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MULTI-USER BEAMFORMING, FAIRNESS AND DEVICE-TO-DEVICE CHANNEL STATE INFORMATION SHARING IN DOWNLINK NON-ORTHOGONAL MULTIPLE ACCESS SYSTEMS

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By

MOHANAD MOHAMMED ABDULHUSSEIN

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DEDICATIONS

To my greatly beloved father and mother, for every single prayer, smile, advice, and time to take care of me.

To my dear wife, who faithfully supported me and endured a lot for me.

To my sister and my brothers, for every single support, advice, and lesson to me.

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

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Non-orthogonal multiple access (NOMA) has been proposed in the past few years to be a key technology for the fifth-generation (5G) cellular networks due to its capability of achieving high spectral efficiency. The feature of NOMA is to serve multiple users at the same time/frequency/code, but with different power levels, which yields a significant spectral efficiency gain over conventional orthogonal multiple access (OMA) techniques. This thesis aims to provide fair resource allocation algorithms for downlink NOMA with multi-user beamforming systems in addition to provide new techniques for interference cancellation to boost the performance of this system in the case of perfect channel state information at the transmitter (perfect CSIT) and limited feedback. The contribution of this thesis can be divided into three main parts:

The first part focuses on enhancing the user fairness with minimum throughput degradation (i.e., enhancing the throughput-fairness trade-off) for downlink NOMA with zero-forcing beamforming (ZFBF) in the case of perfect CSIT. To this end, a fair user clustering algorithm with two stages is proposed, wherein the strong and weak users are selected in the first and second stages, respectively. The algorithm stages are based on integrating the principle of proportional fairness (PF) with semiorthogonal user selection (SUS) in the first stage and with maximum signal to interference ratio (SIR) in the second stage (PF-SUS-SIR). We focus on short term fairness, where short term refers to the minimum time window in which a specified fairness is guaranteed and evaluated using Jain's index. A fixed transmit power allocation then applied to enhance the throughput of NOMA system. Simulation results show that the proposed PF-SUS-SIR clustering algorithm significantly improves user fairness with at least 38.96% over conventional SUS-SIR clustering algorithm while maintaining the total system throughput (near maximum).

In the second part, two user clustering algorithms are proposed. These algorithms are alternatives to the PF-SUS-SIR and can achieve better throughput-fairness trade-off in case of perfect CSIT and limited feedback. The first algorithm is based on integrating the maximum product of effective channel gains and the maximum SIR with the PF principle (PF-MPECG-SIR) to select strong users in the first stage and weak users in the second stage. This algorithm is designed to maximize the throughput with moderate fairness enhancement. Whereas, in the second algorithm, the MPECG and the maximum correlation are combined within the PF selection criterion (PF-MPECG-CORR) in order to maximize the user fairness with a slight degradation in the total throughput. In addition, a new optimal power allocation is proposed which can achieve high sum-rate for the total system without sacrificing the sum-rate of weak users. Simulation results show that the proposed PF-MPECG-CORR can significantly improve the fairness up to 50.82% and 44.90% with only 0.42% and 1.13% degradation in the total throughput with perfect CSIT and limited feedback cases, respectively. All these performance gains are achieved without increasing the computational complexity.

In the third part of this thesis, the problem of imperfect inter-cluster interference (ICI) cancelation at weak users resulted from sharing a single beamforming vector between strong and weak users is addressed. To solve this problem, a new cooperative NOMA system is introduced, in which we *first*, propose a receiver equalizer at weak user known as weak user beam-matching (WBM) equalizer based on device-to-device (D2D) channel state information (CSI) sharing between the nearby strong and weak users. With WBM, the ICI can be effectively eliminated at weak users. *Second*, based on WBM principle, strong user beam-matching (SBM) equalizer is proposed at strong users in order to eliminate the generated ICI in case of limited feedback. *Third*, a new power allocation strategy is proposed to improve weak users' performance by considering the gained throughput from interference cancellation. *Finally*, besides the sum-rate, which is adopted as the performance metric by most of the existing NOMA works, the bit error rate (BER) of NOMA users in cooperative NOMA is calculated with those in other schemes. Simulation results show that our cooperative NOMA with the proposed equalizers achieves significant sum-rate and BER improvements over non-cooperative schemes with both perfect CSIT and limited feedback scenarios.

