UNIVERSITI PUTRA MALAYSIA

RESOURCE ALLOCATION TECHNIQUES FOR INTERFERENCE MITIGATION IN MACRO AND FEMTOCELL HETEROGENEOUS NETWORK-BASED LTE SYSTEM

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By

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

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DEDICATION

I dedicate this thesis to my father, wife, Kids, brothers, sister, and
To my supervisor and entire committee.

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

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December 2017

Chairman: Abdul Rahman b. Ramli, PhD
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In wireless broadband access networks, most indoor environments encounter serious coverage problems due to non-line of sight transmission. Femtocells have been introduced as a cost-effective solution to improve cell coverage, enhance area spectral-efficiency, and provide better Quality-of-Service (QoS) to mobile users. However, interference issue is considered the major technical challenge associated with femtocell deployment. This interference occurs mainly because the radio spectrum is limited; meanwhile, femtocells have to (fully/partly) share/reuse the same available licensed spectrum with existing macrocells in the network, resulting cross-tier interference. Furthermore, FBS not only provides coverage within the owner's home, but also radiates outside, extending coverage to nearby houses, leading to co-tier interference among neighboring femtocells.

This thesis investigates impact of density deployment for femtocell grids with either size (3x3) or (5x5) in the downlink performance in two-tier Heterogeneous Networks (HetNets) based Vienna LTE system level simulator. The thesis further presents two different approaches for mitigating cross-tier interference as well as minimizing co-tier interference in two-tier HetNets. The first proposed hybrid approach consists of two combined schemes, termed as Resource Allocation based Fractional Frequency Reuse and Graph Connectivity algorithm (RAFFRGC). The second proposed interference mitigation technique is a full frequency reuse termed as Resource Allocation based Cuckoo Search Algorithm (RACSA). The RACSA technique targets to maximize system throughput for a specified interference threshold for the ultimate mitigation of cross-tier interference in two-tier HetNets.

The simulation results showed that femtocell deployment improves overall average user throughput in the case of a low-density scenario when deploying femtocells one by one. However, for a high-density scenario, FBS grids deployment had no enhancement in terms of throughput and fairness. Additionally, densely deploying femtocell grids without interference management degraded throughput for macrocell users. The simulation results show that the proposed RAFFRGC is effective in terms of mitigating both cross-tier and co-tier interference at the same time. In addition, RAFFRGC improves average throughput for both macrocell and femtocell users, taking into account a worst-case scenario model for femtocell deployment as grids sized (3x3) or (5x5). Moreover, RAFFRGC offload computational complexity and cost of additional design from FBSs by utilizing the Femtocell Management System (FMS) to achieve interference coordination and resource allocation among FBSs. Furthermore, RAFFRGC maximizes resource blocks efficiency, guarantees QoS for all femtocell users, and can support large-scale femtocell grids deployment. The simulation results revealed that RACSA mitigates cross-tier interference and improves system performance. The performance evaluation showed that RACSA gives 38% and 21% higher in system throughput and a 14% and 35% increase in spectral efficiency, as well as a 55% and 33% reduction for the outage probability when assessment is contrasted with the results produced by genetic algorithm and auction algorithm respectively.

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

TEKNIK PERUNTUKAN SUMBER BAGI PENGURANGAN INTERFERENS DALAM RANGKAIAN HETEROGEN MAKROSEL DAN FEMTOSEL BERASASKAN-SISTEM LTE

Oleh

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Dalam rangkaian capaian jalur lebar wayarles, kebanyakan persekitaran yang tertutup menghadapi masalah liputan yang serius disebabkan oleh penghantaran isyarat yang bukan dalam garis penglihatan. Femtosel telah diperkenalkan sebagai satu penyelesaian cekap kos bagi memperluas liputan sel, meningkatkan kawasan kecekapan spektrum dan menyediakan kualiti perkhidmatan (QoS) yang lebih baik kepada pengguna peranti mudah alih. Walau bagaimanapun, isu interferens menjadi cabaran teknikal utama dalam penempatan femtosel. Interferens ini terjadi disebabkan oleh spektrum radio yang terhad; manakala femtosel perlu berkongsi / mengguna semula (penuh/separa) spektrum sedia ada yang sama dengan makrosel yang telah wujud pada rangkaian tersebut, yang menyebabkan terjadi interferens rentas-peringkat. Malahan, FBS bukan sahaja menyediakan liputan di dalam rumah pengguna, malahan turut meliputi kawasan luar termasuk rumah-rumah berhampiran, yang menyebabkan terjadinya interferens sama-peringkat antara femtosel yang berdekatan. Interferens

