RESOURCE ALLOCATION IN COORDINATED MULTIPOINT LONG TERM EVOLUTION –ADVANCED NETWORKS

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Dedicated to my beloved hubby, parents, siblings and sons.

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ABSTRACT

Coordinated Multipoint (CoMP) in Long Term Evolution-Advanced (LTE-Advanced) improves cell-edge data rates and network spectral efficiency through base station coordination. In order to achieve high quality of service (QoS) in CoMP network, resource allocation approach is one of the main challenges. The resource allocation strategies of cells in CoMP network affect each other's performance. Thus, the resource allocation approach should consider various diversities offered in multiuser wireless networks, particularly in frequency, spatial and time dimensions. The primary objective of this research is to develop resource allocation strategy for CoMP network that can provide high QoS. The resource allocation algorithm is developed through three phases, namely Low-Complexity Resource Allocation (LRA), Optimized Resource Allocation (ORA) and Cross-Layer Design of ORA (CLD-ORA). The LRA algorithm is a three-step resource allocation scheme that consists of user selection module, subcarrier allocation module and power allocation module which are performed sequentially in a multi-antenna CoMP network. The proposed ORA algorithm enhances throughput in LRA while ensuring fairness. ORA is formulated based on Lagrangian method and optimized using Particle Swarm Optimization (PSO). The design of CLD-ORA algorithm is an enhancement of the ORA algorithm with resource block (RB) scheduling scheme at medium access control (MAC) layer. Simulation study shows that the ORA algorithm improves the network sum-rate and fairness index up to 70% and 25%, respectively and reduces the average transmit power by 41% in relative to LRA algorithm. The CLD-ORA algorithm has further enhanced the LRA and ORA algorithms with network sum-rate improvement of 77% and 33%, respectively. The proposed resource allocation algorithm has been proven to provide a significant improved performance for CoMP LTE-Advanced network and can be extended to future 5G network.

ABSTRAK

Pengkoordinatan Berbilang Punca (CoMP) dalam Evolusi Jangka Panjang-Termaju (LTE-*Advanced*) meningkatkan kadar data dan keberkesanan spektrum rangkaian melalui pengkoordinatan stesen pangkalan (BS). Bagi mencapai kualiti perkhidmatan (QoS) yang tinggi dalam rangkaian CoMP, pendekatan pengagihan sumber menjadi satu cabaran utama. Strategi pengagihan sumber oleh sel-sel dalam rangkaian CoMP memberi kesan terhadap prestasi setiap sel. Oleh itu, pendekatan pengagihan sumber perlu mempertimbang kepelbagaian dalam rangkaian tanpa wayar berbilang pengguna, terutama dalam dimensi frekuensi, ruang dan masa. Objektif utama kajian ini ialah membangunkan strategi pengagihan sumber bagi rangkaian CoMP yang memberikan QoS yang tinggi. Algoritma pengagihan sumber ini dibangunkan melalui tiga fasa, iaitu Pengagihan Kuasa Kekompleksan Rendah (LRA), Pengagihan Kuasa Teroptimum (ORA) dan Reka Bentuk Silang Lapisan ORA (CLD-ORA). Algoritma LRA ialah kaedah pengagihan kuasa tiga-langkah terdiri daripada modul pemilihan pengguna, modul pengagihan subpembawa dan modul pengagihan kuasa yang dijalankan secara berturutan dalam rangkaian CoMP berbilang antena. Algoritma ORA yang dicadangkan meningkatkan daya pemprosesan LRA di samping memastikan keadilan. ORA diformulasi berdasarkan kaedah Lagrangian dan dioptimum menggunakan Pengoptimuman Kerumunan Zarah (PSO). Reka Bentuk CLD-ORA adalah penambahbaikan ORA dengan kaedah penjadualan blok sumber (RB) di lapisan kawalan capaian medium (MAC). Kajian simulasi menunjukkan ORA meningkatkan hasil tambah kadar rangkaian dan keadilan sehingga 70% dan 25% setiap satu, dan mengurangkan kuasa pancaran purata sehingga 41% berbanding LRA. CLD-ORA menambahbaik LRA dan ORA dengan peningkatan hasil tambah kadar 77% dan 33%. Algoritma pengagihan sumber yang dicadangkan terbukti meningkatkan prestasi rangkaian CoMP LTE-Advanced dan boleh dipanjangkan kepada rangkaian 5G masa hadapan.