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

PEMBENTUK ALUR BERBILANG PENGGUNA, KEADILAN DAN PERKONGSIAN MAKLUMAT KEADAAN SALURAN PERANTI-KE-PERANTI DALAM SISTEM CAPAIAN BERBILANG BUKAN ORTOGON BAGI LALUAN MENURUN

Oleh

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Akses pelbagai bukan ortogonal (NOMA) telah dicadangkan dalam beberapa tahun terakhir untuk menjadi teknologi utama untuk rangkaian selular generasi kelima (5G) kerana kemampuannya untuk mencapai kecekapan spektrum tinggi. Ciri NOMA adalah untuk melayani beberapa pengguna pada masa / frekuensi / kod yang sama, tetapi dengan tahap daya yang berbeza, yang menghasilkan keuntungan kecekapan spektrum yang signifikan berbanding teknik akses pelbagai (OMA) konvensional. Tesis ini bertujuan untuk menyediakan algoritma peruntukan sumber yang adil untuk NOMA pautan bawah dengan sistem pembentuk beam pelbagai pengguna di samping untuk menyediakan teknik baru untuk pembatalan gangguan untuk meningkatkan prestasi sistem ini sekiranya maklumat keadaan saluran sempurna di pemancar (CSIT sempurna) dan maklum balas terhad. Karya penyelidikan tesis ini dapat dibahagikan kepada tiga bahagian.

Bahagian pertama dari tesis ini memfokuskan pada peningkatan kewajaran pengguna dengan penurunan output yang minimum (iaitu, meningkatkan pertukaran-daya pemprosesan-keadilan) untuk NOMA pautan bawah dengan bentuk Bentuk-Alur memaksa sifar (ZFBF) sekiranya terdapat CSIT yang sempurna. Untuk tujuan ini, dicadangkan algoritma pengelompokan pengguna yang adil dengan dua tahap, di mana pengguna kuat dan lemah masing-masing dipilih pada tahap pertama dan kedua. Tahap algoritma didasarkan pada pengintegrasian prinsip keadilan proporsional (PF) dengan pemilihan pengguna semiorthogonal (SUS) pada peringkat pertama dan dengan nisbah isyarat ke gangguan maksimum (PF-SUS-SIR) pada tahap kedua. Kami memfokuskan pada keadilan jangka pendek, di mana jangka pendek merujuk pada jangka masa minimum di mana keadilan tertentu dijamin dan dinilai menggunakan indeks Jain. Peruntukan kuasa penghantaran tetap kemudian digunakan untuk meningkatkan daya pemprosesan sistem NOMA. Hasil simulasi me-

nunjukkan bahawa algoritma pengelompokan PF-SUS-SIR yang dicadangkan secara signifikan meningkatkan kewajaran pengguna dengan sekurang-kurangnya 38.96% berbanding algoritma pengelompokan SUS-SIR konvensional sambil mengekalkan jumlah keseluruhan sistem (hampir maksimum).

Di bahagian kedua, dua algoritma pengelompokan pengguna dicadangkan. Algoritma ini adalah alternatif kepada PF-SUS-SIR dan dapat mencapai pertukaran hasil-adil yang lebih baik sekiranya CSIT sempurna dan maklum balas terhad. Algoritma pertama didasarkan pada pengintegrasian produk maksimum keuntungan saluran berkesan dan nisbah isyarat ke gangguan maksimum dalam prinsip PF (PF-MPECG-SIR) untuk memilih pengguna yang kuat pada tahap pertama dan pengguna yang lemah pada tahap kedua. Algoritma ini direka untuk memaksimumkan daya pemprosesan dengan peningkatan kewajaran yang sederhana. Manakala, dalam algoritma kedua, MPECG dan korelasi maksimum digabungkan dalam kriteria pemilihan PF (PF-MPECG-CORR) untuk memaksimumkan kewajaran pengguna dengan sedikit penurunan jumlah keseluruhan hasil. Di samping itu, dicadangkan peruntukan daya optimum baru yang dapat mencapai kadar jumlah tinggi untuk keseluruhan sistem tanpa mengorbankan jumlah pengguna yang lemah. Hasil simulasi menunjukkan bahawa PF-MPECG-CORR yang dicadangkan dapat meningkatkan kewajaran sehingga 50.82% dan 44.90% dengan hanya penurunan 0.42% dan 1.13% dalam jumlah keseluruhan dengan CSIT sempurna dan kes maklum balas terhad. Semua keuntungan prestasi ini dicapai tanpa meningkatkan kerumitan komputasi.