Tesis ini mengkaji kesan kepadatan penempatan grid femtosel dengan saiz 3x3 atau 5x5 pada prestasi laluan menurun dalam Rangkaian Heterogen (HetNets) dua-peringkat berasaskan simulator sistem Vienna LTE berperingkat. Tesis ini selanjutnya membentangkan dua pendekatan berbeza bagi mengurangkan interferens rentas-peringkat serta meminimumkan interferens sama-peringkat dalam HetNets dua-peringkat. Pendekatan hibrid pertama yang dicadangkan terdiri daripada gabungan dua skim yang dikenali sebagai algoritma Peruntukan Sumber berasaskan Penggunaan Semula Pecahan Frekuensi dan Kesambungan Graf (RAFFRGC). Pendekatan kedua bagi teknik pengurangan interferens yang dicadangkan ialah penggunaan semula keseluruhan frekuensi yang dinamakan sebagai Algoritma Peruntukan Sumber berasaskan Gelintar Cuckoo (RACSA). Teknik RACSA mensasarkan untuk memaksimumkan sistem penghantaran bagi ambang interferens yang ditentukan

dalam pengurangan muktamad interferens rentas-peringkat dalam sistem HetNets dua-peringkat.

Hasil simulasi menunjukkan bahawa penempatan femtosel dapat meningkatkan purata keseluruhan penghantaran pengguna bagi senario berkepadatan rendah apabila femtosel ditempatkan satu demi satu. Walau bagaimanapun, bagi senario berkepadatan tinggi, penempatan grid FBS tidak menunjukkan peningkatan dari segi penghantaran dan kesaksamaan. Di samping itu, penempatan grid femtosel secara padat tanpa pengurusan interferens akan menyebabkan penghantaran kepada pengguna femtosel merosot. Hasil simulasi juga menunjukkan bahawa RAFFRGC yang dicadangkan berkesan dalam mengurangkan interferens rentas-peringkat dan interferens sama-peringkat pada masa yang sama. Ia juga dapat meningkatkan purata penghantaran kepada pengguna makrosel dan femtosel, dengan mengambil kira model senario terburuk dalam penempatan femtosel bagi grid bersaiz (3x3) atau (5x5). Tambahan lagi, RAFFRGC dapat menghindarkan daripada komputasi yang kompleks dan kos bagi reka bentuk tambahan pada FBS dengan mengguna pakai Sistem Pengurusan Femtosel (SPF) untuk mencapai peyelarasan interferens dan peruntukan sumber di kalangan FBS. RAFFRGC juga memaksimumkan kecekapan blok sumber, menjamin QoS bagi semua pengguna femtosel dan dapat menyokong penempatan grid femtosel berskala besar. Hasil simulasi menunjukkan bahawa RACSA mengurangkan interferens rentas-peringkat dan meningkatkan prestasi sistem ini. Penilaian prestasi menunjukkan bahawa RACSA mencapai 38% dan 21% lebih tinggi dari segi penghantaran. 14% dan 35% peningkatan dari segi kecekapan spektrum, serta 55% dan 33% pengurangan kebarangkalian berlakunya interferens apabila dibandingkan dengan hasil yang iperolehi dengan algoritma genetik dan algoritma lelongan.

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I certify that a Thesis Examination Committee has met on 4 December 2017 to conduct the final examination of Motea Saleh Mohammed Al-Omari on his thesis entitled "Resource Allocation Techniques for Interference Mitigation in Macro and Femtocell Heterogeneous Network-Based LTE System" in accordance with the Universities and University Colleges Act 1971 and the Constitution of the Universiti Putra Malaysia [P.U.(A) 106] 15 March 1998. The Committee recommends that the student be awarded the Doctor of Philosophy.

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TABLE OF CONTENTS

				Page
ABSTRACT				i
ABSTRAK				iii
ACKNOWLEDGEMENTS				v
APPROVAL				vi
DECLARATION				viii
LIST OF TABLES				xiii
LIST OF FIGURES				xiv
LIST OF ABBREVIATIONS				xvii
CHAPTER				
1	**INTRODUCTION**			1
	1.1	Overview on Femtocell Technology		1
	1.2	Research Problem Statement		2
	1.3	Research Objectives		5
	1.4	Research Questions		5
	1.5	Scope and Limitation of Work		6
	1.6	Thesis Organization		6
2	**LITERATURE REVIEW**			7
	2.1	LTE Femtocells		7
		2.1.1	HetNets Indoor Coverage Technologies	8
		2.1.2	The Major Motivation behind HeNBs Deployment	12
		2.1.3	Femtocell General Technical Challenges	13
		2.1.4	LTE Frame and Resource Grid Structure	15
	2.2	OFDMA Based Femtocell Interference Management		18
	2.3	Interference Management Techniques		20
		2.3.1	Radio Resource Allocation Based Approaches	23
		2.3.2	Cognitive Based Approaches	30
		2.3.3	Hardware Based Approaches	37
	2.4	Comparison Among Various Interference Mitigation Approaches		39
	2.5	Chapter Conclusion and Research Directions.		43
3	**RESEARCH METHODOLOGY**			44
	3.1	Introduction		44
	3.2	Effects of Deployment FBSs Grids Density in HetNets (DL)		45