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LIST OF ABBREVIATIONS

APP	-	Application layer
BS	-	Base Station
CEU	-	Cell-edge User
CLD	-	Cross-Layer Design
CLD-ORA	-	Cross-Layer Design of Optimized Resource Allocation
CoMP	-	Coordinated Multipoint
CS/CB	-	Coordinated Scheduling/Coordinated Beamforming
CSI	-	Channel State Information
DCS	-	Dynamic Cell Selection
GA	-	Genetic Algorithm
ICI	-	Inter-Cell Interference
ICIC	-	Inter-Cell Interference Coordination
JFI	-	Jain’s Fairness Index

JP	-	Joint Processing
JT	-	Joint Transmission
KKT	-	Karush-Kuhn-Tucker
LRA	-	Low-Complexity Resource Allocation
LTE	-	Long Term Evolution
LTE-A	-	Long Term Evolution – Advanced
MAC	-	Medium Access Control
MIMO	-	Multiple-Input Multiple-Output
MU-MIMO	-	Multi-User MIMO
NEE	-	Network Energy Efficiency
NSR	-	Noise-to-Signal Ratio
OAM	-	Operation and Management
OFDM	-	Orthogonal Frequency Division Multiplexing
OFDMA	-	Orthogonal Frequency Division Multiple Access
OPO	-	Orthogonal Projection Operator
ORA	-	Optimized Resource Allocation
PDCP	-	Packet Data Control Protocol
PF	-	Proportional Fairness
PFS	-	Proportional Fair Scheduling
PHY	-	Physical layer
PRB	-	Physical Resource Block
PSO	-	Particle Swarm Optimization
QoS	-	Quality of Service
RB	-	Resource Block
RF	-	Radio Frequency
RLC	-	Radio Link Control
RR	-	Round-Robin
RRM	-	Radio Resource Management
SC	-	Selective Combining
SE	-	Spectral Efficiency
SNR	-	Signal-to-Noise Ratio
SINR	-	Signal-to-Interference plus Noise Ratio
SISO	-	Single-Input Single Output
SRM	-	Sum-Rate Maximization

SVD	-	Singular Value Decomposition
TTI	-	Transmission Time Interval
UE	-	User End
UMTS	-	Universal Mobile Terrestrial System
WF	-	Water-Filling
WSRM	-	Weighted Sum-Rate Maximization
3GPP	-	The Third Generation Partnership Project

LIST OF SYMBOLS

$\mathcal{A}$	-	selected user set
B	-	network bandwidth

$\boldsymbol{C_i}$	-	cell $\boldsymbol{i}$
c_1, c_2	-	acceleration coefficients
D	-	number of swarm particles
$\boldsymbol{D_i}$	-	signal transmitted by cell $\boldsymbol{i}$
E_0, E_1, E_2, E_3	-	reference signals for four antenna ports MIMO transmission
$\boldsymbol{F}$	-	fitness
G_best_{iter}	-	global best position
$\boldsymbol{H_{k_j,n}}$	-	channel matrix of UE $\boldsymbol{k_j}$ over subcarrier $\boldsymbol{n}$
$\boldsymbol{H^j_{k_j,n}}$	-	channel matrix of UE $\boldsymbol{k_j}$ in cell $\boldsymbol{j}$ over subcarrier $\boldsymbol{n}$
$\boldsymbol{I_{k_l,n,l}}$	-	interference caused by UE $\boldsymbol{k_l}$ in cell $\boldsymbol{l}$ over subcarrier $\boldsymbol{n}$
$I_{n,j,l}$	-	interference received over subcarrier n in cell j

$\boldsymbol{J}$	-	total number of BSs in the CoMP network
JFI_{CE}	-	fairness index achieved by cell-edge UEs
$\boldsymbol{K}$	-	total number of UEs in the CoMP network
$\boldsymbol{K_j}$	-	total number of UE in cell $\boldsymbol{j}$
$\boldsymbol{K_l}$	-	total number of UE in cell $\boldsymbol{l}$
$\boldsymbol{k_j}$	-	corresponding UE in cell $\boldsymbol{j}$
$\boldsymbol{k_l}$	-	corresponding UE in cell $\boldsymbol{l}$
L	-	number of other cells in the CoMP network
$L_{k_j,j}$	-	path loss between BS j and UE k_j
max_{iter}	-	maximum number of iteration
N	-	total number of subcarriers in the system

