UNIVERSITI PUTRA MALAYSIA

RESOURCE ALLOCATION TECHNIQUES FOR DOWNLINK NON-ORTHOGONAL MULTIPLE ACCESS-BASED 5G WIRELESS SYSTEMS

ZUHURA JUMA ALI

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By

ZUHURA JUMA ALI

Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfilment of the Requirements for the Degree of Doctor of Philosophy

May 2021

DEDICATION

I would like to dedicate this thesis to my beloved husband, family, supervisor, and the entire committee. Their guidance and relentless support have been a great inspiration to the realization of this research.

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of the requirement for the degree of Doctor of Philosophy

RESOURCE ALLOCATION TECHNIQUES FOR DOWNLINK NON-ORTHOGONAL MULTIPLE ACCESS-BASED 5G WIRELESS SYSTEMS

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Chairman : Professor Ir. Ts. Nor Kamariah Noordin, PhD
Faculty : Engineering

The expected usage growth of smart devices in the wireless cellular system and many connected devices with other new, improved technological advancement has resulted in the high data rate demands and spectrum scarcity problems. Hence, efficient resource allocation techniques are required to improve spectrum utilization and address the high data rate demands for future wireless communication networks. Non-Orthogonal Multiple Access (NOMA) is one of the most promising multiple access technology for fifth-generation (5G) and future advancement due to its significant role in achieving high spectral efficiency and energy efficiency together with supporting large number of connectivity required for massive machine-type communication (mMTC). This thesis's main objective is to solve the downlink NOMA systems' resource allocation problems for improving the system sum rate and energy efficiency. The study addressed the optimization of resources in a single-cell and heterogeneous transmission systems using convex optimization techniques. First, the downlink NOMA-based single-cell systems' resource allocation problems are addressed. The closed-form solutions are derived using Karush-Kuhn-Tucker (KKT) conditions to maximize the system sum rate and the Dinkelbach (DKL) algorithm to maximize system energy efficiency. Moreover, the Hungarian (HNG) algorithm is utilized for pairing two users into the sub-channel. For 10 users, 2 W Base Station (BS) power, the system sum rate of the proposed NOMA with optimal power allocation using KKT conditions and HNG (NOMA-PKKT-HNG) achieves a higher sum rate by 20.02 %, 40.09 %, and 50.32 % than NOMA with a Difference of Convex programming (NOMA-DC), NOMA with Fractional Transmitting Power Allocation (NOMA-FTPA), and conventional Orthogonal Frequency Division Multiple Access (OFDMA) techniques respectively. Besides, with 20 users at the BS, the system energy efficiency presented an optimal power allocation using DKL and HNG (NOMA-PDKL-HNG) with greater performance than those from NOMA-DC,

NOMA-FTPA and OFDMA by 40 %, 59 %, and 86 % respectively. Second, the downlink NOMA's resource allocation problems in a heterogeneous network (NOMA-HetNets) are investigated. The results show that the femtocell user's minimum energy efficiency by applying NOMA with power allocation method using Sequential Convex Programming and user pairing based on Greedy Algorithm (NOMA-SCP-GA) is higher by 38.22 %, 58.84 %, and 76.39 % compared to NOMA-DC, NOMA-FTPA, and OFDMA methods respectively. The obtained results from both NOMA scenarios confirm that the proposed NOMA-PKKT-HNG, NOMA-PDKL-HNG, and NOMA-SCP-GA methods are promising approaches for the 5G capability demands.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Doktor Falsafah