	3.2.1	Deployment of Femtocell as (3x3) Gird	46
	3.2.2	Deployment of Femtocells as (5x5) Grid	47
3.3	Performance Evaluation and Metrics		49
	3.3.1	Signal to Interference Noise Ratio.	49
	3.3.2	Outage Probability (SINR Distribution)	52
	3.3.3	Throughput Performance	52
	3.3.4	Fairness Performance	53
	3.3.5	Spectral Efficiency Performance	53
3.4	DL Cross and Co-tier Interference Mitigation Approach.		54
	3.4.1	System Model Description and Problem Formulation	54
	3.4.2	RAFFRGC Interference Mitigation Technique	56
	3.4.3	Interference Mitigation Between Macrocell and Femtocell (Stage 1)	56
	3.4.4	Interference Mitigation Among Neighboring Femtocells (Stage 2)	60
	3.4.5	Performance Evaluation Metrics	76
3.5	The Proposed RACSA Interference Mitigation Approach		78
	3.5.1	Overview of Cuckoo Search Algorithm	78
	3.5.2	System Model and Problem Formulation	79
	3.5.3	Problem Mathematical Formulation	81
	3.5.4	Resource Allocation	82
	3.5.5	Performance Evaluation Metrics	85
3.6	The Vienna LTE simulators		85
3.7	Simulator Validation		89

4	**RESULTS AND DISCUSSION**		90
4.1	Introduction		90
4.2	Effects of FBSs Density on DL Performance in HetNets		90
	4.2.1	Simulation Environment and Parameters Setup	90
	4.2.2	Results and Performance Evaluation	93
4.3	DL Cross and Co-tier Interference Mitigation in HetNets		101
	4.3.1	Simulation Environment and Parameters Setup	101
	4.3.2	Results and Performance Evaluation	104
4.4	RACSA Cross-tier Interference Mitigation Approach		109
	4.4.1	Simulation Parameters for Proposed RACSA	109
	4.4.2	Performance Evaluation for Proposed RACSA	109
	4.4.3	System Throughput versus Number of Femtocells	110
	4.4.4	Spectral Efficiency versus Number of Femtocells	111
	4.4.5	Outage Probability versus SINR Threshold	112

5	**CONCLUSION AND RECOMMENDATIONS FOR FUTURE RESEARCH**	114
	5.1 Conclusion	114
	5.2 Thesis Contribution	116
	5.3 Recommendation for Future Research	118
REFERENCES		119
BIODATA OF STUDENT		131
LIST OF PUBLICATIONS		132

LIST OF TABLES

Table		Page
1.1	Interference scenarios for two-tier macrocell and femtocell HetNets	5
2.1	Comparison among various indoor wireless access technologies	11
2.2	Femtocell versus Wi-Fi	12
2.3	Benefits of femtocells for operator and users	13
2.4	Transmission Bandwidth Configuration	17
2.5	All interference scenarios for two tier HetNets	20
2.6	Comparison among various interference mitigation approaches	42
3.1	Sub-band and RBS allocation for MUEs based FFR	60
3.2	Sub-band and RBs Allocation for FUEs	63
3.3	QCI for different connection services based LTE standard	67
3.4	Modulation scheme and target SINR for macrocell zones	80
4.1	Macrocell simulation parameters	91
4.2	Femtocell specific simulation parameters	92
4.3	Macrocell simulation parameters	103
4.4	Femtocell specific simulation parameters	103
4.5	Comparison for overall average user throughput	108
4.6	Simulation parameters	109

LIST OF FIGURES

Figure		Page
1.1	Interference scenarios in two-tier macrocell and femtocell HetNets	4
2.1	A typical indoor OFDMA femtocell architecture in LTE	8
2.2	Layout of a heterogeneous cellular wireless network concept	9
2.3	LTE Frame Structure type 1	15
2.4	LTE Frame Structure type 2	16
2.5	Relationship between a slot, symbols and Resource Blocks	16
2.6	Relationships between Channel Bandwidth, Transmission Bandwidth Configuration, and Transmission Bandwidth	17
2.7	Types of interference in OFDMA-based two-tier HetNets	18
2.8	OFDMA-based femtocell networks interference scenarios	19
2.9	Interference management techniques in two-tier HetNets	23
2.10	Interference management scheme using FFR	27
2.11	Sensing –based opportunistic power control	29
2.12	Interference management using cognitive approach	31
2.13	Femto-aware spectrum arrangement scheme	33
2.14	Different access control mechanism in femtocell network	37
3.1	A block diagram of overall design of the proposed work	44
3.2	Outdoor and indoor user distribution per macrocell area	45
3.3	(a) FBSs grid size (3x3) (b) Co-tier interference in FBS grid (3x3)	47
3.4	Tow-tier HetNets for macrocell overlaid with femtocell grids (3x3)	47
3.5	(a) FBS grid size (5x5) (b) Co-tier interference in FBS grid (5x5)	48
3.6	Tow –tier HetNets for macrocell overlaid with femtocell grids (5x5)	48
3.7	Tri-sector macrocell system model with center and edge region	55
3.8	System model for FBS grids deployment	56
3.9	Sub band assignment for tri- sector macrocell using FFR	57