Pada bahagian ketiga penyelidikan ini, masalah pembatalan interferens inter-cluster (ICI) yang tidak sempurna pada pengguna yang lemah disebabkan oleh berkongsi vektor Bentuk-Alur tunggal antara pengguna kuat dan lemah ditangani. Untuk menyelesaikan masalah ini, sistem NOMA koperasi baru diperkenalkan, di mana kami *pertama*, mencadangkan penyamaan penerima pada pengguna lemah yang dikenali sebagai penyamaan pemadan rasuk pengguna lemah (WBM) berdasarkan peranti ke peranti (D2D) perkongsian maklumat keadaan saluran (CSI) antara pengguna kuat dan lemah yang berdekatan. Dengan WBM, ICI dapat dihilangkan dengan berkesan pada pengguna yang lemah. *Kedua*, berdasarkan prinsip WBM, penyamaan pemadan rasuk pengguna (SBM) yang kuat dicadangkan pada pengguna yang kuat untuk menghilangkan ICI yang dihasilkan sekiranya terdapat maklum balas yang terhad. *Ketiga*, strategi peruntukan kuasa baru diusulkan untuk meningkatkan prestasi pengguna yang lemah dengan mempertimbangkan hasil yang diperoleh dari pembatalan gangguan. *Akhirnya*, selain daripada jumlah-nilai, yang diadopsi sebagai metrik prestasi oleh kebanyakan NOMA yang ada, kadar kesalahan bit (BER) pengguna NOMA dalam NOMA koperasi dikira dengan yang ada dalam skema lain. Hasil simulasi menunjukkan bahawa NOMA koperasi kami dengan penyamaan yang dicadangkan mencapai peningkatan jumlah dan peningkatan BER berbanding skema NOMA bukan koperasi dengan kedua-dua senario CSIT yang sempurna dan maklum balas terhad.

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LIST OF ABBREVIATIONS

1G	The first generation
2G	The second generation
3G	The third generation
4G	The fourth generation
5G	The fifth generation
B5G	The beyond fifth generation
6G	The sixth generation
AWGN	Additive white Gaussian noise
BF	Beamforming
BER	Bit error rate
BS	Base station
CDF	Cumulative distribution function
CDI	Channel direction information
CQI	Channel quality idicator
CSI	Channel state information
CSIR	Channel state information at receiver
CSIT	Channel state information at transmitter
D2D	Device-to-device
DPC	Dirty paper coding
FDD	Frequency division duplex
FD	Full-duplex
FDMA	Frequency division multiple access
ICI	Inter-cluster interference
i.i.d.	Independent and identically distributed
IUI	Inter-user interference
LTE	Long term evolution

MIMO	Multiple-input multiple-output
mMTC	Massive machine type communications
mmWave	Millimeter-wave
MRT	Maximal-ratio transmission
MU-MIMO	Multiuser multiple-input multiple-output
MU-MISO	Multiuser multiple-input single-output
MPECG	Maximum product of effective channel gains
NOMA	Non-orthogonal multiple access
OFDMA	Orthogonal frequency division multiple access
OMA	Orthogonal multiple access
PDF	Probability density function
PF	Proportional fairness
QoS	Quality-of-service
QPSK	Quadrature phase shift keying
SC	Superposition coding
SDMA	Spatial division multiple access
SIC	Successive interference cancellation
SISO	Single-input single-output
SIR	Signal-to-interference-ratio
SINR	Signal-to-interference-plus-noise-ratio
SNR	Signal-to-noise-ratio
SUS	Semiorthogonal user selection
SVD	Singular value decomposition
TDMA	Time division multiple access
ZFBF	Zero forcing beamforming

