



HAL
open science

Mobility and Security Management in Femtocell Networks

Seifeddine Bouallegue

► **To cite this version:**

Seifeddine Bouallegue. Mobility and Security Management in Femtocell Networks. Networking and Internet Architecture [cs.NI]. Université Pierre et Marie Curie - Paris VI; École nationale d'ingénieurs de Tunis (Tunisie), 2016. English. NNT : 2016PA066084 . tel-01552289

HAL Id: tel-01552289

<https://theses.hal.science/tel-01552289>

Submitted on 2 Jul 2017

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.

PIERRE AND MARIE CURIE UNIVERSITY
NATIONAL ENGINEERING SCHOOL OF TUNIS

Ph.D. Dissertation

Mobility and Security Management in Femtocell Networks

Presented by:

Seifeddine BOUALLEGUE

To obtain the Degree of:

Doctor of Philosophy in Communications

Specialty:

Technology of Information and Communications

Supervisor:

Pr. Guy PUJOLLE

Supervisor:

Dr. Kaouthar SETHOM

Defended on June 30th, 2016 in front of the Jury:

Mrs. Houria REZIG	Professor, ENIT, Tunisia	President
Mr. Kosai RAOOF	Professor, ENSIM, France	Reviewer
Mr. Noureddine HAMDI	Professor, ENIT, France	Reviewer
Mr. Anthony BUSSON	Professor, IUT, France	Examiner
Mr. Tahar EZZEDINE	A. Professor, ENIT, Tunisia	Examiner
Mr. Guy PUJOLLE	Professor, UPMC, France	Supervisor
Mrs. Kaouthar SETHOM	A. Professor, ENIT, Tunisia	Supervisor

To my grand parents: Turkia, Makki, Habiba and Hedi.

To my parents: Ridha and Noura

To my sisters: Takwa and Sirine.

To my wife Abir.

Acknowledgment

I would like to gratefully thank my supervisors, Prof. Guy PUJOLLE and A. Prof. Kaouthar SETHOM whose support and guidance made my thesis work possible. They have been actively interested in my work and have always been available to advise me. I am very grateful for their patience, motivation, enthusiasm, and immense knowledge that, taken together, make them great mentors.

I would like to show my gratitude to my thesis reviewers: Prof. Kosai RAOOF and Prof. Nouredine HAMDI, and to the jury members: Prof. Houria REZIG , Prof. Anthony BUSSON and Dr. Tahar EZZEDINE, for evaluating my Ph.D. work.

This work was possible because of the unconditional support provided by Dr. Mazen Omar HASNA. A person with an amicable and positive disposition, he has always made himself available to clarify my doubts despite his busy schedules.

I would like to express my sincere appreciation and gratitude to Dr. Ridha HAMILA, who has been a constant source of encouragement and enthusiasm.

I would also like to sincerely thank Dr. Aymen OMRI for his precious help. He was there when I needed him and he never declined a call for assistance. Thank you, for all your help and support.

I truly thank Dr. Adel CHERIF for his continuous support and motivation. His words always pushed me forward and inspired me to achieve better results.

To my grand-mother, Turkia, god bless her soul. I would like to thank her like no one did in this world. I would like to tell her that if I had to dedicate this achievement to only one person it would be you. I wish you could be there. Your prayers are with me whenever I go, protecting me, pushing me and making me feel secure. I can never thank you as it should be. Rest in peace grand-mother.

A few words about my father: Prof. Ridha BOUALLEGUE. This acknowledgment is not enough, and will never be. It will not be enough if I wrote I totally owe him my success. It will not be enough if I wrote he made me what I am now. It will not be enough if I wrote my father is my only true hero. Superman may has super powers, but not as my father has. He could make me

a man, raise a happy family and be the reason behind thousands of smiles. Go home Superman, my father is around.

My mother: Noura GZARA BOUALLEGUE, the most precious person on earth. Numbers on this earth can not be enough to evaluate her kindness and love. I hope that I could make her proud of me. I hope.

My sisters: Takwa and Syrine, thanking them is just not fair. They are part of me, and they are part of this achievement. I grew up with Takwa as my best friend, had hard times, but we could always figure out a solution. I mean, she could because I was stubborn and selfish, what she never was. I raised Syrine, sometimes I see in her a little me, yes with the stubborn and selfish aspects sometimes, but I find myself in her and I wish this achievement would make her proud of her big brother. I wish.

Dr. Abir EDDHAOUI, the real Doctor in the house, the one I proudly call 'my wife'. My beloved Dentist. Patience? Support? Not a day that passes without her waving at me to work harder. She could always find the right words to get the best of me. I hope she will be proud to call her husband Dr. Seifeddine BOUALLEGUE, because she contributed so much in making me achieve this goal. So much.

Mohamed Said EDDHAOUI, god bless his soul, my father in law. I wish could be there to see me. I hope you are proud of your son. Me.

A special and warm thanks to Naima SMAOUI, my mother in law. She provided me with unending encouragement and support.

Seifeddine BOUALLEGUE

Résumé

Les réseaux de télécommunications sont soumis à des processus d'amélioration et d'optimisation continue. Chaque nouvelle itération apporte son lot de défis et limites. En effet, la croissance exponentielle des appareils de télécommunication, des stations de base aux équipements utilisateurs conduisent à de sérieux problèmes d'économie d'énergie. En plus des menaces à la vie privée, en particulier pour les réseaux sans fil car les canaux utilisés par les opérateurs peuvent également être utilisés par une oreille indiscreète quelconque. L'optimisation de l'utilisation du spectre est également un défi en raison du fait que le spectre disponible dans les systèmes de communication sans fil est devenu une ressource très rare en raison de la demande croissante. Les réseaux émergents, tels que les femtocells, souffrent également des défis mentionnés précédemment.

Le travail de thèse actuel se concentre sur la proposition de solutions aux défis cités précédemment: l'efficacité énergétique, le partage du spectre et la sécurité. Le travail de recherche présenté dans cette thèse a porté sur trois axes principaux: Premièrement, trouver un moyen de réduire au minimum la consommation d'énergie des femtocellules dans les réseaux BWA femto/macro-cellulaire en diminuant le nombre d'événements de mobilité non désirés et l'introduction de nouveaux états de puissance pour la femtocellule. En second lieu, proposer une solution qui vise à réduire le temps de transmission prévu dans le temps de séjour de l'utilisateur secondaire (SU) dans la couverture d'une femtocellule en utilisant un algorithme basé sur le temps minimum prévu de transmission dans le temps de séjour de l'équipement utilisateur (UE). Enfin, introduire un nouveau modèle qui basé sur la sélection du meilleur relais qui maximise le taux de confidentialité et les avantages de l'augmentation du nombre de relais sous la contrainte de qualité de service à la destination.