3.10	Sub-band Allocation for Femtocells with FBS grid size (3x3)	58
3.11	Sub-band Allocation for Femtocells with FBS grid size (5x5)	58
3.12	LTE Spectrum division for resource allocation purpose	59
3.13	Frequency sub-band allocation for FBSs	61
3.14	Resource blocks allocation for FBSs based RAFFRGC	62
3.15	Resource Allocation for FUEs through FMS	64
3.16	FBS self-organization stages	64
3.17	Interfering FBSs network converted to undirected graph	65
3.18	FMS indicators for resource blocks assignment to FBS	66
3.19	FBS grid (3x3) located in macrocell sector 1 center zone C1	70
3.20	FMS convert the network of neighboring FBSs to graph	71
3.21	Number of RBs demand for each FBSs required connection	71
3.22	Available RBs for FBS when its located in center zone C1	72
3.23	Illustrated example of RAFFRGC procedures.	75
3.24	FBS grids deployment as 2nd tier per macrocell sector area	76
3.25	System Model of two-tier macro and femtocell HetNets	80
3.26	Vienna LTE link level simulator overall structure	86
3.27	Schematic block diagram of the LTE system level simulator	87
3.28	Schematic class diagram showing implementation of link-to-system model in the LTE	88
4.1	10 FBS grids (3x3) deployment per macrocell sector area	92
4.2	10 FBS grids (5x5) deployment per macrocell sector area	93
4.3	Outage probability for macrocell with various femtocell densities	94
4.4	Average user throughput for various density of FBS grids (3x3)	95
4.5	Average user throughput for various density of FBS grids (5x5)	96
4.6	User throughput for one by one femtocell deployment	96
4.7	Throughput of MUE vs FUE when deploy 1 FBS grid (3x3)	97
4.8	Throughput of only MUEs when deploy 1 FBS grid (3x3)	97

4.9	Throughput of MUE vs FUE when deploy 1 FBS grid (5x5)	98
4.10	Single macrocell user throughput degradation	98
4.11	Jain's fairness index vs. the number of FBS grids	100
4.12	UE average spectrum efficiency vs. the number of FBS grids	101
4.13	6 FBS grids (3x3) deployed per macrocell centre-sector area	102
4.14	5 FBS grids (5x5) deployed per macrocell centre -sector area	102
4.15	Average throughput for only Macrocell UEs	105
4.16	Average throughput for only femtocell UEs	106
4.17	Average throughput for all UEs (MUEs and FUEs)	107
4.18	Number of femtocells vs. throughput for different techniques	111
4.19	Femtocells vs. spectrum efficiency for different techniques	112
4.20	Outage probability vs SINR threshold. for different techniques	113

LIST OF ABBREVIATIONS

ACM	Autonomous Control Module
ACO	Ant Colony Optimization
AEs	Antenna Elements
AHRS	Adaptive Hard Reuse Scheme
AI	Available intervals
AMC	Adaptive Modulation and Coding
BP	Bandwidth Parts
BS	Base Station
BW	Bandwidth
CA	Close Access
CAPEX	Capital Expenditure
CC	Component Carriers
CDMA	Code Division Multiple Access
CLPS	Closed-Loop Power Setting
CP	Cyclic Prefix
CQI	Channel Quality Indicator
CSA	Cuckoo Search Algorithm
CSG	Closed Subscriber Group
DAs	Distributed Antennas
DE	Differential Evaluation
DL	Down Link
DSL	Digital Subscriber Line
DwPTS	Downlink Pilot Time Slot
FAP	Femtocell Access Point
FBS	Femtocell Base Station
FBSID	FBS Identification
FDD	Frequency Division Duplexing
FFR	Fractional Frequency Reuse
FGW	Femtocell Gate Way
FMC	Fixed Mobile Convergence
FMS	Femtocell Management System
FNC	Femtocell Network Controller