N_o	-	noise power
N_R	-	total number of receive antennas
N_{sub}	-	number of subcarriers fixed for each user in LRA
N_T	-	total number of transmit antennas
n_{k_j}	-	corresponding subcarrier of UE k_j
n_R	-	number of transmit antennas at UE device
n_T	-	number of transmit antennas at the BS
$\mathbb{N}_i$	-	white noise at the receiver in cell i
$P\_best_{iter}^{a}$	-	personal best position of particle a
P_{BSmax}	-	maximum BS transmit power
P_{BSave}	-	average transmit power
P_{k_j}	-	total power allocated for user k_j over the set of subcarriers Ω_{k_j}
$p_{k_j,n,j}$	-	power allocated to UE k_j in cell j over subcarrier n

$p^*_{k_j,n,j}$	-	optimal power allocated to UE k_j in cell j over subcarrier n
$p_{k_l,n,l}$	-	power allocated to UE k_l in cell l over subcarrier n
Q^a_{iter}, q^a_{iter}	-	random numbers uniformly distributed on (0,1)
$R_{j,CE}$	-	total achievable rate of cell-edge UEs in cell j
$R_{k_j,n,j}$	-	achievable rate of UE k_j in cell j over subcarrier n
R_{k_j}	-	achievable rate of UE k_j
$R_{k_j,req}$	-	minimum rate requirement of UE k_j
$R_{k_j,total}$	-	total achieved rate in a previous time window of fixed duration
$r_{k_j,b}(t)$	-	achievable rate for the k_j-th user over b-th RB at time TTI t
$\boldsymbol{S}$	-	rank of $\boldsymbol{H}_{k_j,n,j}$
$\boldsymbol{U}_{k_j,n,j}$	-	unitary matrix of UE $\boldsymbol{k_j}$ in cell $\boldsymbol{j}$ over subcarrier $\boldsymbol{n}$
$u^{(s)}_{k_j,n,j}$	-	right singular vector of $H_{k_j,n,j}$on spatial layer s
$\boldsymbol{V}_{k_j,n,j}$	-	vector matrix of UE $\boldsymbol{k_j}$ in cell $\boldsymbol{j}$ over subcarrier $\boldsymbol{n}$
$v^{(s)}_{k_j,n,j}$	-	left singular vector of $H_{k_j,n,j}$ on spatial layer s
w	-	inertia weight

$\boldsymbol{W}_i$	-	precoding matrix at cell $\boldsymbol{i}$
w_{max}	-	final weight
w_{min}	-	initial weight
$X_{i.0}^{a}$	-	current position of particle a
α	-	Lagrange multiplier
$\gamma_{k_j,n,j}$	-	subcarrier allocation indicator

$\boldsymbol{\Psi}_{k_j,n,j}$	-	singular matrix of user $\boldsymbol{k_j}$ in cell $\boldsymbol{j}$ over subcarrier $\boldsymbol{n}$
$\lambda_{k_j,n,j}^{(s)}$	-	singular value of $H_{k_j,n,j}$ on spatial layer s
$\lambda_{k_l,n,l}^{(s)}$	-	singular value of $H_{k_l,n,l}$ on spatial layer s
Ω_{k_j}	-	subset of subcarriers allocated for user k_j in cell j
$\sigma_{n,j}^{2}$	-	noise power over subcarrier n in cell j
φ	-	Lagrange multiplier
μ	-	Lagrange multiplier

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CHAPTER 1

INTRODUCTION

1.1 Overview

The Third Generation Partnership Project (3GPP) Long Term Evolution (LTE)-Advanced is envisaged as the fourth generation cellular standard, and is aligned with existing third generation deployments, e.g., Universal Mobile Telecommunications System (UMTS). The goals of LTE-Advanced are to improve the peak throughput by increasing the numbers of transmit and receive antennas. One of the key enabling technologies of LTE-Advanced is coordinated multipoint (CoMP) that targets to improve the cell-edge performance as well as overall network spectral efficiency through base stations (BSs) coordination.

The continually increasing number of users and the rise of resource-demanding services require a higher link rate. Due to the limited resources at the base station (BS) such as bandwidth and power, intelligent allocation of these resources is crucial for delivering the best possible quality of service (QoS) to the consumer with the least cost. This is especially important with the high data rates envisioned for the future wireless standards.

In this thesis, resource allocation algorithm for CoMP LTE-Advanced network that provides high QoS while is proposed. The proposed algorithm takes advantage of frequency, spatial and time diversities in the time-varying wireless channel to increase the CoMP network performance.