Mots clés: Systèmes de radio cognitive, Informations d'état de canal imparfaite, Gestion des interférences, Chaînes de Markov, Analyse de performance, Sélection de relais.

Abstract

Telecommunications networks are subject to continuous improvement and enhancement processes. Every new iteration brings its set of challenges and limitations. In fact, the exponential growth in telecommunication devices, from base stations to user equipments lead to serious energy efficiency issues. Along with the privacy threats, especially for wireless networks as the channels used by operators can also be used by any eavesdropper. Spectrum usage optimization is also a challenge due to the fact that the available spectrum in wireless communications systems has been a very rare resource because of the increasing demand. Emerging networks, such as femtocells, suffer also from the previously mentioned challenges.

The current thesis work focuses on proposing several solutions to the previously cited challenges: energy efficiency, spectrum sharing and security. The research work introduced in this thesis has focused on three main axes: First, find a way to minimize the energy consumption of femtocells in macro/femto-cellular BWA networks by decreasing the number of unwanted mobility events and introducing new power states for the femtocell device. Second, propose a solution that aims to reduce the expected transmission time within the dwell time of Secondary User (SU) in the coverage of a femtocell using an algorithm based on the minimum expected transmission time within the dwell time of the User Equipment (UE) in the coverage of the femtocell. Finally, introduce a new scheme that is based on best relay selection method that maximizes the secrecy rate and benefits from increasing the number of relays under QoS constraint at the destination.

Keywords: Cognitive radio systems, Imperfect channel state information, Interference management, Markov chains, Performance analysis, Relay selection.

Abbreviations

In this thesis, we have adopted the following abbreviations:

A

AF	Amplify-and-Forward
AWGN	Additive White Gaussian Noise

B

BER	Bit Error Rate
BS	Base Station
BSH	Best Second Hop

C

CF	Compress-and-Forward
CR	Cognitive Radio
CSI	Channel State Information

D

DF	Decode-and-Forward
----	--------------------

E

E-UTRAN	Evolved UMTS Terrestrial Radio Access Network
---------	---

F

F-BS	Femto-cell Base Station
FCC	Federal Communications Commission
FDMA	Frequency Division Multiple Access
FFR	Fractional Frequency Reuse
FIA	Full Interference Avoidance
F-MS	Femto-cell Mobile Station

G

GA Genetic Algorithm

GF General Form

H

HSH Highest Second-Hop

I

IA Interference Avoidance

IC Interference Cancellation

ICSI Imperfect Channel State Information

IM Interference Management

L

LI Low Interference

LS least square

LSH Lowest Second-Hop

LTE Long Term Evolution

M

MAC Media Access Control

M-BS Macro-cell Base Station

MIMO Multiple Input Multiple Output

MinI Minimum Interference based Selection Scheme

MLSE Maximum Likelihood Sequence Estimation

MMSE Minimum Mean Square Error

M-MS Macro-cell Mobile Station

M-PAM M-ary Pulse Amplitude Modulation

MS Mobile Station

M2H Maximum Second Hop

M2HScS Maximum Second Hop SNR Sub-channel Selection Scheme

O

OFCOM	Office of Communications
OFDM	Orthogonal Frequency Division Multiplexing
OSA	Opportunistic Spectrum Access

P

PAScS	Power Adjustment Sub-channel Selection Scheme
PCSI	Perfect Channel State Information
PDF	Probability Density Function
PIP	Peak Interference Power
PN	Primary Network
PSD	Power Spectrum Density
PU	Primary User

Q

QoS	Quality of Service
-----	--------------------

R

RBSH	Restricted Best Second
RS	Relay Station

S

SC	Standard Scheme Constellation
SOScS	Sequential Order Sub-channel Selection Scheme
SN	Secondary Network
SNR	Signal to Noise Ratio
SS	Standard Scheme
SU	Secondary User

T

TDMA	Time Division Multiple Access
------	-------------------------------

W

WREL	Worst Relay-Eavesdropper Link
------	-------------------------------

Notations

In this thesis, we have adopted the following notations:

$$j \quad j^2 = -1$$

$\Re(\cdot)$ Real part

$\Im(\cdot)$ Imaginary part

$|\cdot|$ Magnitude

$B_I(\cdot)$ Incomplete beta function

$Q(\cdot)$ Q-function

$erfc(\cdot)$ Complementary error function

$E(\cdot)$ Expectation function

$\exp(\cdot)$ Exponential function

$E_{int}(\cdot)$ Exponential integral function

E_s Transmitted energy per symbol

N_0 Noise power spectral density

N_R Number of relays

N_1 Number of relays that are satisfying the transmission and interference constraints

N_2 Number of relays that are satisfying only the transmission constraint

N_{SC} Number of sub-carriers

S_P Primary source

S_S Secondary source

R_j Relay index j

D_P Primary destination

-
- γ_{SD} The instantaneous SNR of the link between the source and the destination.
- γ_{SE} The instantaneous SNR of the link between the source and the eavesdropper.
- $\gamma_{R_k D}$ The instantaneous SNR of the link between the k^{th} relay and the destination.
- $\gamma_{R^* D}$ The instantaneous SNR of the selected relay and the destination for BSH scheme.
- $\alpha_{R^* D}$ The instantaneous SNR of the selected relay and the destination for RBSH scheme.
- $\beta_{R^* D}$ The instantaneous SNR of the selected relay and the destination for RBSH scheme.
- $\gamma_{R_k E}$ The instantaneous SNR of the link between the k^{th} relay and the eavesdropper.
- $\gamma_{R^* E}$ The instantaneous SNR of the selected relay and the eavesdropper for BSH scheme.
- $\alpha_{R^* E}$ The instantaneous SNR of the selected relay and the eavesdropper for WREL scheme.
- $\beta_{R^* E}$ The instantaneous SNR of the selected relay and the eavesdropper for RBSH scheme.
- $\bar{\gamma}_{SD}$ The average SNR of the link between the source and the destination.
- $\bar{\gamma}_{SE}$ The average SNR of the link between the source and the eavesdropper.
- $\bar{\gamma}_{RD}$ The average SNR of the link between the different relays and the destination.
- $\bar{\gamma}_{RE}$ The average SNR of the link between the different relays and the eavesdropper.
- γ_D^{eq} The instantaneous equivalent SNR of the link between the selected relay and the destination for BSH scheme.
- α_D^{eq} The instantaneous equivalent SNR of the link between the selected relay and the destination for WREL scheme.
- β_D^{eq} The instantaneous equivalent SNR of the link between the selected relay and the destination for RBSH scheme.
- γ_E^{eq} The instantaneous equivalent SNR of the the link between the selected relay and the eavesdropper for BSH scheme.
- α_E^{eq} The instantaneous equivalent SNR of the link between the selected relay and the eavesdropper for WREL scheme.