FSC	Femtocell System Controller
FTH	Fiber optics to Home link
FUEs	Femtocell User Equipment's
GA	Genetic Algorithm
GBR	Guaranteed Bit Rate
GC-DSA	Graph Coloring for Dynamic Sub-band Allocation
GSM	Global System Mobile communication
HA	Hybrid Access
HBS	Home Base Station
HeNBs	Home Evolved Node BS
HetNets	Heterogeneous Networks
HNBs	Home Node Base stations
HSG	Hybrid Subscriber Group
IC	Interference Cancellation
ICI	Inter-Carrier Interference
IMS	IP multimedia subsystem signaling
ISI	Inter Symbol Interference
JFI	Jain's Fairness Index
LDO	Low Duty Operation
LTE	Long-Term Evolution
LTE-A	LTE-Advanced
MA	Margin Adaptive
MAMSRL-SS	Multiple-Agent Multiple-state RL with Soft-max Selection
MBS	Macrocell Base Station
MeNB	Macrocell e-Node BS
MIMO	Multiple Input Multiple Output
MIS	Maximal Independent Set
MUEs	Macrocell User Equipments
NEIGHBORING_MSG	Neighboring Message
NLOS	Non-Line-Of-Sight
non-GBR	Non- Guaranteed Bit Rate
OA	Open Access
OFDMA	Orthogonal Frequency Division Multiple Access

O-FFR	Optimal FFR
OLPS	Open Loop Power Setting
OOP	Object-Oriented Programming
OPEX	Operating Expenditure
OSG	Open Subscriber Group
OTA	Over-The-Air
PC	Power Control
PIC	Parallel Interference Cancellation
PSO	Particle Swarm Optimization
QCIs	QoS Class identifiers
QoS	Quality -of-Service
RA	Rate Adaptive
RA	Resource Allocation (Resource Assignment)
RACSA	Resource Allocation based Cuckoo Search Algorithm
RAFFRGA	Resource Allocation based Fractional Frequency Reuse and Graph Algorithm
RAN	Radio Access Network
RBGs	Resource Blocks Groups
RBs	Resource Blocks
RE	Resource Element
RF	Radio Frequency
RRBs	Radio resource blocks
RXs	Receivers
RxFBS-ID	Received FBS-ID
RSSI	Received Signal Strength Indication
SAMSRL-AAS	Single-Agent Multiple-State RL with Adaptive Action Selection
SB	Sub Band
SE	Spectrum Efficiency
SIA	Swarm Intelligent algorithms
SIC	Successive Interference Cancellation
SINR	Signal to Interference and Noise Ratio
SMDP	Semi Markov Decision Process
SOHO	Small Office Home Office
TCP	Transmission Control Protocol

TDD	Time Division Duplexing
Ts	Time slot
TTI	Transmission Time Interval
TxFBS_ID	Transmission FBS-ID
UAI	Unavailable Interval
UEs	User Equipment's
UL	Up Link
UMTS	Universal Mobile Telecommunications System
UpPTS	Uplink Pilot Time Slot
VoIP	Voice over IP
WCDMA	Wideband Code Division Multiple Access
WiMAX	Worldwide Interoperability for Microwave Access
WLAN	Wireless Local Area Networks

CHAPTER 1

INTRODUCTION

1.1 Overview on Femtocell Technology

Due to the advances in modern cellular technology, wireless devices have become an essential indispensable element in our daily life. The rapid growth and proliferation of wireless devices and gadgets have turned the cellular networks from being basically voice networks to become mostly data networks. To provide this higher rate of data, operators across the world have switched to higher frequency to increase the bandwidth. However, increasing number of wireless nodes in sub-urban and urban areas has created a bigger challenge for the outdoor base station to provide quality coverage in indoor environments. According to recent studies, roughly 66% of the phone calls and 90% of the data services take place in indoor environments (e.g. home, office, enterprises) [1]–[3]. However, more and more users complain of poor connectivity as the received signal strength from outdoor Base Station (BS) weakens and deceases in performance due to the high penetration loss in the walls [4]. As stated in article [5], 45% of the residential subscribers and 30% of the corporate subscribers complain of poor indoor coverage. The existing outdoor base station cannot increase the transmission power in an infinite level to ensure the coverage in outage areas. The growing demand for broadband wireless access inside residential (indoors) environment along with the shortage of capacity in the existing outdoor base stations have motivated wireless service providers to look for possible solutions to improve indoor coverage with high data rates and enhanced Quality of Service (QoS). To handle these challenges, different deployment strategies have been proposed earlier including installation of extra macrocell, Distributed Antennas (DAs), hot spots, In-Building Solution (IBS), picocells, and multi-hop relays. The infrastructure for doing so, nonetheless, is expensive and cannot guarantee high quality indoor coverage. The concept of femtocells has recently been introduced as the cheapest solution for indoor wireless broadband [6]–[9]. Femtocell Base Station (FBS) or Femtocell Access Point (FAPs), is a small base station typically designed for indoor use in a Small Office Home Office (SOHO) environment to provide voice and broadband services. FBS is a cost competitive, low power, short-range wireless device operating in the licensed spectrum. The term femtocell itself was first coined in 2006. FBS is not a new concept as it was first studied in 1999 by Bell Labs, while GSM based home base station were brought to the market by Alcatel in 2000. The first 3G-based home base station was introduced by Motorola in 2002 [10]. In the metric measurement system, “Femto” means one-quadrillionth (10^{-15}). FBS is installed by the users to ensure seamless indoor coverage with better voice and data reception [11], [12]. FBS, on the air interface, provides radio coverage to a given cellular standard [13], such as Global System Mobile (GSM) communication, Wideband Code Division Multiple Access (WCDMA), Universal Mobile Telecommunications System (UMTS), Worldwide Interoperability for Microwave Access (WiMAX), and Long Term Evolution (LTE). The 3rd Generation Partnership Project (3GPP) refers to this FBS as Home Node Base station (HNBs). The LTE femtocell is referred to as Home evolved Node Base station (HeNB) [14]. FBSs are connected to the Internet via broadband backhaul connection such as, cable modem, digital subscriber line (DSL), on home fiber optic link, separate