TEKNIK PERUNTUKAN SUMBER UNTUK DOWNLINK NON-ORTHOGONAL PELBAGAI SISTEM TANPA WAYAR BERASASKAN AKSES 5G

Oleh

ZUHURA JUMA ALI

Mei 2021

Pengerusi : Professor Ir. Ts. Nor Kamariah Noordin, PhD
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Jangkaan pertumbuhan penggunaan peranti pintar dalam sistem selular tanpa wayar dan kebanyakan peranti penghubung bersama-sama dengan pembangunan kemajuan teknologi baru dan dipertingkatkan telah menyebabkan permintaan kadar data yang tinggi dan masalah kekurangan spektrum. Oleh itu, teknik peruntukan sumber yang cekap diperlukan untuk meningkatkan penggunaan spektrum dan menangani permintaan kadar data yang tinggi untuk rangkaian komunikasi tanpa wayar masa depan. Non-Orthogonal Multiple Access (NOMA) merupakan salah satu teknologi pelbagai akses yang menjanjikan untuk generasi kelima (5G) dan pada masa hadapan kerana peranannya yang penting dalam mencapai kecekapan spektrum tinggi dan kecekapan tenaga dengan jumlah sambungan yang besar yang diperlukan untuk massive machine-type communication (mMTC). Objektif utama tesis ini adalah untuk menyelesaikan masalah peruntukan sumber dalam sistem downlink NOMA untuk meningkatkan kadar jumlah sistem, dan kecekapan tenaga. Kajian ini dapat menangani pengoptimuman sumber dalam satu sel dan sistem penghantaran heterogen menggunakan teknik pengoptimuman convex. Pertama, masalah peruntukan sumber sistem sel tunggal berasaskan downlink NOMA ditangani. Penyelesaian bentuk tertutup diperoleh menggunakan syarat Karush-Kuhn-Tucker (KKT) untuk memaksimumkan kadar jumlah sistem dan algoritma Dinkelbach (DKL) untuk memaksimumkan kecekapan sistem tenaga. Selain itu, algoritma Hungarian (HNG) digunakan untuk menggandingkan dua pengguna ke dalam sub-saluran. Keputusan menunjukkan bahawa dengan 10 pengguna, dan kuasa 2 W Base Station (BS), kadar jumlah sistem NOMA yang dicadangkan dengan peruntukan kuasa optimum menggunakan syarat-syarat KKT dan HNG (NOMA-PKKT-HNG) mencapai kadar jumlah yang lebih tinggi sebanyak 20.02 %, 40.09 %, dan 50.32 % daripada NOMA-difference convex programming (NOMA-DC), NOMA-fractional transmitting power allocation (NOMA-FTPA), dan konvensional orthogonal frequency division multiple access (OFDMA).

Sementara itu, dengan 20 pengguna di BS, kecekapan sistem tenaga dengan peruntukan kuasa yang optimum menggunakan DKL dan HNG (NOMA-PDKL-HNG) dengan prestasi yang lebih baik daripada NOMA-DC, NOMA-FTPA dan OFDMA masing-masing sebanyak 40 %, 59 %, dan 86 %. Kedua, masalah peruntukan sumber downlink NOMA dalam rangkaian heterogen (NOMA-HetNets) telah disiasat. Keputusan menunjukkan bahawa kecekapan tenaga minimum pengguna femtocell menggunakan NOMA dengan kaedah peruntukan kuasa optimum menggunakan SCP dan GA (NOMA-SCP-GA) adalah lebih tinggi sebanyak 38.22 %, 58.84 %, dan 76.39 % berbanding kaedah NOMA-DC, NOMA-FTPA, dan OFDMA. Keputusan yang diperoleh daripada kedua-dua senario NOMA mengesahkan bahawa, cadangan NOMA-PKKT-HNG, NOMA-PDKL-HNG, dan kaedah NOMA-SCP-GA adalah pendekatan yang baik yang dapat menjamin permintaan keupayaan 5G.

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All praise be to Allah, the Most Beneficent the Most Merciful, and peace be upon His Messenger. I would like to express my utmost gratitude and deepest thanks to my supervisor, Prof. Ir. Ts. Nor Kamariah binti Noordin, for her continuous guidance, exemplary kindness, support and encouragement throughout this research period. Thank you for the invaluable advice and assistance. Without her helping hand, this might not have been a success; God bless her and her family. I would not forget the kind gestures received from my co-supervisors in the person of Prof. Ir. Aduwati binti Sali and Associate Prof. Fazirulhisyam Hashim for their overwhelming support, valuable comments and guidance along this research journey. Thanks all. God bless them and their family.

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My appreciation to my beloved mother Mwanakheri Mussa, my uncle Abdi Mussa, my brothers and sisters, for their endless love, patience, prayer, support and encouragement throughout my study. May the Almighty Allah bless you and provide for all your needs (Amen). Last but not least, I acknowledge my sincere indebtedness and grateful to my loving husband Abdulla Mohamed, and my beautiful daughter Nusayba Abdulla for their patience, encouragement, support and unconditional love throughout my stay in Malaysia.

This thesis was submitted to the Senate of the Universiti Putra Malaysia and has been accepted as fulfilment of the requirement for the degree of Doctor of Philosophy. The members of the Supervisory Committee were as follows:

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Declaration by Members of Supervisory Committee

This is to confirm that:

- the research conducted and the writing of this thesis was under our supervision;
- supervision responsibilities as stated in the Universiti Putra Malaysia (Graduate Studies) Rules 2003 (Revision 2012-2013) were adhered to.