β_E^{eq}	The instantaneous equivalent SNR of the link between the selected relay and the eavesdropper for RBSH scheme.
p_{SD}	PDF of γ_{SD} .
p_{SE}	PDF of γ_{SE} .
p_{R^*D}	PDF of γ_{R^*D} .
f_{R^*D}	PDF of α_{R^*D} .
g_{R^*D}	PDF of β_{R^*D} .
p_{R^*E}	PDF of γ_{R^*E} .
f_{R^*E}	PDF of α_{R^*E} .
g_{R^*E}	PDF of β_{R^*E} .
p_D	PDF of γ_D^{eq} .
f_D	PDF of α_D^{eq} .
g_D	PDF of β_D^{eq} .
p_E	PDF of γ_E^{eq} .
f_E	PDF of α_E^{eq} .
g_E	PDF of β_E^{eq} .
P_{out}^{BSH}	The average outage probability for BSH scheme at the destination.
P_{out}^{WREL}	The average outage probability for WREL scheme at the destination.
P_{out}^{RBSH}	The average outage probability for RBSH scheme at the destination.
P_e^{BSH}	The average BER for BSH scheme at the destination.
P_e^{WREL}	The average BER for WREL scheme at the destination.
P_e^{RBSH}	The average BER for RBSH scheme at the destination.
C_D^{BSH}	The average ergodic capacity for BSH scheme at the destination.
C_D^{WREL}	The average ergodic capacity for WREL scheme at the destination.
C_D^{RBSH}	The average ergodic capacity for RBSH scheme at the destination.
C_E^{BSH}	The average ergodic capacity for BSH scheme at the eavesdropper.
C_E^{WREL}	The average ergodic capacity for WREL scheme at the eavesdropper.
C_E^{RBSH}	The average ergodic capacity for RBSH scheme at the eavesdropper.

List of Figures

2.1	Femtocells in E-UTRAN Architecture.	9
2.2	Network Life Cycle.	12
2.3	Interference in Femtocell Network.	17
3.1	System Model.	29
3.2	Power saving algorithm	31
3.3	Handover probability.	36
3.4	Prasun solution energy consumption[83].	37
3.5	Seifeddine solution energy consumption.	37
3.6	Energy gain of our solution compared to Prasun solution.	38
3.7	Energy gain of our solution in function of the number of femtocells.	39
4.1	LTE Architecture.	42
4.2	System Model.	43
4.3	Flowchart of the Handover Decision Algorithm.	48
4.4	The dwell time.	49
4.5	The Simulation Topology.	53
4.6	Total Transmission Time by data size.	54
4.7	Total Transmission Time by Pu.	54
4.8	Total Transmission Time by PUs.	55
4.9	Throughput by data size.	56
5.1	System Model.	58
5.2	Average outage probability vs. number of relays, with $\gamma_{th} = 10$ dB.	69
5.3	average outage probability vs. SNR, with $\gamma_{th} = 10$ dB.	69
5.4	Average BER vs. number of relays.	70

5.5	Average secrecy rate vs. number of Relays.	70
5.6	Secrecy rate vs. average second hop SNR.	71

Contents

Résumé	i
Abstract	ii
Abbreviations	iii
Notations	vi
List of Figures	x
1 Introduction	1
1.1 Problem Statement and Motivations	1
1.2 Contributions	2
1.3 Thesis Organization	4
2 State of the Art	5
2.1 Femtocell Overview	6
2.1.1 GSM	7
2.1.2 UMTS	7
2.1.3 High Speed Packet Access (HSPA)	7
2.1.4 UMTS/CDMA2000 Femtocells	7
2.1.5 LTE Femtocells	8
2.2 Femtocells in E-UTRAN Architecture	9
2.3 Access Control	11
2.4 Challenges	12
2.4.1 Self Organization	12
2.4.2 Energy Efficiency	13

2.4.3	Interference Management	16
2.4.4	Interference management techniques classification	17
2.4.5	Security	25
2.4.6	Spectrum Sharing	26
3	Energy Saving by Handover Classification in Femtocells Network	28
3.1	Introduction	28
3.2	System Model	29
3.2.1	Main Scheme	29
3.2.2	Power Saving Algorithm.	30
3.3	Performance Analysis	31
3.4	Numerical Results	35
3.4.1	Simulation Setup	35
3.4.2	Simulation Results	35
3.5	Conclusion	39
4	Spectrum Mobility Management	40
4.1	Introduction	40
4.2	Basic Ideas	41
4.2.1	LTE Architecture	41
4.2.2	Proposition Context	44
4.3	Proposed Solution	47
4.3.1	Sensing Phase	49
4.3.2	Handover Selection Criteria	50
4.3.3	Analytical Evaluation	51
4.4	Simulations Results	52
4.4.1	Total Transmission Time	53
4.4.2	Throughput	55
4.5	Conclusion	56
5	Improved Relay Selection Under Secrecy Rate Maximization	57
5.1	Introduction	57
5.2	System Model	58

5.3	Related and Proposed Schemes	59
5.3.1	Best Second Hop (BSH) Scheme	59
5.3.2	Worst Relay-Eavesdropper Link (WREL) Scheme	60
5.3.3	Restricted Best Second Hop (RBSH) Scheme	61
5.4	Performance Analysis	63
5.4.1	Outage Probability	63
5.4.2	Average Bit Error Rate (BER)	64
5.4.3	Average Ergodic Capacity and Secrecy Rate	65
5.5	Numerical Results	67
5.5.1	Simulation Setup	67
5.5.2	Simulation Results Interpretation	68
5.6	Conclusion	71
6	General Conclusion and Perspectives	72
6.1	General Conclusion	72
6.2	Future Work	74

Chapter 1

Introduction

1.1 Problem Statement and Motivations

The last two decades have seen an explosion in the growth of radio systems. The wireless communication systems evolved from the first generation (1G) analog narrow-band systems in the 1980s, to the second generation (2G) digital narrow-band systems in the 1990s, to the third generation (3G) multimedia wide-band systems in the 2001, and to the fourth generation (4G) with the high-speed mobile broadband [1–3].

Nowadays, and after evolving over a century, wireless communication can find its applications in various aspects of our lives, ranging from daily used WiFi networks to rarely seen deep space communication systems, from highly commercialized cellular and satellite communication systems to privately used amateur radio. New wireless applications are still keeping emerging as the demand for them never stops [1].