NOTATIONS AND SYMBOLS

$(\cdot)^{-1}$	Inverse of a Matrix
$(\cdot)^{T}$	Matrix or vector transpose
$(\cdot)^{H}$	Conjugate transpose
$\lvert\cdot\rvert$	Absolute value
$\lVert\cdot\rVert$	Norm of a matrix or vector
$\mathbb{E}(\cdot)$	Expectation of a random variable
$\mathcal{O}(\cdot)$	Complexity estimation
$\boldsymbol{h}_k$	Perfect CSI channel for user k
$\hat{\mathbf{h}}_k$	Quantized channel of $\mathbf{h}_k$
$\tilde{\mathbf{h}}_k$	Channel direction information for user k
$\hat{\mathbf{g}}_k$	Quantized channel direction information of $\tilde{\mathbf{h}}_k$
B	Number of feedback bits per user
γ_k^{we}	CQI of the weak user at the k-th cluster
$\gamma_k^{\overline{we}}$	γ_k^{we} after equalization at weak user side
$\hat{\gamma}^{we}$	Estimation of γ_k^{we} at the BS
$\hat{\gamma}_k^{\overline{we}}$	Estimation of γ_k^{we} after equalization at the BS
$\mathcal{CN}(0, \sigma_n^2)$	Complex normal distribution with mean 0 and variance σ_n^2
λ_k^{st}	Effective channel gain of the strong user at cluster k
Λ	Lagrange multipliers
P	Transmit power
α_k	Power allocation coefficient of strong user
$\mu_i(t)$	Average throughput of user i
t	Time slot
t_c	Window size determine the throughput-fairness trade-off
K	Number of users in the MU-MISO system
$SINR_k^{st}$	SINR at the receiver of the strong user in the k-th cluster

$SINR_k^{\overline{st}}$	$SINR_k^{st}$ after equalization process
$\mathbf{W}^{st}$	Norm ZFBF matrix designed based on strong user channels
n_k^{st}	Noise term of the strong user in the *k*-th cluster
n_k^{we}	Noise term of the weak user in the *k*-th cluster
s_k^{st}	Data symbol of the strong user in the *k*-th cluster
$\hat{s}_k^{st}$	Estimated symbol of the strong user in the *k*-th cluster
s_k^{we}	Data symbol of the weak user in the *k*-th cluster
$\hat{s}_k^{we}$	Estimated symbol of the weak user in the *k*-th cluster
x_k	Superimposed symbols of the *k*-th cluster
Ψ_j	Surface area of a spherical cap

CHAPTER 1

INTRODUCTION

In this chapter, an overview on the fifth-generation (5G) and beyond (B5G) wireless networks is presented, followed by the related problems occurring in these networks. A brief methodology to overcome the aforementioned problems and to achieve the research objectives is then introduced, and then the research contributions are enlisted before ending the chapter with the thesis organization.

1.1 Background

The wireless communication system has been developed and regenerated for almost every decade to meet the tremendous growth of mobile data traffic and to support various emerging applications with diverse requirements. The upcoming cellular networks such as beyond fifth-generation (B5G) or 6G networks are expected to support extremely high data rates (up to 1 Tbps), lower latency (1 ms for a roundtrip latency), massive connectivity of mobile users and Internet-of-Things (IoT) devices (up to 10^6 devices/km^2) with a variety of applications and services [1–3]. However, in conventional orthogonal multiple access (OMA) systems such as time-division multiple access (TDMA) and orthogonal frequency division multiple access (OFDMA), each user should occupy a distinct time/frequency channel, which limits the number of users that can access the network resources and thereby reduces the spectral efficiency (SE) of the system [4, 5].

In addition, energy-efficient wireless communications have received a lot of attention from both industry and academia due to its valuable impact on the environment [6–9]. More specifically, wireless communications consume two percent of the entire world energy [10], and this percentage will grow exponentially with the increasing number of wireless devices and new emerging wireless technologies. Therefore, this growth in energy consumption will result in more carbon emission and electromagnetic pollution to the environment [11, 12]. To this end, energy-efficient communications is very important issue for future wireless networks to achieve a balance between energy consumption and throughput [6–9, 13, 14].

