G network.

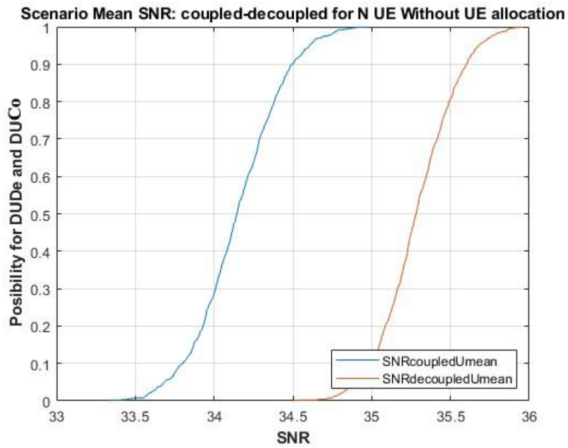

Fig. 7. DUCo/DUDe comparison without UE allocation for N=2000.

B. Evaluation and analysis of 2nd scenario

We run the simulation of 2nd scenario for 100 UE, 1000 UE and 2000 UE (Fig 8 to Fig.10). This simulation considers the capacity limitations of the macro, micro, and pico BSs, which are 2000, 200, and 46 respectively. The UE are in an area with 14 BSs. The results show that lower SNR values increase the probability of efficient coupling due to the high gain of the BS antenna, while higher SNR values increase the effectiveness of the DUDe technique. Finally, the possibility of efficient coupling decreases significantly above 30dB.

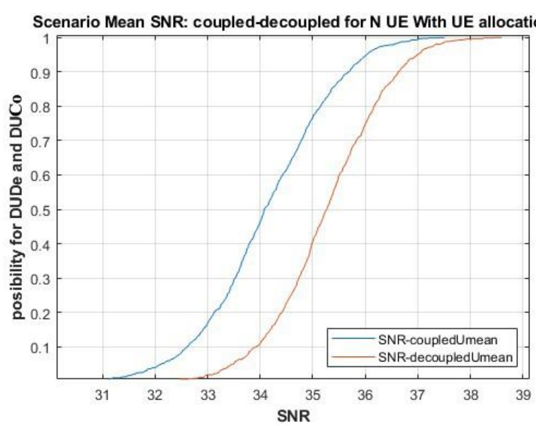

Fig. 8. DUCo/DUDe comparison with UE Allocation for N=100.

The outcome of our implementation of various scenarios and consideration of the capacity of 14 BSs in our network is as follows. The evaluation of UE values in various scenarios has led to the following conclusion: the choice between the DUCo and DUDe techniques for network connection depends on the signal strength (SNR). For weak signals (low SNR values), the DUCo technique is more efficient due to the higher gain of the Macro cell BS antenna. However, for strong signals (high SNR values), the DUDe technique is more efficient and the DUCo technique is not viable for SNR values greater than 36db. Hence, the optimal infrastructure for a 5th generation network would be a hybrid approach that directs UE to the most suitable choice based on signal strength, to ensure efficient communication and minimize interference.

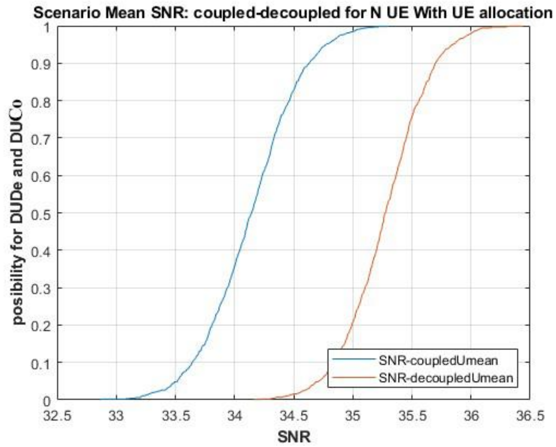

Fig. 9. DUCo/DUDe comparison with User Allocation for N=1000.

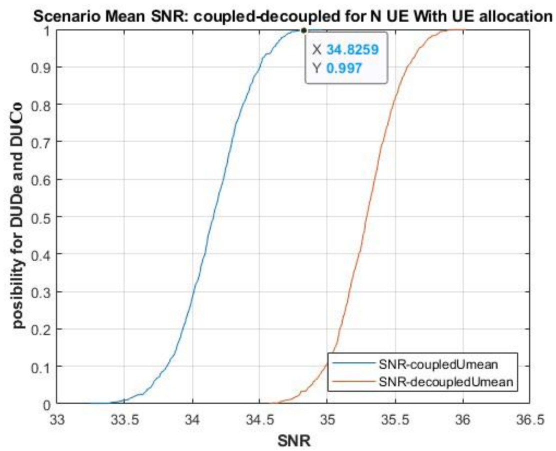

Fig. 10. DUCo/DUDe comparison with User Allocation for N=2000.