1.2 Problem Statement

In wireless communication systems, two major detrimental effects that degrade network performance are the channel's time-varying nature and interference [1], [2]. Because of effects such as multipath fading, shadowing and path loss, the signal to interference plus noise ratio (SINR) at a receiver output can fluctuate [3], [4]. The other major challenge for the system design is the limited resources such as bandwidth and power. Frequency reuse is a common method used to improve the wireless system capacity [5]–[8]. However, it causes interference to users located at the cell-edge area known as inter-cell interference (ICI) that degrades the link quality. Since different users have different channels and locations at different times, resource allocation should be designed to take advantage of the time, frequency and spatial diversities [9], [10].

One of the tasks carried out by BS in LTE-Advanced network is to manage network resources for uplink and downlink transmissions to meet the expectation of the users. It should take into account the quality of service (QoS) requirements of the respective users' applications. Moreover, coordinated multipoint (CoMP) allows BS coordination through backhaul link such that interference generated to neighboring cells can be minimized [1], [11]–[16]. However, there exists a performance and signaling overhead tradeoff that needs to be considered. Therefore, different cooperation levels should be applied in CoMP network in order to reduce the amount of signaling over the backhaul link [17]–[22] .

Resource allocation problems in wireless network are often solved using either suboptimal or optimal approaches [9], [10], [23]. The suboptimal resource allocation schemes are formulated based on less complexity algorithms which lead to lower computational time. Optimized resource allocation schemes on the other hand, are typically solved using more complex algorithms that require higher computing time. In general, the optimal solutions yields better performance results compared to the suboptimal solutions. Hence, trade-off between performance and computational complexity is a major factor that should be considered in solving resource allocation problems. The requirements on complexity must be realistic for practical implementation.

To optimize the system's overall performance, the resource allocation schemes often allocate most of the radio resources to the users with good channel conditions [24]–[32]. However, this allocation can be very unfair, because the users with poor channel conditions will not have the chance to get the resources at all, although the users in the same class may pay the same cost for their services. For instance, allowing users with good channel quality to transmit may result in high throughput, but meanwhile sacrifice the transmissions of other users. Therefore, there is a need to trade-off between system performances and fairness among users.

Moreover, it is beneficial to incorporate the upper-layer (e.g., MAC layer) resource allocation together with the physical layer to exploit various diversities of wireless channel [33]–[37]. The approach is known as cross-layer design (CLD). The conventional single-layer design approach at physical layer and MAC layer for example, fails to exploit the dynamic nature of the physical layer and is suboptimal in multiuser wireless channels. This motivates the need for CLD in order to achieve good system-level performance.

1.3 Research Objectives

The main goal of the work is to develop resource allocation strategies for CoMP LTE-Advanced network that provides high QoS. The resource allocation approach should be able to take advantage of diversities offered in multiuser wireless networks, specifically in frequency, spatial and time domains. In order to achieve the main goal of the work, the specific objectives of the research include:

i) To develop low-complexity resource allocation algorithm that can achieve high throughput.

ii) To develop optimized resource allocation algorithm that can improve network throughput while ensuring fairness.

iii) To include cross-layer design (CLD) in the proposed optimized resource allocation algorithm to further enhance network performance.

The low-complexity resource allocation algorithm is assumed suboptimal since it gives reasonable network performance using simple algorithm. The resource allocation takes advantage of frequency, spatial and time diversities to benefit additional network improvement. The optimized resource allocation algorithm tries to achieve high network throughput while ensuring fair allocation among users. The CLD approach employs prioritize scheduling in the optimized resource allocation.

1.4 Scope of Research

The proposed algorithm allocates system bandwidth and power among users in multi-antenna CoMP LTE-Advanced network. The work exploits diversities in different domains, specifically in frequency, spatial and time available at physical layer and MAC layer. Furthermore, cooperative communications such as CoMP efficiently take advantage of the broadcasting nature of wireless networks. The basic assumption is that BSs in CoMP network share useful information such as CSIs and data streams, form a virtual antenna array thus providing diversity that can significantly improve system performance.

In addition, the proposed resource allocation algorithm is optimized to select a set of users to be scheduled together with optimal subcarrier and power allocation. The ORA algorithm tries to achieve its desired performance goal by considering two practical constraints; the available BS power and the individual user minimum rate requirement.

Besides, CLD scheduling approach is used to exploit time diversity in the time-varying wireless channels. In this research work, the proportional fair scheduling scheme is employed at the MAC layer to ensure unbiased allocation of frequency-time resources among participating users.