1.2 Motivation

In recent years, various new technologies, such as millimeter wave (mmWave) communications [15–20], massive multiple-input multiple-output (MIMO) [21, 22], non-orthogonal multiple access (NOMA) [23–26], device-to-device (D2D [27–33], heterogeneous networks (HetNets) [34–37], and energy harvesting communications

[38–40] etc., have been proposed to further meet the overwhelming requirement of data rates. In addition, it is highly expected to employ a future radio access technology, which is flexible, reliable, and efficient in terms of energy and spectrum for 5G or B5G networks [7–9]. In fact, multiple access technology is one of the most important aspects of wireless networks due to its valuable impact in determining the performance of each generation of mobile cellular networks. Thus, this thesis focuses on non-orthogonal multiple access (NOMA) which can exploit the available spectrum more efficiently by supporting multiple users with different quality of service (QoS) requirements in the same resource slot [41].

1.3 Problem Statements

Throughout this study, four main problems have been addressed as follows:

- In downlink multiuser NOMA with beamforming, most of the existing clustering algorithms aim to enhance the system sum-rate (i.e., greedy algorithms), and therefore, the QoS is dropped for some users especially the weak users (cell-edge users) as they may not be selected for a long time, due to their low channel qualities.

- In case of limited feedback, there is a lack of robust clustering algorithm that can achieve a high trade-off between throughput and user fairness. In addition, most of the existing power allocation (PA) strategies are designed based on perfect channel state information at the transmitter (CSIT). In practical, CSIT is not perfect at the transmitter. Therefore, it is important to propose an efficient clustering algorithm with a dynamic PA, which can effectively work under both perfect and limited feedback cases.

- In multiuser NOMA with beamforming systems, a single beamforming vector is used to precode the signals of both strong users (cell-center users) and weak users' (cell-edge users). Since beamforming vectors are designed based on strong user channels, the inter-cluster interference (ICI) cannot be totally removed at weak users and it is highly increases with the number of transmit antennas, making a severe degradation in the performance of weak users and total NOMA system. Moreover, in case of limited feedback, the performances of strong users is highly degraded, due to the ICI resulted from quantization error of limited feedback channels. Therefore, it is highly important to upgrade the receivers' structures at strong and weak users in order to eliminate these interferences.

- To evaluate the performance of MU-MISO-NOMA system compressively starting from signal generation and modulation to signal detection and demodulation, a full system design is required (end-to-end system) wherein the bit error rate (BER) of NOMA users is tested and compared. To the best of our knowledge, end-to-end design for this system has not been considered in the previous studies and providing it is an is important issue to examine the robustness of the received signal detection and error rate.

1.4 Research Objectives

Based on the aforementioned problems, the main objectives of this research are listed as follows:

- To introduce a fair user clustering algorithm that can enhance the user fairness with minimum throughput degradation (i.e., enhancing the throughput-fairness trade-off) of multiuser NOMA system and guarantee the QoS of weak users. Besides this, to improve the short-term fairness (demonstrated in Chapter 3).
- To propose fair user clustering algorithms which can achieve a better throughput-fairness trade-off in case of perfect CSIT and limited feedback while maintaining the computational complexity. Also, to introduce a new power allocation strategy which can ensure weak users' sum capacity with both channel feedback cases (demonstrated in Chapter 4).
- To propose receiver equalizers at the receivers of NOMA users which are capable to cancel out the generated ICI due to imperfect beam design at weak users and the generated ICI at strong users in the case of limited feedback, in order to get the advantage of obtaining better sum-rate with increasing the number of transmit antennas. In addition, to propose a new dynamic power allocation that can allocate the proper power portions for NOMA users (demonstrated in Chapter 5).
- To provide a full system design (end-to-end system) for MU-MISO-NOMA system to evaluate the performance of NOMA users comprehensively and to compare it with those in other schemes (demonstrated in Chapter 5).

1.5 Research Scope and Study Module

This work is dedicated to study the downlink multi-user NOMA with beamforming (also known as MU-MISO-NOMA system). In particular, MU-MISO-NOMA system play a key rule to provide a massive connectivity and increase the system capacity in the upcoming B5G or 6G wireless networks. The other multiple access such as OFDMA, and the non precoded systems are out of the scope of this work.