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2G	second-generation
3G	third-generation
3GPP	3rd generation partnership project
4G	fourth-generation
5G	fifth-generation
AWGN	additive white gaussian noise
BS	base station
BSs	base stations
CDF	cumulative distribution function
CDMA	code division multiple access
CD-NOMA	code domain-non-orthogonal multiple access
CEB	center-based
CNR	channel gain-to-noise ratio
CR	cognitive radio
CRAN	cloud radio access network
CR-NOMA	cognitive radio-non-orthogonal multiple access
CRS	cooperative relay systems
CSI	channel state information
DC	difference of convex programming
DIWA	double iterative water filling algorithm
DKL	dinkelbach
D-NLUP	divide-and-next-largest-difference-based user pairing
eMBB	enhanced mobile broad band
EPA	equal power allocation
EPAS	equal power across sub-channel
fCUE	femtocell user

fCUEs	femtocell users
FDMA	frequency division multiple access
FEPA	fair energy-efficient power allocation
FPA	fixed power allocation
FSPA	full search power allocation
FTPA	fractional transmit power allocation
GA	greedy algorithm
GPRS	general packet radio service
GPS	global positioning system
GRPA	gain ratio power allocation
GSM	global system for mobile communication
HetNets	heterogeneous networks
HNG	hungarian
IA	initialization algorithm
IGS	improper gaussian signaling
IoT	internet of things
ITU	international telecommunication union
KKT	karush-kuhn-tucker
LDS	low density spreading
LTE	long-term evolution
LTE-A	long-term evolution-advanced
MADS	mesh adaptive direct search
mCUE	macrocell user
mCUEs	macrocell users
MIMO	multiple-input multiple-output
MISO	multiple-input single-output
MISO-NOMA	multiple-input single-output-non-orthogonal multiple access
MISO-OMA	multiple-input single-output-orthogonal multiple access

MKP	multiple-choice knapsack problem
MMSE	minimum mean square error
mMTC	massive machine-type communication
mmWave	millimeter wave
MUSA	multi-user shared access
NOMA	non-orthogonal multiple access
NOMA-DC	non-orthogonal multiple access-based on power allocation using difference of convex programming
NOMA-FTPA	non-orthogonal multiple access-based on power allocation using fractional transmitting power allocation
NOMA-HetNets	non-orthogonal multiple access in heterogeneous networks
NOMA-PDKL-HNG	non-orthogonal multiple access-based on power allocation using dinkelbach approach and hungarian algorithm
NOMA-PKKT-HNG	non-orthogonal multiple access-based on power allocation using karush-kuhn-tucker conditions and hungarian algorithm
NOMA-SCP	non-orthogonal multiple access-based on power allocation using sequential convex programming
NOMA-SCP-GA	non-orthogonal multiple access-based on power allocation using sequential convex programming and greedy algorithm
NOMA-VLC	non-orthogonal multiple access with the visible light communication
NP	non-deterministic polynomial
OFDMA	orthogonal frequency division multiple access
OMA	orthogonal multiple access
P	polynomial
PDKL	power allocation using dinkelbach approach
PDMA	pattern division multiple access
PD-NOMA	power domain-non-orthogonal multiple access
PGS	proper gaussian signaling
PKKT	power allocation using karush-kuhn-tucker conditions
QoS	quality of service

SC	superposition coding
SC-FDMA	single carrier-frequency division multiple access
SCP	sequential convex programming
SCPC	single-carrier power control
SCUS	single-carrier user selection
SDP	semidefinite programming
SIC	successive interference cancellation
SINR	signal-to-interference-plus-noise-ratio
SISO	single-input single-output
SOEMA	swap operation enabled matching algorithm
SOMSA	sub-optimal matching scheme algorithm
TDMA	time division multiple access
UCGD	uniform channel gain difference
UE	user
UEs	users
UMTS	universal mobile telecommunication system
UPAS	unequal power across sub-channel
URLLC	ultra-reliable and low latency communications

CHAPTER 1

INTRODUCTION

The research in wireless communication systems moves towards the fifth generation (5G) and beyond. The capabilities of 5G are expected to be more extended than the previous generations, which enable massive connectivity with different and powerful requirements, such as high data rates, very low latency, ultra-high reliability, and energy-efficient techniques, etc. The current wireless communication networks may not achieve these demands, which also needs the usage of different advanced technologies. Non-orthogonal Multiple Access (NOMA) is among the non-orthogonal transmission techniques that have attracted tremendous interest by researchers due to its high spectral efficiency improvements and high data rates performance, which appears to meet the 5G capability demands. This chapter highlights the background of wireless communication systems, the problems existing in the NOMA system, states the main research objectives to be achieved and research questions to be answered, followed by the scope and the main contributions, and then the significance of the study. Finally, this chapter outlines the thesis organization.