The performance of the proposed resource allocation algorithm is carried out through simulation using MATLAB simulation environment. The network model and the proposed resource allocation algorithm is developed and evaluated through mathematical analysis.

1.5 Significance of Research

In wireless systems, interference is a major factor that limits the total network capacity. In this work, the allocation of system bandwidth and power among users in the network are coordinated such that the interference generated to other cells is minimized. This is also known as inter-cell interference coordination (ICIC), which is able to increase the overall network throughput.

The proposed optimized resource allocation that exploits CLD approach can also be adopted in multi-cellular network such as multi-tier mesh WiFi network. However, the mesh nodes (base stations) should be able to coordinate among themselves. The proposed algorithm is also applicable in highly dense populated cellular network as it is able to achieve high throughput performance while ensuring fairness.

1.6 Research Contribution

In this research, a resource allocation strategy for CoMP LTE-Advanced network has been proposed. The proposed algorithms allocate system bandwidth and transmission power to the users in the network. The algorithm provides high QoS in the downlink transmissions by exploiting diversities available at the physical layer and MAC layer. The research contributions provided in this thesis includes:

i. Low-complexity Resource Allocation (LRA) algorithm

The initial resource allocation algorithm, LRA has been formulated for total network throughput maximization. The Frobenius norm of users' channels is adopted as the utility function because it reflects the total channel gain. LRA consists of three modules; user selection module, subcarrier allocation module and power allocation module. These modules are performed sequentially to reduce computational complexity. LRA is a simple algorithm suitable for practical system implementation.

ii. Optimized Resource Allocation (ORA) algorithm

The ORA has been proposed to improve throughput performance in LRA while ensuring fairness. The ORA algorithm is formulated to maximize the network proportional fairness utility under practical constraints. The algorithm optimally allocates available bandwidth and power among participating users in the network. The Lagrangian method is used to find the closed-form solution for the constrained optimization problem.

iii. Cross-Layer Design of ORA (CLD-ORA)

The ORA algorithm has been further enhanced to CLD-ORA approach. The approach combines parameter from MAC layer together with the proposed ORA algorithm to exploit time diversity through scheduling. The scheduling algorithm allocates the time resources (e.g., resource blocks) among active users in the network based on proportional fair scheduling.

LRA can be used for network operator that requires low complexity scheme, however at the expense of lower throughput and fairness problem. On the other hand, ORA can be selected to achieve good throughput and fairness tradeoff but it is more complex. CLD-ORA can be adopted to gain further throughput enhancement, however at the expense of higher complexity due to MAC scheduling.

1.7 Thesis Organization

This thesis consists of seven chapters which cover the three main contributions of the research. The background, problem statement, objectives, scopes and contributions of the research are presented in Chapter 1.

Chapter 2 highlights the literature review on CoMP technology, resource allocation strategy, scheduling scheme, optimization techniques, cross-layer design and the related work to this research. This chapter also presented several key design issues and related works in bandwidth allocation and power allocation for LTE-Advanced network. Additionally, current resource allocation approaches addressing the issues of throughput performance and fairness among users for CoMP LTE-Advanced network have also been analyzed and several research gaps have been identified to become the niche for this research work.

Chapter 3 primarily emphasizes on the design architecture of the proposed resource allocation algorithm. It covers the basic design concept and the network model. The algorithm of the proposed resource allocation algorithm is described in detail using flowchart, block diagram and pseudocode for ease of understanding. In addition, it also includes the simulation platform, parameter configurations and the performance metrics used.

Chapter 4 presents the detail on the first contribution which is the initial resource allocation algorithm with low-complexity, LRA. This includes the design approach of the proposed resource allocation scheme. More importantly, this chapter also provides the simulation study and performance analysis of LRA in comparison to other low-complexity algorithm.

Chapter 5 describes the detail on second contribution which is ORA. It covers the optimization framework and formulation. The optimization is based on Lagrangian method. Then, the chapter evaluates its performance in terms of network sum-rate, average transmit power, fairness, spectrum efficiency and energy efficiency.

Chapter 6 presents the third contribution which is CLD-ORA. In this chapter, the framework of the proposed resource allocation scheme is presented. Basically, CLD-ORA is an advancement of ORA presented in the previous chapter. Scheduling algorithm employed at MAC layer has the responsibility for allocating time resources among users. Simulation study and performance analysis of CLD-ORA are also provided in this chapter.

Finally, Chapter 7 concludes the thesis with summary of the research work, along with recommendations for future work.

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