The summary of the chosen approaches in this thesis is illustrated in Figure 1.1, where the solid lines along with the colored boxes denote the followed direction to achieve determined objectives, while the uncolored boxes shows the other multiple access techniques and protocols which are not covered in this thesis.

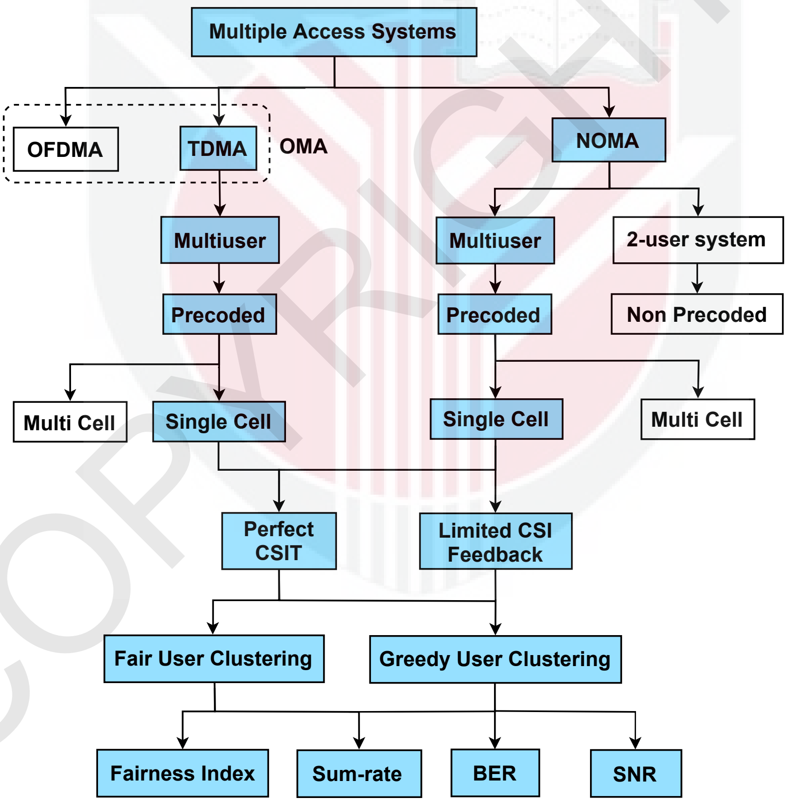

Figure 1.1: System module.

1.6 Brief Methodology

Based on the aforementioned objectives, the used methods to achieve the main objectives of this thesis is divided into three stages as shown in Figure 1.2. In the first stage, the basic design of NOMA system is implemented with perfect CSIT assumption, wherein, the conventional SUS-SIR clustering algorithm proposed in [42] is verified. Then, it is integrated with the proportional fairness (PF) criterion (i.e., proposing the PF-SUS-SIR algorithm). The system is then tested in terms of sum-rate, user fairness. The short-term fairness is considered in the tests to examine the robustness of the proposed algorithm with relatively small-time intervals (Objective 1).