1.1 Background

Wireless communication has become an essential part of our everyday lives since it improves our countries' economic growth and attends to human needs. It has witnessed historical changes due to the need for high capacity and high-quality communications, so the development of new generation became significant. The Frequency Division Multiple Access (FDMA) [1], [2], and Time Division Multiple Access (TDMA) technologies were deployed to achieve higher data rate and improve the spectrum efficiency [2], [3] in the early generations. The evolution of third-generation (3G) in 2000 became a significant step for the introduction of General Packet Radio Service (GPRS), which was introduced by the International Telecommunication Union (ITU). The 3G networks, also known as Universal Mobile Telecommunication System (UMTS), offered a higher data rate and greater security than second-generation (2G) networks. In this network, the Code Division Multiple Access (CDMA) technology was deployed, which allows users to share the same frequency at the same time, but with different orthogonal codes assignment. The 3G offered applications such as Global Positioning System (GPS), location-based service, mobile internet access, video calls, and mobile television [2], [4]. The main limitation of 3G is broad bandwidth usage, which leads to the development of other generations.

New generation standards have appeared approximately every ten years. So, by 2010, the 3G evolved to the current fouth-generation (4G) mobile communication systems such as Long-Term Evolution (LTE) and LTE-Advanced (LTE-A), which was standardized by the 3rd Generation Partnership Project (3GPP). In these 4G networks, Orthogonal Frequency Division Multiple Access (OFDMA) and Single-

Carrier OFDMA (SC-OFDMA) has been widely utilized to allocate resources to users and achieving a high data rate [5], [6]. The multiple access techniques mentioned above are termed as Orthogonal Multiple Access (OMA), in which resources are allocated to users in the orthogonal approach. The rapid development of internet-enabled smart devices, termed as Internet of Things (IoT) and innovative applications promotes the development of fifth-generation (5G). The 5G networks are predicted to be high in performance with more users' capability than the current 4G networks [7], [8]. There are three main areas of applications in which 5G is expected to revolutionize our future life; which are enhanced Mobile Broad Band (eMBB), massive machine type communication (mMTC) and Ultra-Reliable and Low Latency Communications (URLLC). Several requirements are needed for 5G to meet the demand for eMBB (e.g., high resousolution video streaming), mMTC (e.g., IoT services), and URLLC (e.g., autonomous driving). The fundamental requirements of 5G technology are summarized in Figure 1.1.

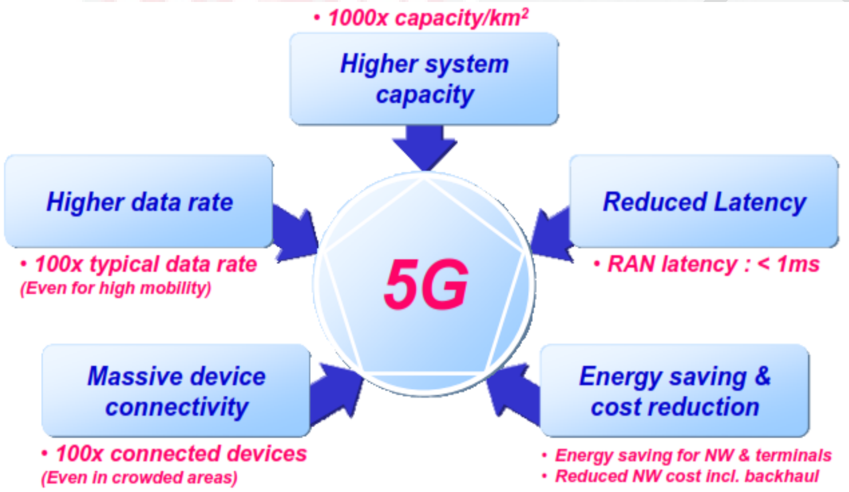

Figure 1.1 : Illustration of 5G requirements [9]

Power and resource-saving have been captured more attention recently. Hence, meeting the high data traffic and solving the power efficiency problems has become the critical challenges for the evolution of the 5G cellular wireless communication systems. Therefore new advanced technological advancement such as Multiple-Input Multiple-Output (MIMO) technology, millimetre wave technology, ultra-dense network technology [5], [10], [11] and NOMA schemes are required [12]. NOMA has risen as one among the promising multiple access scheme that can improve the spectrum efficiency and meet 5G requirements. There are two types of NOMA schemes, which are Power Domain NOMA (PD-NOMA) and Code Domain NOMA (CD-NOMA) [13], [14]. Figure 1.2 illustrates the historical overview of a different mobile cellular generation with the corresponding multiple access.