The existing challenges of current communication networks such as: energy efficiency, shadow zones, spectrum sharing, security, etc. urged researchers in this field to come up with new technologies to overcome the latter challenges. Femtocells represents an actual attempt to resolve these issues. In fact, using a small radio device (delivered with the internet box of the communication operators) that is connected to the customer's DSL line can solve multiple issues at a time: reduce the load on macro base stations thus reduce energy consumption, increase network coverage even in the toughest zones such as houses, caves, etc.

In this thesis, we will propose several solutions to the previously cited challenges: energy efficiency, spectrum sharing and security.

1.2 Contributions

This thesis work focuses on studying and developing solutions for the following femtocell networks challenges: energy efficiency, spectrum sharing and security.

The key contributions of the thesis are summarized as follows:

- **New energy efficient handover decision algorithm:**

Our first contribution is based on a new handover decision algorithm that aims to reduce the energy consumed by femtocell/macrocell networks by prohibiting unwanted handovers and introducing new femtocell energy states: idle, active-minimal, active-average and active-maximal.

- **Spectrum sharing handover decision algorithm:**

The objective of this contribution is to improve the spectrum sharing through new decision making algorithm that will optimize spectrum usage and reduce the number of unnecessary Handovers. The proposed solution aims to reduce the expected transmission time within the dwell time of Secondary User (SU) in the coverage of a Femtocell.

- **Best relay selection algorithm:**

We propose a best relay selection based cooperative scheme that maximizes the secrecy rate and the QoS at the destination. The best relay is chosen over two steps. In the first step, a sub-group of relays verifying a quality condition on the link between them and the eavesdropper is first chosen. In the second step, the relay among the selected sub-group that has the best link to the destination is selected as the best one.

The work presented in this thesis has led to the following publications:

Journal paper:

- **S. Bouallegue**, K. Sethom and G.Pujolle, "Spectrum Mobility Management in Cognitive Two-Tier Networks", Submitted May 2015, Elsevier Computer Communications.

Conference papers:

1. **S. Bouallegue**, K. Sethom and G.Pujolle, "Power optimization in two-tier networks", *I4CT 2015*, Malaysia.
2. **S. Bouallegue**, M. O. Hasna, R. Hamila and K. Sethom, "Improved relay selection for decode-and-forward cooperative wireless networks under secrecy rate maximization", *IEEE IWCMC 2014*, Cyprus.
3. **S. Bouallegue**, K. Sethom and G.Pujolle, "Energy Saving by Handoff Classification in Femtocells Network", *IEEE CCNC 2014*, Las Vegas.
4. **S. Bouallegue**, Nozha Cherif, K. Sethom and G.Pujolle, "Transparent real time service on connected train", *CCECE 2014*, Canada.
5. A. Ben Salem, **S. Bouallegue** and K. Sethom, "A QoS Based Resource Allocation in Femtocell Networks", *EUC 2014*, Italy.

1.3 Thesis Organization

The outline of the thesis are as follows:

Chapter 2 is a study on the communication networks state of the art. It also presents the benefits of using the femtocell technology as it is a solution for several ICT issues such as energy consumption and coverage but also it brought a set of challenges that need to be studied further.

Chapter 3 proposes an energy efficient solution which reduces energy consumed by femto-cells based on the removal of unwanted mobility events by classifying them according to their probabilistic importance in the context of BWA (Broadband Wireless Access) networks. The analytical model of the solution is derived and validated by simulation results.

In Chapter 4, a new decision making algorithm that will optimize spectrum usage and reduce the number of unnecessary Handovers is proposed. It aims to reduce the expected transmission time within the dwell time of SU in the coverage of a Femtocell. Simulation results are used to validate the analytical expressions.

A best relay selection based cooperative scheme that maximizes the secrecy rate and the QoS at the destination is proposed in Chapter 5. To evaluate the performance of the proposed scheme, we derive the expressions of average secrecy rate, average outage probability, and average BER. Monte Carlo simulations are used to confirm the analytical results and the advantage of the proposed scheme when compared to related works.

Finally, a general conclusion and perspectives are drawn.

Chapter 2

State of the Art

Introduction

Communication has always been a major need for living beings. Since the first forms of primitive communication until the current era, humans have encountered the same challenges.

Indeed, when the Indian Americans started using the smoke as mean of communication between two tribes, they could not ensure that other tribes do not have access to the message they are sending. Also, burning amounts of wood to make smoke is at a cost. Finding and transporting the wood was also not an easy task. Another example in the middle ages, when civilizations used pigeons as mean of communication, the same challenges were encountered but in a different way; people could not ensure that a pigeon sent from a village to another is not intercepted by the enemy. Also hunting, feeding and teaching these birds comes at a cost.

The latest iteration of wireless standards Long Term Evolution (LTE) also known as 4G is not an exception to the previously mentioned challenges. In fact, one of the most annoying issues existing in current wireless communication is the Network Coverage.

Numerous works and improvements have been made in the base stations (BSs) technologies in order to increase their coverage and improve the signal strength even in the

worst weather conditions of urban obstacles. But that was not enough, as the problem of Shadow Zones is still persistent. These zones were, and still are, a headache for telecommunication researchers because of their hard to reach urban specifications which nearly annihilates any signal sent from/to a BS.

This is where femtocells come to the rescue. The latter are considered as a major candidate to overcome the shadow zone issues, but also a bunch of other challenges in wireless telecommunications that we will discuss about in the rest of this chapter. A femtocell is a radio equipment that is intended to be in the consumer's building (house, plant, etc.) in order to extend the operator's telecommunication network thus 'enlighten' the shadow zones.

Femtocells are considered as emerging networks that are full of potential. In fact, their existence will help telecommunication operators in various ways and also create new limitations that we will details in the following sections.

2.1 Femtocell Overview

From a technology point of view, a femtocell is not only characterized by short communication range and high throughput, but also by its ability to seamlessly interact with the traditional cellular network at all layers of the network stack, performing tasks like handovers (HOs), interference management, billing, and authentication. This necessitates substantial support by the appropriate standards bodies.

The Femto Forum is the governing body with arguably most impact onto standardization bodies. Founded in 2007, it is a not-for-profit membership organization which aims to enable and promote femtocells and femto technology worldwide. More than 70 providers of femtocell technology joined the organization, including mobile operators, telecommunication hardware and software vendors, content providers and start-ups.

It has had a major impact in various standardization bodies, such as ETSI and 3GPP.

It aims, among others, for developing a policy framework that encourages and drives the standardization of key aspects of femtocell technologies worldwide. It is active in two main areas: 1) standardization, regulation interoperability; and 2) marketing promotion of femtocell solutions across the industry and to journalists, analysts, regulators, special interest groups and standards bodies. Below are the most commonly used radio technologies.