Radio Frequency (RF) backhaul channel, satellite, or a similar IP backhaul technology. The wired connection is used to integrate the FBS with the mobile operator's core network. FBSs were introduced in the 3GPP release 8 in 2008 [15]. Given the continuous evolving of technologies of cellular networks, several femtocell specifications and standards are being included in the technical reports of 3GPP1 and 3GPP2 [16],[17] . Triggered by its highly spectral efficiency and low implementation cost, OFDMA has been utilized in many high-speed wireless transmission standards (e.g. LTE, WiMAX, and Wi-Fi). Long Term Evolution (LTE) is a broadband wireless access technology designed to support mobile Internet access via cell phones or handheld devices. As LTE exhibits significant performance improvements over previous cellular communication standards, it is commonly referred to as fourth generation (4G) technology [18]. This Thesis treats LTE as a standard to investigate the interference problem in OFDMA-based femtocell networks. The standard was developed by the 3GPP and was specified and enhanced in Release 8 and Release 9 of its document series respectively [19]. Besides LTE, LTE-Advanced has been developed as successor standard of LTE. There are many solutions which have been specified in release 10 and release 11 (LTE- Advanced) of LTE, and more solutions are studied and developed in the next release (Rel-12 and beyond). A number of worldwide mobile operators showed interest in LTE HeNB technologies as a promising solution to increase system capacity in the near future [20].

1.2 Research Problem Statement

In wireless broadband access networks, most indoor environments encounter serious coverage problem due to non-line of sight transmission. Femtocells have been introduced as cost efficient solution to improve cell coverage, enhance area spectral-efficiency and provide better quality-of-service (QoS) to mobile users. However, vast deployment of femtocell network in the absence of proper network planning strategy makes it difficult to maintain the desired quality of service. Additionally, the service of femtocell in densely deployed heterogeneous network is challenged by interference. In reality, interference mainly occurs due to the fact that the radio resource is scarce. Femtocells have to (fully/ party) share/ ruse the available spectrum resource (the same licensed frequency band) with the existing macrocells in the network. This process is referred to as co-channel deployment. In co-channel deployment, the femtocells and macrocells can fully or partly share/reuse the available frequency bandwidth, thereby resulting in severe interferences between macrocells and femtocells.

A femtocell not only provide coverage within the owner's home or in the office, but also radiates outside, as well as extends coverage to nearby premises and other outdoor spaces, leading to interference among the neighboring femtocells [11],[12]. Moreover, the deployment of new femtocells may result to disturbances in the operations of the existing femtocells in the network. Besides, the femtocell base stations will be randomly deployed and installed by users themselves, with no prior planning by either the user, mobile operator, or the internet service provider (ISP), thereby making interference management even more challenging [21]. Such interference will decrease the quality of communication and therefore lead to degradation for the system performance. Interferences in general can have negative impacts on the performance of femtocells, and also hinders the performance of other devices connected to the macro cellular network. Moreover, extreme cases of interference may result to “Dead zones” (i.e. regions experiencing degrading QoS thereby making it impossible to establish communication). In general, the quality of received signal at the receiving end is determined and quantified using the Signal to Interference plus Noise Ratio (SINR). Precisely, the SINR depends on the BS’s transmitted power, transmitted power from each of the interfering transmitters, shadowing, fading as well as path losses [22]. For communication to take place, the prevailing SINR reading must surpass a particular threshold. If the SINR reading falls below this threshold as a result of interference, the communication link cannot be established thereby creating a dead zone. In general, the threshold of the SINR is defined based on the radio frequency being utilized, and may also be different in accordance with the various QoS requirements of the different technologies [23].