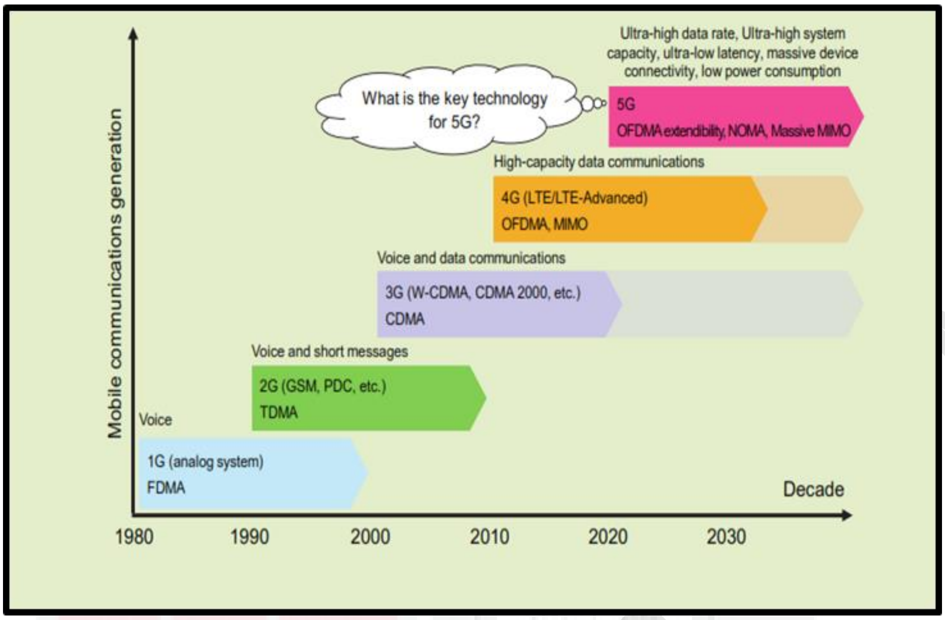

Figure 1.2 : Illustration of the evolution of mobile communication systems and representative technologies for each generation [7]

In recent years, the green communication technology, which focuses on energy efficiency, has become an inevitable trend in both academic and industrial worlds [15]–[17]. The 5G is expected to reduce energy consumption and achieve green communication [18]. Thus, saving energy and meeting green communication requirements in 5G systems motivate the study on energy-efficient resource optimization in NOMA systems by designing different resource allocation schemes that are highly efficient and capable of achieving 5G demands.

1.2 Problem Statement

The ultimate growth of mobile internet users and the IoT raises some challenges for the 5G wireless communication, such as high data rate, higher energy efficiency and spectral efficiency, low latency, low cost, and massive connectivity. It is difficult for the OMA scheme currently utilized in 4G networks to overcome these challenges, which are limited by simultaneously transmitting users and orthogonal resource allocation [12], [19]. NOMA is a promising solution to address these challenges by employing multiple users on the same sub-channel, where users are distinguished by their power level and achieve user's fairness. NOMA can use the limited available frequency/power/time resources, connect massive devices, and provide higher data rate requirements [13]. For the Quality of Service (QoS) achievement for each user, optimization and assignment of limited resources should be considered under realistic constraints. The sub-optimal or optimal resource allocation approaches are mainly used in solving resource allocation problems in wireless cellular networks [20], [21]. The sub-optimal resource allocation approaches have less complexity algorithm formulation, leading to lower computational time. On the other hand, the optimal resource allocation approaches have higher complexity algorithm formulation, leading to higher computational time usage. However, the optimal strategy achieves better performance compared to sub-optimal ones. Thus, the considerations of cellular system performance and complexity are the main aspects that need to be considered in designing the resource allocation schemes for practical cellular systems design.

In summary, the following problems have been identified and will be addressed in this thesis:

i. In real networks, resource allocation can be well managed when the number of users is small. Since the NOMA is addressed for massive connectivity by allowing multiple users in the same sub-channels, user pairing/clustering becomes a challenge in the NOMA systems. Therefore, efficient user pairing is required.

ii. After the user assignment process is done, the Base Station (BS) is required to allocate the power for each of the sharing users in the same sub-channel and across sub-channels, which is a challenging concern in NOMA systems. This allocated power mostly affects the overall system performance, such as rate distribution and user admission. Suppose the power allocation is not well distributed among the multiplexed users. In that case, it may lead to unfair user rate distribution and system outage performance due to failure of the Successive Interference Cancellation (SIC) process. Therefore, efficient power allocation schemes are needed to be developed and utilized in the NOMA systems.

iii. Heterogeneous Networks (HetNets) are another effective solution to address the 5G challenges. HetNets can improve network capacity growth, spectral efficiency improvement with low energy consumption, and useful for resource utilization [22]–[24]. However, maintaining fairness among users is the fundamental challenge of HetNets. Hence, to provide better user capability and network performance, NOMA’s application in HetNets is essential to harness the benefits of both technologies. However, the combination of NOMA-HetNets faces challenges on co-tier and cross-tier interferences, as well as fair resource allocation [25], [26]. Therefore, it is essential to consider fair resource allocation in designing hybrid NOMA-HetNets.