2.1.1 GSM

The most commonly used wireless technology, GSM accounts for 85% of the current mobile market share. GSM cell sites are termed as picocells rather than femtocells because they are no auto-configuring. They require the operator to get these cell sites up and running for use.

2.1.2 UMTS

This technology is an evolution of GSM; hence it is also known as 3G. It was derived from GSM by replacing the standard GSM radio sub-system, with one based on the CDMA technique. It offers a much larger capacity as compared to GSM and also requires a lesser number of cell sites. UMTS networks are usually used in combination with GSM technologies.

2.1.3 High Speed Packet Access (HSPA)

This is an improved version of UMTS obtained by increasing coding on radio transmissions, thereby improving throughput to a large extent. They provide data rates of up to 21Mbits/sec. They work satisfactorily with UMTS equipment. However, new handsets would be required to take advantage of the high data rates provided by HSPA.

2.1.4 UMTS/CDMA2000 Femtocells

UMTS' three main embodiments (put forward by 3GPP) and cdma2000 (put forward by 3GPP2) have similar architectures and are based on CDMA. Being IMT-2000 compliant, they theoretically offer order of magnitude higher data rates than the GSM family,

although depending on the load, the user experience may not be much different.

CDMA networks are interference-limited and their performance has a fragile dependence on power control. Without accurate centralized power control, the “near far effect” causes nearby users to overwhelm the received power of farther users, since they use the same band. With femtocells, such centralized power control is nearly impossible to accomplish because the received power levels cannot be simultaneously equalized at numerous points in space. For example, an uplink macrocell mobile user may transmit at a power level that effectively disables many nearby femtocells in that band. Therefore, adding even a small number of CDMA femtocells can have a profound impact, as seen theoretically in [4].

Two straightforward solutions to this problem exist, however. The first is to go to an open access control paradigm, where each mobile simply communicates with the strongest available base station: thus, strong interferers are simply handed off and subsequently lower their power. When this is not possible, and the femtocells are closed access, the mobile can switch to another 3G band (most operators have at least two paired 5 MHz channels per market) or revert to GSM.

2.1.5 LTE Femtocells

3GPP is now focused on Long Term Evolution (i.e. LTE, formally 3GPP Release 8 onwards) and LTE-Advanced technologies (LTE-A, Release 10 onwards), while 3GPP2 activities are now essentially discontinued. WiMAX marches on, including femtocell standardization activities [5], but its impact in developed markets figures to be small.

The physical and MAC layer impact of femtocells on LTE and WiMAX are quite similar, due to their comparable physical and MAC layer designs, which are based on orthogonal frequency division multiple access (OFDMA). Since LTE is likely to be the dominant cellular data platform for the foreseeable future, the smooth integration of femtocells into LTE is particularly important, and is the subject of a paper in the special issue [6]. A key difference in OFDMA (both LTE and WiMAX) is the large quantity of dynam-

ically allocated time and frequency slots [7]. This considerable increase in the flexibility of resource allocation is both a blessing and a curse.

Because femtocells can be allocated orthogonal resources to nearby pico and macro-cells, the possibility for fine-tuned interference management exists, whereas it did not in GSM or CDMA. That is, in theory, a complex network-wide optimization could be done whereby femtocells claim just as much resources as they “need”, with the macrocells then avoiding using those time and frequency slots. And therein lies the curse: potentially a large amount of coordination is necessary.

2.2 Femtocells in E-UTRAN Architecture

Since LTE is likely to be the dominant cellular data platform for the foreseeable future, the smooth integration of femtocells into LTE is particularly important, that’s why we will focus on LTE femtocell Architecture.

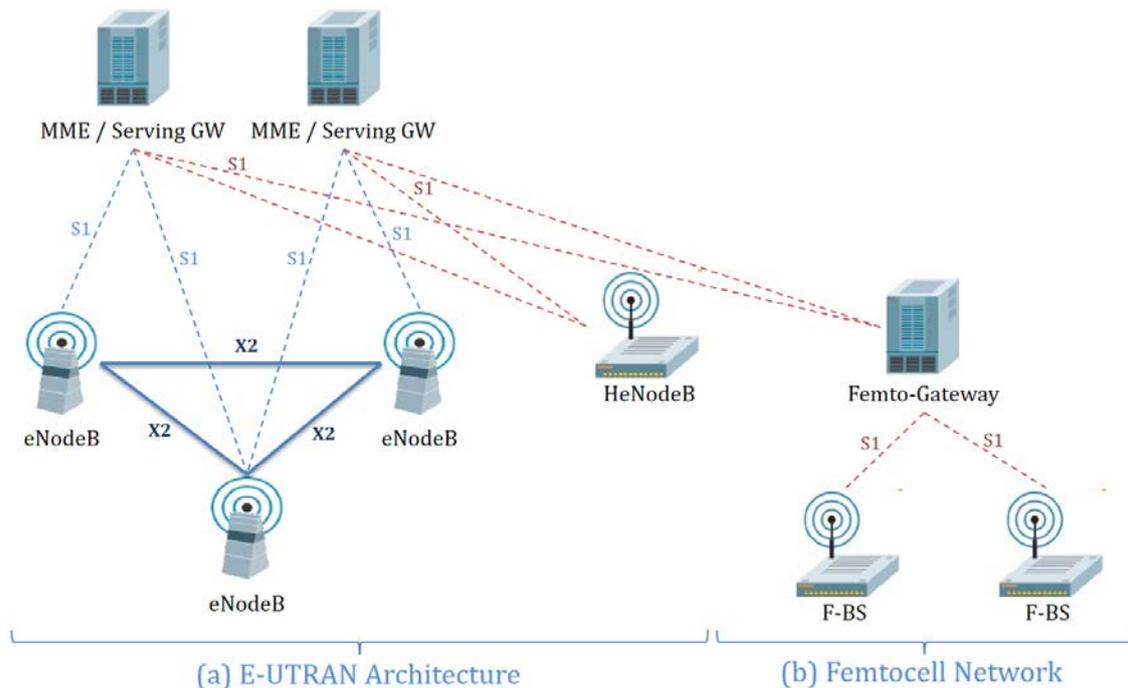


Figure 2.1: Femtocells in E-UTRAN Architecture.

A simplified E-UTRAN architecture is as shown in Figure 2.1-(a). E-UTRAN mainly consists of eNBs, providing the E-UTRA User Plane (PDCP/RLC/MAC/PHY) and con-

control plane (RRC) protocol terminations towards the User Equipment (UE). The X2 interface is used for interconnecting the eNBs with each other which is mainly used for inter-eNodeB handover purpose. The eNBs are also connected by means of the S1 interface to the Evolved Packet Core (EPC) and more specifically to the MME (Mobility Management Entity) by means of the S1-MME and to the Serving Gateway (S-GW) by means of the S1-U. The S1 interface supports a many-to-many relation between MMEs / Serving Gateways (S-GW) and eNBs. The MME handles control plane signaling, especially for mobility management and idle mode signaling. The S-GW processes the user plane data and is the local mobility anchor point.