C. UE Allocation comparison between DUCo/DUDe

In order to evaluation the UE allocation, we run the simulation 100 UE, 1000 UE and 2000 UE (Fig 11 to Fig.13). The Fig below show the mean UE capacity of the BSs for different number of UE. By running these simulations, we prove that the comparison of the DUDe and DUCo techniques, considering the BS capacity, reveals that DUDe has a more balanced user distribution compared to DUCo. This means that DUDe ensures that no BS will have more UE than its capacity, leading to both efficient operation of the BSs and

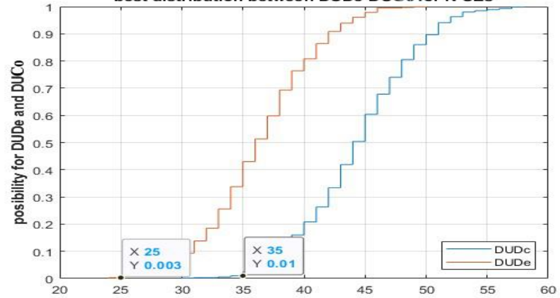

Fig. 11. User Allocation comparison for N=100.

Indeed, the results of the simulation suggest that the DUDe technique provides a more uniform distribution of UE in the network compared to DUCo. As the number of UE in the network increases, the need for the DUDe technique becomes more apparent to ensure efficient communication between UE and BSs. The improved distribution of UE leads to better utilization of the BSs, thereby providing a more efficient service to UE. It is concluded that DUDe has a significant advantage over DUCo in terms of user distribution and network performance.

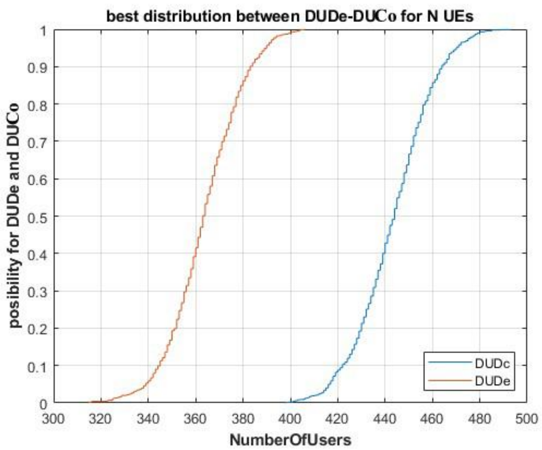

Fig. 12. User Allocation comparison for N=1000.

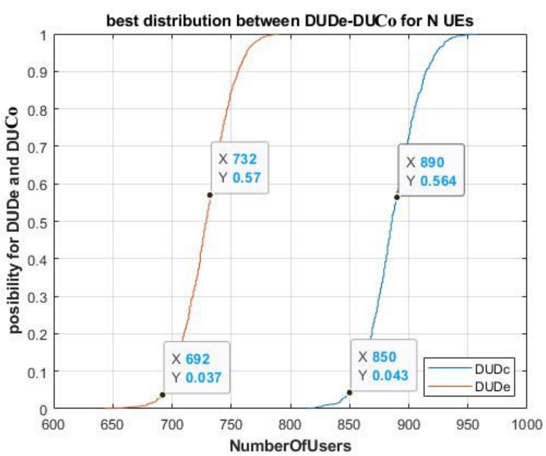

Fig. 13. User Allocation comparison for N=2000.

VI. Conclusions and Future Work

The study of 5G networks has become increasingly important in recent years, given the exponential growth in the demand for mobile data and the increasing number of connected devices. As a result, new resource allocation schemes are needed to meet the demands of 5G networks in terms of capacity, fairness, and user satisfaction. The comparison between DUCo and DUDe user allocation schemes provides valuable insights into the trade-offs between these two approaches.

Our results showed that the Decoupling approach has several advantages over the coupled approach, such as higher network capacity, improved fairness, and thus increased user satisfaction. This is because the Decoupling approach allows for more flexible and efficient resource allocation, which results in improved network performance. However, it should be noted that the Decoupling approach requires more complex resource allocation algorithms, which can lead to higher implementation costs.

The results of this study can serve as a starting point for further research in the field of 5G network resource allocation and can contribute to the development of more efficient and effective resource allocation algorithms for 5G networks and beyond. The future work of this study can be focused on optimizing the resource allocation of bandwidth and energy efficiency in 5G networks. Advanced techniques such as machine learning, deep reinforcement learning, and game theory can be utilized to enhance the performance of resource allocation algorithms. Moreover, further research is necessary to investigate the trade-off between network capacity, fairness, and energy efficiency, as optimizing one of these metrics may negatively impact the others.

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