1.3 Aim and Objectives

The main aim of this research is to investigate the resource allocation problems in the downlink NOMA-based single-cell systems and HetNets systems by focusing on achieving higher data rates and high energy efficiency performance. Effective and efficient resource allocation solutions are designed to achieve the desired performance. The following specific objectives are considered to accomplish the goal, as mentioned:

1. To propose a resource allocation mechanism that can improve the overall NOMA system performance in terms of sum rate using an efficient user pairing approach and a closed-form optimal power allocation solution.

2. To design an efficient and optimal resource allocation scheme that can improve the NOMA system in terms of energy efficiency performance.

3. To investigate NOMA's combination with HetNets technology and optimize their performance by using the max-min approach to achieve fair and optimal energy efficiency performance.

1.4 Research Questions

The following research questions have been outlined to be answered throughout this thesis:

1. Considering the BS transmitting power and minimum user rate constraints, how to design an optimal resource allocation schemes that will improve the NOMA system's sum rate in the downlink NOMA single-cell systems?

2. With the assignment of two users in the sub-channel, how to optimize the power at the BS and assign to them to increase their energy efficiency and overall NOMA systems performance?

3. With considerations to the co-tier and cross-tier interference, together with transmitter and receiver energy power consumption, how to design fair energy-efficient resource allocation scheme in the downlink NOMA-HetNets systems?

1.5 Thesis Contributions

The main contributions of this thesis are summarized as follows:

i. The sum rate maximization problem for the downlink NOMA single-cell system was identified as a joint user pairing and power allocation problem. The problems were analyzed separately to reduce complexity. In solving the user pairing problem, an optimal user pairing approach based on Hungarian (HNG) algorithm that considers the pairing of two users at each sub-channel is adopted. This algorithm guarantees optimal performance of both the sum rate and energy efficiency maximization process in a downlink NOMA single-cell system. The sum rate maximization problem is formulated by considering SIC for each user in the sub-channel where constraints are the minimum acceptable data rate and the maximum available transmission power at the BS. A power allocation solution is proposed based on Karush-Kuhn-Tucker (KKT) conditions (PKKT) to solve this problem and obtain the optimal power for each of the paired users in a sub-channel. The closed-form optimal power allocation solution for multiplexed users is then obtained. The PKKT solution is applied after pairing users based on HNG to obtain the downlink NOMA single-cell system's optimal sum rate. Thus, we refer to this technique as NOMA-PKKT-HNG.

ii. The energy efficiency maximization problem is formulated with power constraint consideration, and SIC is applied to reduce complexity at the receiver. The study adopted a power allocation solution using the Dinkelbach (DKL) algorithm (PDKL) to solve this problem and obtain the multiplexed users' optimal power. The formulated objective function is in fractional form. Hence, the DKL algorithm transformed the objective function into linear form (subtractive function) and iteratively solved the problem with considerable error tolerance. The PDKL solution is applied after pairing users based on HNG to obtain the optimal energy efficiency in the downlink NOMA single-cell system. Thus, we refer to this technique as NOMA-PDKL- HNG.

iii. The fair energy-efficient resource allocation problem for downlink NOMA-HetNets is a joint problem of user pairing and power allocation problem. A user pairing approach based on Greedy Algorithm (GA) is proposed by considering two users pairing at each sub-channel to solve the first sub-problem. This approach achieves the sub-optimal performance with low computational complexity at the downlink NOMA-HetNets.

iv. A formulation of the fairness-based energy efficiency maximization problem for solving the second sub-problem is developed for the downlink NOMA-HetNets with the following stated constraints: the user's transmission rate, transmit power budget at the BS, and interference from femtocell's users. An optimal sub-channel power allocation solution based on the Sequential Convex Programming (SCP) is adopted to obtain the optimal power across sub-channels. The SCP optimization approach's application updates the optimal energy efficiency parameter iteratively to obtain the optimal power allocation solution. A new algorithm termed as Fair Energy-Efficient Power Allocation (FEPA) is developed to achieve the sub-optimal power between the paired users, which iteratively improves the energy efficiency in their assigned sub-channel. The SCP solution is applied after pairing users based on GA to obtain the optimal and fair energy-efficient at the downlink NOMA-HetNets. Thus, referred to the technique as NOMA-SCP-GA.