As hundreds of thousand of femtocells are deployed, the scalability issue imposes costly reconfiguration and operation in MME/S-GW. Because femtocells use residential broadband as the backhaul to connect to the mobile core network (CN), security issue needs be considered in order to protect the integrity of the network from malicious operations. Therefore, the femtocell network needs to consider both of the problems.

Figure 2.1-(b). shows a femtocell E-UTRAN architecture where femtocell is referred to as Femto-Base Station (F-BS). An intermediate node called Femto-Gateway (Femto-GW) is proposed to be located between F-BSs and the mobile CN. It acts as a “virtual” macro eNodeB towards CN and as a “virtual” CN node towards the F-BSs. The interface between F-BS Femto-GW, and the interface between Femto GW/MME/S-GW are S1 interface, no X2 interface exists between neighboring F-BSs.

Two main functions are located in the Femto GW: Concentration/Distribution (CNT / DST) and Security Gateway (SeGW). CNT/DST is a concentrator at Transport Network Layer (TNL), i.e., the Femto GW transports many S1AP connections generated by a large number of F-BSs in single SCTP association between Femto GW and MME (SCTP is the protocol used for signaling transport). As a distributor, Femto-GW distributes messages and traffic to different F-BSs with its range. Se-GW performs F-BS and UE authentication for the access to the mobile CN. It is the end point for an IP-Sec tunnel to protect traffic in the public transport network between F-BS and Femto-GW. Femto GW also

have interface to operator's OM system for configuration and control.

Since the UMTS RNC was removed in LTE, most of the RNC functionalities are shifted to eNodeB. The introduction of Femto GW in E-UTRAN will affect the functional split. Accordingly, Femto-GW has the mobility management function, it needs also to analyze dedicated S1AP messages for routing purpose at the Radio Network Layer (RNL).

2.3 Access Control

One important classification for femtocells that strongly affects the model is the type access control. For a Closed Subscriber Group (CSG), only pre-registered mobile users (subscribers) can use a certain femtocell. This would typically be a tiny fraction of the mobile population. At the other extreme, in an Open Subscriber Group (OSG), any mobile can use any femtocell, or at least one that is "open". Naturally, hybrid approaches are possible: it reaches a compromise between the impact on the performance of subscribers and the level of access that is granted to non-subscribers.

Therefore, the sharing of femtocell resources between subscribers and non-subscribers needs to be finely tuned. Otherwise, subscribers might feel that they are paying for a service that is to be exploited by others. The impact to subscribers must thus be minimized in terms of performance or via economic advantages, e.g. reduced costs. Unlike open and closed, where the access mode is clearly defined, hybrid access offers a full range of algorithms that can be defined in order to control who accesses the femtocell and how the connection is configured.

Generally speaking, open access is a superior approach from a network capacity point of view, and from the mobile users point of view. A particular femtocell owner might expect to see degraded QoS by opening it up to all mobiles in the network, but in fact this generally does not happen, and in the CDMA uplink in particular the femtocell performance is much better even for the home user with open access, since strong interferers are handed off, mitigating the near-far problem [8]. In any case, the type of access control

is one of the key features in any cellular model that includes femtocells.

2.4 Challenges

2.4.1 Self Organization

Femtocell networks are unique in that they are largely installed by customers or private enterprises often in an ad hoc manner without traditional RF planning, site selection, deployment and maintenance by the operator. Moreover, as the number of femtocells is expected to be orders of magnitude greater than macrocells, manual network deployment and maintenance is simply not scalable in a cost-effective manner for large femtocell deployments. Femtocells must therefore support an essentially plug-and play operation, with automatic configuration and network adaptation as it's described by the figure fig 2.3. Due to these features, femtocells are sometimes referred to as a self-organizing network (SON).

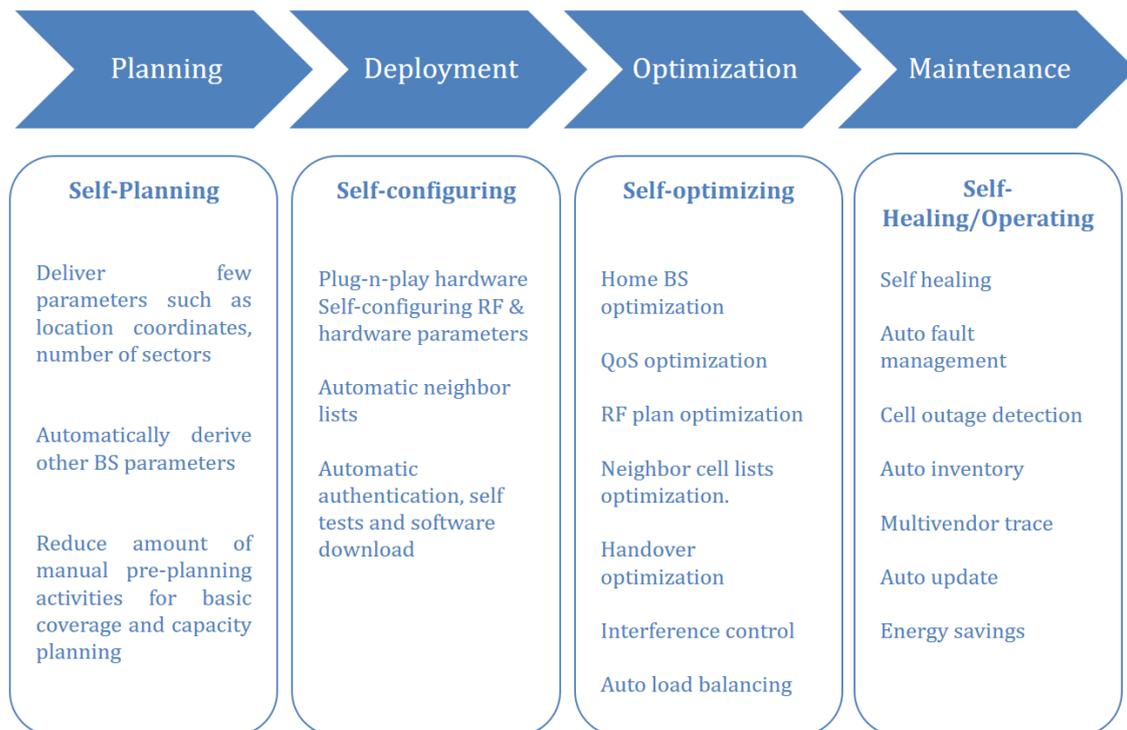


Figure 2.2: Network Life Cycle.