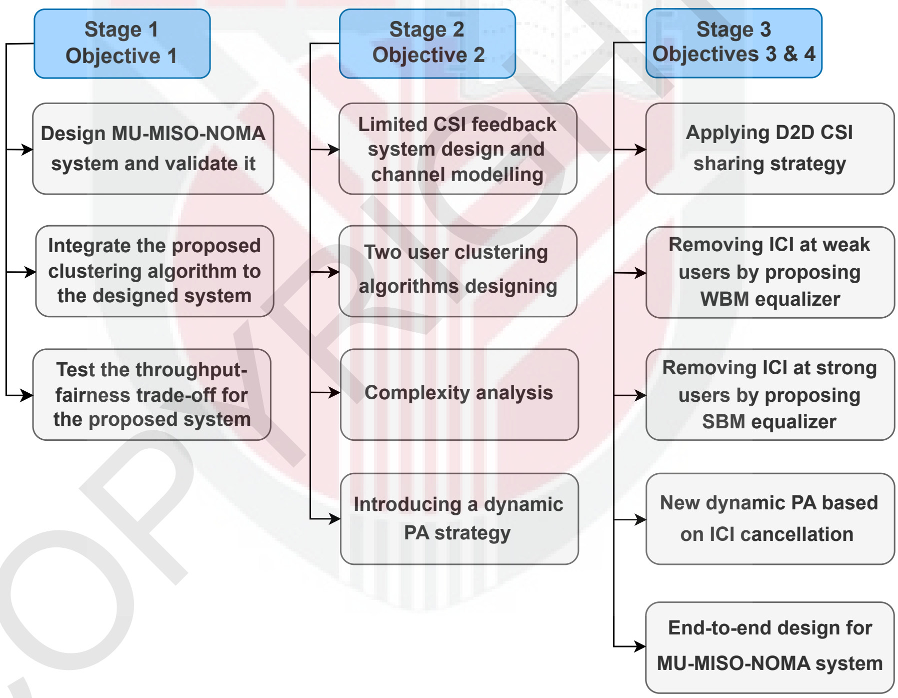

Figure 1.2: Research Methodology.

In the second stage, limited feedback system is considered instead of perfect CSIT considered in the first stage, because perfect CSIT cannot be achieved in practical transmission. In the case of limited feedback, each mobile user quantizes its channel into B bits and fed back it to the BS. The quantized channel (limited feedback channel) is modeled based on the random vector quantization (RVQ) quantization technique [43]. In addition, two user clustering algorithms are proposed; the first algorithm maintain the throughput and can achieve a moderate fairness enhancement over the SUS-SIR [42] while the second algorithms maximize user fairness with a slight degradation in the total throughput compared to the over the SUS-SIR [42]. The computational complexity for the proposed algorithms is analyzed and compared with the complexity of conventional algorithms. Moreover, a new dynamic power allocation is proposed which can guarantee a high level of total throughput without compromising weak user sum-rate (Objective 2).

In the third stage, the problem of imperfect inter-cluster interference (ICI) cancellation at weak users [42, 44, 45] is tackled and solved with aid of the D2D CSI sharing between the nearby strong and weak users. The CSI sharing is needed in the equalization process of the proposed weak user beam-matching (WBM) equalizer at weak users. The problem of imperfect ICI cancellation is also occurs at srong users in the case of limited feedback. Therefore, the strong user beam-matching (SBM) equalizer is proposed at the receivers of strong users to remove this ICI based on the same principle of WBM equalizer. Moreover, a new dynamic power allocation is proposed based on exploiting the gained throughput from ICI cancellation at weak users to achieve a balanced performance for both NOMA users. (Objective 3).

Finally, a full system design (end-to-end system) is provided for MU-MISO-NOMA to calculate the BER performance of NOMA users using the proposed equalizers (Objective 4).

1.7 Research Contributions

The research contributions are listed as follows:

- Achieve a better throughput-fairness trade-off by proposing a two-stage user clustering algorithm for both strong and weak users based on combining semi-orthogonal user selection and maximum signal to interference ratio (SUS-SIR) algorithm with proportional fairness (PF) selection criterion (PF-SUS-SIR) for downlink MU-MISO-NOMA system.

- Two fair user clustering algorithms are proposed as an alternative to the PF-SUS-SIR based on combining PF with two types of resource allocation: the first algorithm combines the maximum product of effective channel gains (MPECG), and the maximum signal to interference ratio within the PF selection criterion (PF-MPECG-SIR) which is able to maintain the total system capacity (achieved by SUS-SIR) with a moderate enhancement in user fairness. The second clustering algorithm integrates the MPECG and the maximum correlation into the PF selection criterion (PF-MPECG-CORR), and it is designed to maximize fairness with a slight degradation in the total throughput compared to the PF-MPECG-SIR algorithm. In addition, these algorithms are tested in case of limited feedback (using random vector quantization (RVQ) quantization model) as well as to the case of perfect CSIT. Moreover, the computational complexity is analyzed for the proposed clustering algorithms and it was shown that they have the same complexity of SUS-SIR algorithm. Furthermore, a new power allocation strategy is proposed which guarantees a balance between maximizing the total throughput and maintaining high sum-rates for weak users under both feedback scenarios.