1.6 Scope and Limitation of the Study

This thesis focus on resource allocation for NOMA-based-single-cell and NOMA-HetNets systems. The femtocells are particularly considered in the NOMA-HetNets. The study is mainly based on the most popular NOMA type, which is the PD-NOMA deployment in the downlink NOMA scenario to achieve high data rate and energy efficiency performance. The other different types of NOMA are considered out of scope in this study. The investigations are carried out under a Single-Input Single-Output (SISO) antenna system with perfect Channel State Information (CSI) at the BS. The analysis of power allocation and user pairing problems is considered and solved by proposing effective and efficient resource allocation solutions through the optimization process. To improve the NOMA system performance and investigate the effectiveness of the proposed resource allocation solutions, the system sum rate, the system energy efficiency, spectral efficiency, complexity of the proposed algorithms, and fairness are considered. Figure 1.3 illustrates the flow of the study in which the solid lines show the direction followed to achieve the set goal while the dotted lines refer to other research areas that are out of the scope of this thesis.

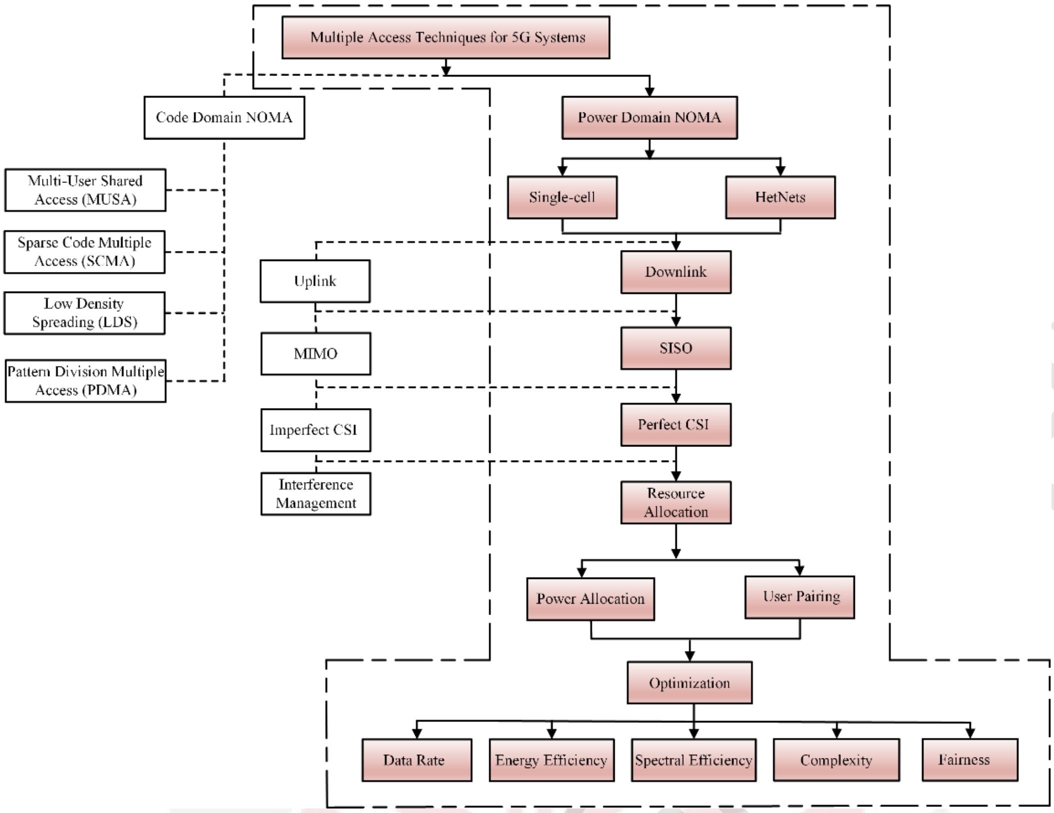

Figure 1.3 : Study module

1.7 Significance of the Study

The NOMA scheme's application is an ultimate way of achieving high capacity for 5G and future wireless networks. It improves the system sum rate and the cellular networks' energy efficiency performance. The multiple users' assignment in the same sub-channel enhances the users' data rate performance and spectrum efficiency. Also, fairness among users is maintained by allocating different powers to strong and weak users. The NOMA scheme's deployment in the cellular system has more flexibility with low-complexity by using effective resource allocation design. Moreover, employing NOMA in HetNets harness both technologies' benefits and improves the spectral efficiency, energy efficiency, and coverage area.

1.8 Thesis Organisation

This thesis is formatted with 5 chapters, as shown in Figure 1.4, to ensure that the proposed resource allocation solutions' main findings are highlighted and discussed. Chapter 1 entails the introduction and overview of the research study, the general background on the history of the wireless communication systems, defining the problem statement of the research study, stated the research objectives and research questions, the scope of the study, and the main contributions and the significance of the study. The rest of the thesis is organized as follows:

Chapter 2 presents a brief overview of the proposed NOMA system alongside with conventional OMA system. Then, enumerate recent related works in the reviewed literature about the resource allocation techniques in downlink NOMA in single-cell and HetNets systems. Several resource allocation techniques proposed in the earlier studies to improve NOMA system performance, and the research gaps discovered as the novelty for further improvement of the NOMA system.