The 3GPP standards body has placed considerable attention on SON features [9][10][11][12] defining procedures for automatic registration and authentication of femtocells, manage-

ment and provisioning, neighbor discovery, synchronization, cell ID selection and network optimization. One aspect of SON that has attracted considerable research attention is automatic channel selection, power adjustment and frequency assignment for autonomous interference coordination and coverage optimization.

For example, a major challenge is the interference between femtocells and macro cells. Therefore, there is a need to authenticate and identify the location of the F-BSs before authorizing it to transmit in the licensed radio spectrum. The F-BSs also sniff the configuration information broadcast by the surrounding macro cells, and select appropriate physical cell IDs, location area IDs, etc. To reduce the work required from the operator side and to improve the radio quality for the FBSs users, it is also possible to involve the users more actively in the management of the FBSs.

An example of this is to use a trouble-shooting assistant similar to one that is available in computer operating systems. The radio settings can also be optimized on the basis of measurements made with the help of the users in a way that is analogous to a drive test used for optimization of macro cells. Such problems are often formulated as a mathematical optimization problems for which a number of algorithms have been considered [13][14].

2.4.2 Energy Efficiency

World's energy consumption reached a dangerous level in the last decade. Although crude oil reserves are limited, human energy consumption is increasing everyday.

Information and communication technologies (ICT) represents 2% of the world's CO_2 emissions. The same amount as the global air transport. Wireless networks and land lines represents 24% of the ICT emissions [15]. These numbers urged telecommunication researchers to multiply their efforts and focus on finding ways to reduce ICT energy consumption.

Femtocells, by their local nature, are intended to be on-site. In other words, the lo-

cation of these devices are the telecommunication operators consumers' building. Users will connect to their femtocells because of the signal strength they offer which allows energy gain in multiple ways:

- The user equipment will use less energy to connect to a femtocell than to connect to a macro BS
- The load on the macro BS will be reduced, thus a decrease in its energy consumption
- The femtocell device consumption is intended to be minimal since it is a DSL box extended with an antenna.

Telecommunication operators will see their electricity bills reduced since their consumers will participate in the BS load reduction and pay their femtocells electricity bills.

Of course, as for any technology in the world, femtocells networks are not all benefits. Let's take an average residence building with 15 apartments each one equipped with a femtocell. If a moving user walks near the building, its user equipment will detect several femtocells signals and then will perform multiple handovers which will increase energy consumption of both devices (the user equipment and the femtocell).

Several previous studies have dealt with the management of mobility in femtocell networks [16–18], to ensure continuity of service to users mainly due to the spontaneous and ad hoc nature of these cells. We will briefly summarize the most interesting results. These studies have been widely developed for the case Orthogonal Frequency-Division Multiple Access (OFDMA) [19–22].

First, Moon and Cho [19] introduced a protocol for handover based on received signal strength in a context of hierarchical macro / femtocell networks. The idea is to combine the values of received signal strength from a macro BS and a target femto BS considering the asymmetry between their transmission power. By not only considering the Signal-to-noise ratio (SNR), other results also consider the speed of the User Equipment (UE) in

designing a handover protocol [20–22].

Then, Wu and al. [20] proposed a handover algorithm in the context of a macro / femtocell network, considering the received signal strength and the speed of the UE. Ulvan and al. [21] and Zhang and al. [22] have recently proposed a new algorithm for handover in the context of LTE femtocell based on the speed of the EU and the Quality of Service (QoS).

Three different ranges of velocities were considered, i.e. *low mobile state* (0 – 15 km / h), *medium mobile state* (15 – 30 km / h) and *high mobile state* (> 30 km / h). In addition, real-time traffic and non-real-time were seen as affecting the quality of service. The main purpose of the algorithms mentioned above is the establishment of handover in a transparent way to the user and to reduce latency. These algorithms consider the SNR and the UE speed for the design of protocols handover, the energy consumption of femtocells is not taken into account. This is why these mobility protocols are not energy efficient solutions.

The focus was increased on issues related to energy efficiency [23–25]. 3rd Generation Partnership Project (3GPP) TS 35.927 (release 10) [25] identified potential solutions to save energy consumed by E-UTRAN, indicating that the cell can be completely turned off during the energy saving procedure (ES). The ES procedure can be triggered in case of light traffic or no traffic.

Ashraf and al. [23, 24] have recently proposed an improved energy efficiency of a femto BS by detecting the activity of the user. The proposed energy-saving procedure is to shut down the radio transmissions and associated treatments of a femto BS, when it is not involved in an active call.

From our point of view, this method is not really efficient in terms of energy saving. Indeed, if the signal strength of the EU is just larger than a threshold power, it suffices that the UE approaches the coverage area of a femtocell to wake it up to perform a procedure handover. This can cause a recurrent change between wake up and sleep modes for

femtocell a high density macro / femtocell network.

The table 2.1 contains a comparison between the previously mentioned protocols. While the first four protocols are not energy efficient, the last one is considering green handover to reduce energy consumption.

Protocol	Moon [19]	Wu [20]	Ulvan [21]	Zhang [22]	Ashraf [23, 24]
User Velocity	No	Yes	Yes	Yes	No
Signal Strength	Yes	Yes	Yes	No	Yes
Traffic Load	No	No	No	No	No
Energy Efficiency	No	No	No	No	Yes

Table 2.1: Comparative table of handover algorithms.

2.4.3 Interference Management

Frequency planning in femtocell networks is very crucial. Without precise spectrum allocation for the femtocell network could suffer from severe interference problems. When dealing with a two tier network, two types of interference need to be addressed: co-layer and cross-layer interference.

2.4.3.1 Co-layer Interference

Co-layer interference happens between two adjacent femtocells when no sufficient isolation is presented, hence the quality of communication decreases. This is obvious, in particular, between houses and apartments close to each other. This problem occurs because femtocell access points (FAPs) are deployed in a distributed manner according to the users' interest, which is not the case in macrocell BSs.

2.4.3.2 Cross-layer Interference

On the other hand, Cross-layer interference arises between a macrocell and a femtocell base station, especially when sharing the same frequency band.

Generally, two frequency planning schemes are specified; co-channel and orthogonal frequency planning schemes.