Generally, interference in two-tier macro and femtocells HetNets can classified into two types:

Cross-tier interference or (inter-tier interference): refers to interference occurs between network elements belonging to dissimilar tiers of the network (for example, between elements of the macrocell tier and those of the femtocell tier, vice versa. Here, the femtocell UEs (FUEs) and macrocell UEs (MUEs) are the sources of uplink cross-tier interferences towards the nearby Femtocell Base Stations (FBSs) as well as the serving Macrocell Base Station (MBS) respectively as illustrated with index 1 and index 3 in both Figure 1.1 and Table 1.1. Conversely, the serving MBS, together with the FBS result in forward link (downlink) cross-tier interferences on to the MFUEs and the neighboring FUEs as illustrated with indexes 2 and 4 respectively showed in both Figure 1.1 and Table 1.1. Figure 1.1 provides a summary of the various cross-tier scenarios. Nevertheless, for OFDMA networks, cross-tier forward (DL)/reverse link (UL) interferences happen exclusively in cases where both the aggressor and the victim attempted to use the same radio spectrum resources (sub-channels, resource blocks). Thus, efficient resource allocation is indeed vital for interference avoidance is such systems [21],[70].

Co-tier interference (intra-tier interference): As the name suggests, co-tier interference, in general, is the interference which takes place between network elements belonging to the same tier. In terms of femtocell networks, co-tier interference refers to the interference among neighboring femtocells. Co-tier interference occurs in two different forms uplink co-tier interference and downlink co-tier interference. The former occurred when femtocell user equipment FUE (aggressor) may cause uplink co-tier interferences with its neighboring femtocell base stations FBS (victim) as illustrated with index 5 in both Figure 1.2 and Table 1.1, while the latter occurred when a FBS (aggressor) may also cause downlink co-tier interferences to a nearby FUEs (victims) as illustrated with index 6 shown in both Figure 1.1 and Table 1.1. For femtocell networks based on OFDMA, the occurrence of co-tier Uplink (UL)/Downlink (DL) interferences takes place only when both the aggressor and the victim attempt to communicate using the same spectrum resources (sub-channels, or

Resource blocks). Thus, for interference mitigation in such networks, an intelligent and efficient radio resource allocation mechanism is required.

In orthogonal Frequency Division Multiple Access (OFDMA) based macro cellular Long-Term Evolution (LTE) femtocell networks, (uplink/downlink) interferences occur only when the aggressor and the victim attempted to share and/ or reuse the same radio frequency resource (sub-channels, Resource Blocks). Since the radio spectrum (frequency) resources are limited then the resource allocation considers an important factor in terms of interference avoidance in two-tier HetNets. Therefore, by adopting suitable resource allocation, the cross-tier interferences can be considerably minimized; while the co-tier interferences can be effectively avoided and this will lead to improve the overall system performance.

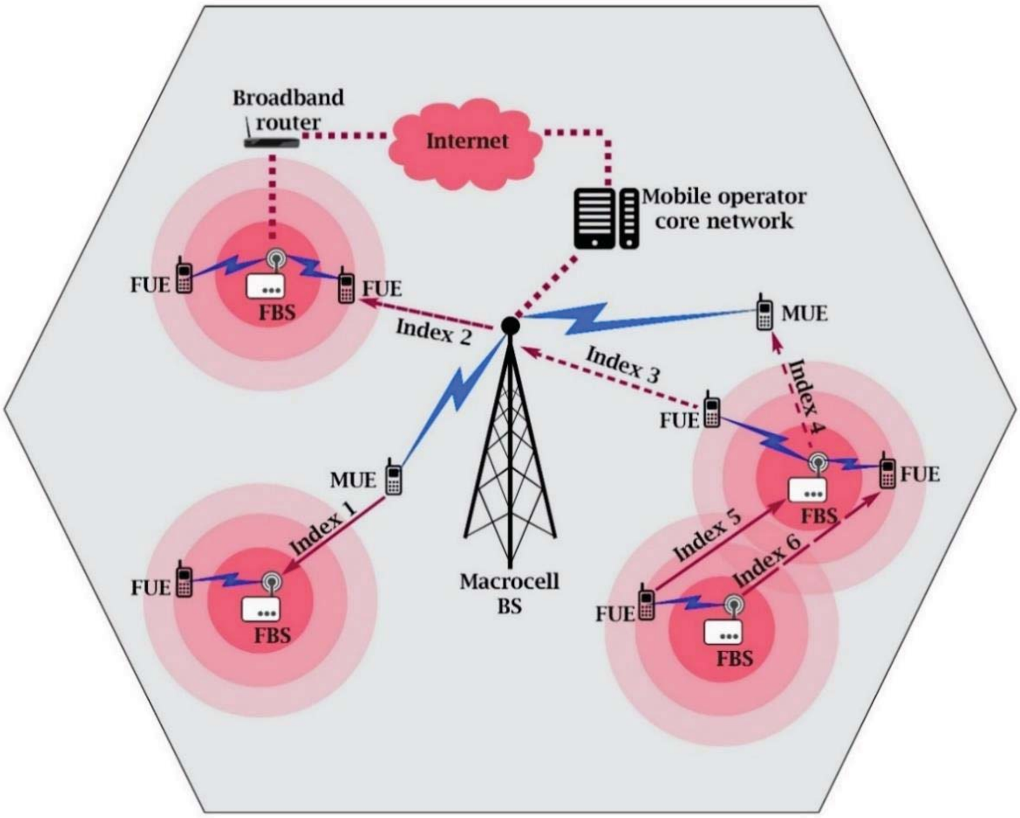

Figure 1.1: **Interference scenarios in two-tier macrocell and femtocell HetNets.**