Chapter 3 presents the research design, the description of NOMA's system models in single-cell and HetNets deployment scenarios, and the provided mathematical problem formulations. Moreover, the proposed resource allocation techniques' detailed procedures that address the problems are presented. Finally, the chapter is summarized.

Chapter 4 provides the simulation settings, simulation results and the complexity of the proposed resource allocation techniques in both downlink NOMA single-cell systems and HetNets systems. Furthermore, the proposed resource allocation schemes' performance evaluations indicate that the proposed solutions offer great improvement compared to the benchmarked methods. In the end, the summary of this chapter is provided.

Finally, Chapter 5 presents the thesis's conclusion by highlighting the research study's novelty and considering the implication of the achieved results on the proposed objectives and recommends some potential future research direction on the NOMA system.

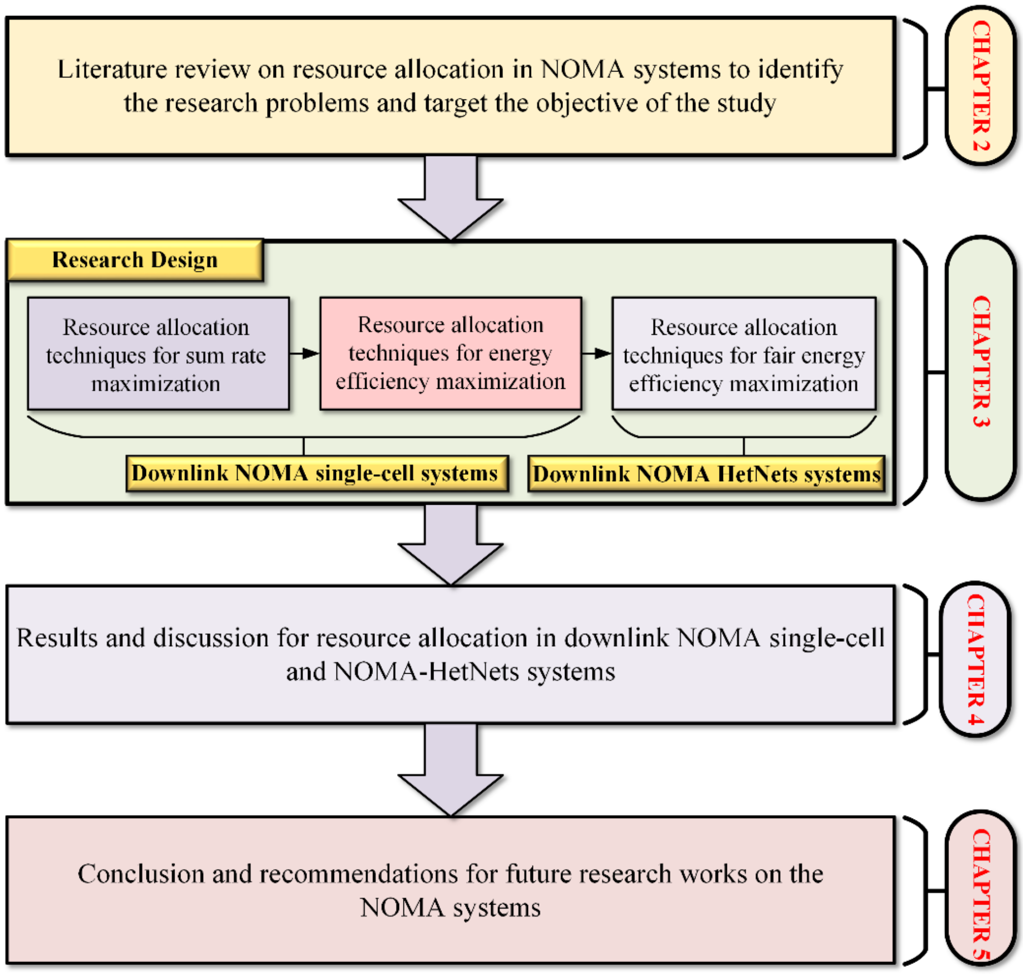

Figure 1.4 : Thesis organization

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LIST OF PUBLICATIONS

International Refereed Journals

Zuhura J. Ali, Nor K. Noordin, Aduwati Sali, and Fazirulhisyam Hashim, "Fair Energy-Efficient Resource Allocation for Downlink NOMA Heterogeneous Networks," *IEEE Access*, vol. 8, pp. 200129–200145, 2020.

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