- Proposing a receiver equalizer at weak users namely weak user beam matching (WBM) based on D2D CSI sharing between the nearby strong and weak users to cancel out the ICI at weak users that arises under both perfect CSIT and limited feedback cases. In addition, based on WBM principle, strong user beam-matching (SBM) equalizer is proposed at strong users in order to eliminate the generated ICI signals in case of limited feedback. Moreover, a new dynamic power allocation strategy is introduced, in which a high sum-rate can be achieved for weak users, by considering the gained throughput from removing ICI of weak users. Furthermore, the limited feedback channel (the quantized channels) are generated with two models: the RVQ and the quantization cell upper bound (QUB). To the best of our knowledge, this is the first work on NOMA that tests the sum-rate performance with QUB and examines the BER performance with these two models.

- A full design of MU-MISO-NOMA system (end-to-end system) is presented for the first time in the literature, in which the bit-error rate (BER) performance of NOMA users using the proposed equalizers is tested and compared with those in other schemes, with both perfect CSIT and limited feedback scenarios.

1.8 Thesis Organization

The remainder of this thesis is organized as follows:

Chapter 2 provides an overview of 5G communication scenarios, key requirements, and enabled technologies. Then, the motivation of the considered research questions of the thesis and the relevant existing works are presented. It also provides the outline and the main contributions of this thesis.

Chapter 3 we consider a MU-MISO-NOMA system with perfect CSIT where multiple transmit antennas serves multiple single antenna users via beamforming and user clustering. The related background knowledges are firstly presented, including the fundamental concepts of multi-user resource allocation design methodologies. The basic user selection algorithms, semiorthogonal user selection (SUS) and the proportional fairness scheduling is then described. Followed by the system model of NOMA with ZFBF, the received signal models at NOMA users. After that, the proposed PF-SUS-SIR clustering algorithm based on proportional fairness is presented. Fixed power allocation (PA) is presented then to assign power for NOMA users according to NOMA PA principle. Numerical comparisons with conventional SUS-SIR algorithm schemes confirm the effectiveness of PF-SUS-SIR.

Chapter 4 presents MU-MISO-NOMA system with perfect and limited feedback cases. Three different problems are investigated: i) Fair beamforming design, ii) Limited feedback channel modeling and design and iii) optimal PA strategy for both perfect and limited feedback cases. After presenting the channel and the received signal models at NOMA users under limited feedback, the quantized channel components, the CDI and CQI are analyzed based on RVQ model for CDI and the expected CQI for CQI. Then, two fair clustering algorithms are proposed, the PF-MPECG-SIR and PF-MPECG-CORR. Different from PF-SUS-SIR presented in Chapter 3, these algorithms can achieve better throughput fairness trade-off with both feedback scenarios. In addition, a dynamic PA is proposed which can achieves a superior performance over other schemes. Numerical results showed that the proposed algorithms achieve better throughput fairness trade-off compared to other clustering algorithms is with both perfect CSIT and limited feedback scenarios.

Chapter 5 presents a new cooperative NOMA based on D2D CSI sharing. WBM equalizer is proposed at weak users which can be exploited to remove the inter cluster interference (ICI) in case of perfect CSIT and limited feedback. In addition, the SBM equalizer is introduced at strong users to remove the generated ICI in case of limited feedback. Furthermore, a new dynamic PA is proposed which exploits the gained throughput from interference cancellation at weak user to achieve a better performance compared to those with non-cooperative NOMA. Moreover, the quantized channel is modeled with the QUB approach and the conventional RVQ. Finally, a full design for MU-MISO-NOMA is presented to calculate the BER of NOMA users in addition to test the sum-rate.

Chapter 6 concludes this thesis and suggests some recommendations for future works.

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LIST OF PUBLICATIONS

Journal Articles

M. M. Al-Wani, A. Sali, N. K. Noordin, S. J. Hashim, C. Y. Leow, and I. Krikidis, "Robust beamforming and user clustering for guaranteed fairness in downlink noma with partial feedback," IEEE Access, vol. 7, pp. 121 599–121 611, 2019.

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