Table 1.1, gives a brief description on interference types (cross-tier, co-tier), source (aggressive), victim of interference, and transmission mode (UL, DL) for various interference scenarios that depicted in Figure 1.1 and indexed from 1 to 6.

Table 1.1: **Interference scenarios for two-tier macrocell and femtocell HetNets**

Index	Interference type	Aggressor	Victim	Transmission mode
1	Cross-tier	MUE	FBS	UL
2	Cross-tier	MBS	FUE	DL
3	Cross-tier	FUE	MBS	UL
4	Cross-tier	FBS	MUE	DL
5	Co-tier	FUE	FBS	UL
6	Co-tier	FBS	FBS	DL

Generally, more details in interference types and scenarios together with various interference management techniques will be discussed in details in Chapter 2.
An effective and optimal resource allocation (spectrum and power) for interference mitigation in two-tier HetNets is considered a key challenge of this thesis and the research will carryout to solve it.

1.3 Research Objectives

The main aim of this thesis is to mitigate downlink interference in two-tier macro and femtocell HetNets based radio resource allocation approaches that ensure a better QoS and improve the overall system performance. The objectives of this study are:

1. To investigate and analyze, the impacts of femtocell grids deployment density on the downlink performance for two-tier HetNets based LTE system.
2. To develop a hybrid resource allocation technique to mitigate both cross-tier and co-tier interference for two-tier HetNets using combined Fractional Frequency Ruse (FFR) and Graph Connectivity (GC) based LTE system.
3. To propose a cross-tier interference mitigation technique-based resource allocation, that assign the suitable resources (frequency and power) for all mobile users using the heuristic bio inspired cuckoo search algorithm.

1.4 Research Questions

What level of performance degradation can be expected if Femto-cells are overlaid on the same spectral infrastructure as with a macro-base station in multi cell?
Which system models can be applied for two-tier macro- and femtocell heterogeneous networks?
What is the effect of cross-tier interference rising between macrocell and femtocell HetNets?
What is the impact of co-tier interference originating among neighboring femtocells?
How will achieve resource allocation (i.e. spectrum, Radio resource blocks (RRBs) in the absence of coordination between macrocells and femtocells?

How to avoid and/or mitigate cross-tier interference in two-tier HetNets?
How to avoid and/or reduce co-tier interference among neighboring femtocells in two-tier HetNets?

1.5 Scope and Limitation of Work

The work in this thesis focuses on the area of radio resource allocation and interference management in heterogeneous networks with femtocells deployments. This thesis scope focus on downlink cross and co-tier interference management approaches for based resource (frequency) allocation techniques in two-tier Heterogeneous Networks (HetNets) to improve the overall system performance. Furthermore, a co-channel deployment and either close or hybrid access modes was used for femtocells in the context of this thesis. The frequency resource allocation applied in this thesis depend on FFR-3, graph connectivity concept, and cuckoo metaheuristic search. The other different types of interference management approaches for two-tier HetNets are considered out of scope in this thesis. In other words, this study focuses for interference mitigation for HetNets based the management of radio resource allocations. The proposed models, algorithms and techniques for interference mitigation are implemented and integrated with Vienna LTE system level simulator.

1.6 Thesis Organization

Chapter 2 presents a brief background on LTE femtocell, indoor coverage technologies used in heterogeneous networks, the motivation behind femtocell deployment, and femtocell general technical challenges. In addition, it presents types and possible scenarios of interference in OFDMA based femtocell networks followed by a comprehensive literature review on the different state of the interference management and resource allocation approaches. Furthermore, a qualitative comparison among various interference mitigation techniques is provided in this chapter. Chapter 3 presents the methodology, system models for different femtocell deployment scenarios, and the problem mathematical formulas are provided. Moreover, the operational algorithms for the proposed schemes for interference mitigation in two-tier macro and femtocell heterogeneous networks are presented. Chapter 4 investigate the experimental circumstance, presents the simulation environment, simulation parameters, simulation results. In addition, a performance evaluation is discussed in this Chapter through comparing the results of proposed interference mitigation techniques with some other recent related techniques from the previous studies. In Chapter 5, the thesis conclusion, and contribution is presented. Directions and recommendations for future research topics are discussed.

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