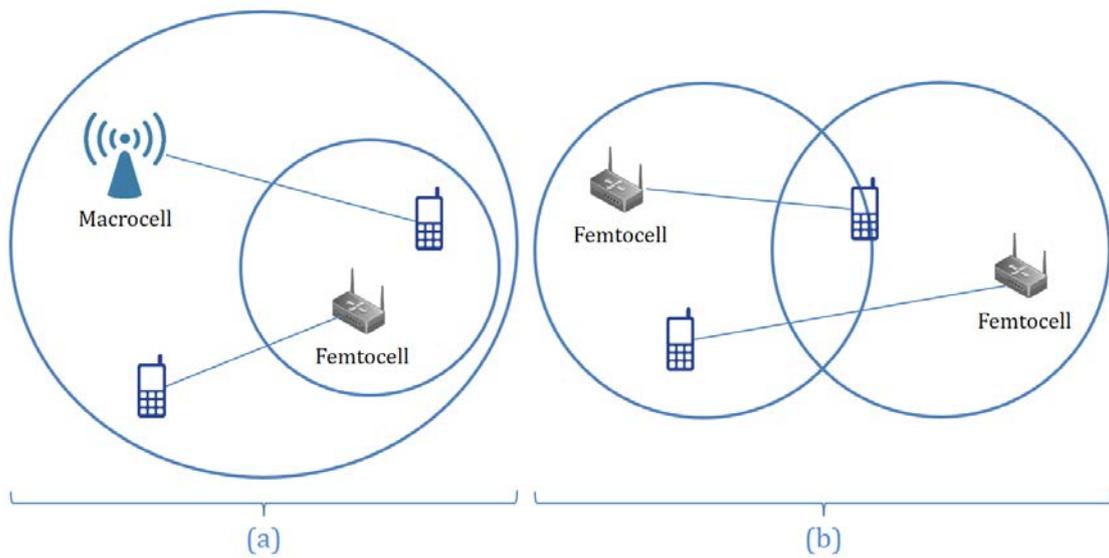


Figure 2.3: Interference in Femtocell Network.

2.4.3.2.1 Orthogonal frequency planning scheme This scheme provides completely separated frequencies to both femtocells and macrocells as in Figure 2.3 . This scheme avoids any co-channel interference; however, it might not be an option for many operators due to additional cost of extra spectrum.

2.4.3.2.2 Co-channel frequency planning scheme In this scheme, full frequency bandwidth of the total system bandwidth is allocated to the macrocell base station (MBS). Part of this bandwidth (BW) is shared with the bandwidth of the femtocell as in Figure 2.3 . In this case, femtocells and macrocells might cause interference to each other depending on their transmitting powers.

2.4.4 Interference management techniques classification

Precise characterizations of the interference conditions in such heterogeneous and multi-tier networks have been the subject of extensive study [26], [27]. One of the important and perhaps surprising results shown in [28] is that in principle, with open access and strongest cell selection, heterogeneous, multi-tier deployments do not worsen the overall interference conditions or even change the SINR statistics. This “invariance property” has

also been observed in real-world systems by Nokia Siemens [29] and Qualcomm [30], and provides optimism that femtocell deployments need not compromise the integrity of the existing macrocell network.

Recognizing these challenges, standards bodies have initiated several study efforts on femtocell interference management including those by the Femto Forum [31] and 3GPP [32], [33]. 4G LTE femtocells offer more tools for interference coordination including backhaul-based coordination, dynamic orthogonalization, subband scheduling, and adaptive fractional frequency reuse. How to best exploit these techniques is an active area of research, [34]–[35]. According to their self-organizing capability, two basic schemes can be used for dynamic resource partitioning in femtocells network: centralized or distributed. In a centralized approach as in [36][37], sub-bands are assigned to the macro BS and femtocells by means of a central controller, which generally achieves more efficient resource utilization, at the expense of higher complexity and signaling overhead. From the overall performance point of view, the networks with centralized control can achieve better performance than that with distributed control. However, the distributed control avoids the bottleneck effect of a centralized control entity, which is quite advantageous from the implementation point of view. Some examples of such approach are given here-after.

2.4.4.1 Power Management

Power control methods generally focus on reducing transmission power of F-BSs for crosstier interference mitigation. These methods are advantageous in that the macro-BSs and F-BSs can use the entire bandwidth with interference coordination. Dynamic or adjustable power setting, which is preferred over fixed femtocells power setting. This can be performed either in proactive or in reactive manner or in hybrid mode where the femtocell switches between the two modes according to the operation scenarios [38]. Game theoretic (GT) models were used to design and analyze distributed power control methods in a heterogeneous cellular wireless network with macrocells and femtocells [39][40]. This strategy is also considered the dominant method for interference coordination for 3G CDMA femtocells network [33]–[41].

Adjusting transmit power with the use of universal frequency reuse can be applied to the mitigation of Inter-Femtocell-Interference IFI when femtocells are deployed in a systematic way with low density [42]. However, when multiple femtocells are densely deployed in a building environment, they are more likely to interfere with each other.

2.4.4.2 Cross-tier Resource Partitioning

The basic mechanism of this method divides the entire frequency spectrum into several sub-bands [43]. Afterwards, each sub-band is differently assigned to each macrocell or femtocells. Since the resource for the macro and Femto-BS is not overlapped, interference between them can be mitigated. S. Huan et al, in [44] in order to solve interference problem in the OFDMA-based femtocell network had introduced the use of a spectrum splitting which was done by assigning a subset of orthogonal subcarriers to the FAPs. However, to ensure the subcarrier orthogonality, hence, not interfering with the existing macro users, the signals from the strongest FAPs should be synchronous with the desired macro signal, otherwise an intercarrier interference (ICI) and a potential multiple access interference (MAI) will influence the users' performance.

In [45] a Clustering Algorithm (CFCA) is proposed for OFMDA Femtocell and Macrocell Overlaid System FMOS. The entire frequency bandwidth is divided into two bands: the FMOS reuse band and the macrocell dedicated band. Ratios of these two bands are determined by the proposed clustering algorithm. Frequency reuse among femtocells takes cluster as a unit. To mitigate the cross-tier and the same-tier interference and realize co-channel reuse, the optimal clustering problem in terms of interference mitigation is constructed, and an Adaptive Clustering Heuristic Algorithm (ACHA) is proposed to solve the optimal clustering problem based on the graph method. Simulation results show that high spectrum efficiency is achieved and probability of cross-tier spectrum reuse is higher than 97.4%.

Therefore, the above limitation of the partitioning concept has become an obstacle in attaining high channel efficiency and motivated the development of the Fractional Frequency Reuse scheme.

2.4.4.3 Flexible Re-use Partitioning scheme

From a cell point of view, Flexible Re-use Partitioning (FRP) is a method which implements different re-use zones per cell i.e. which divides the cell coverage area into concentric zones with different re-use factors based on the received Broadcast Channel (BCH) level. A “cell” is recognized by its BCH geographical coverage area. The inner zone in each cell is re-use 1 zone and therefore will be exempted from resource partitioning restrictions. The simplest yet promising form of implementing FRP is to divide the cell into inner (re-use 1) and outer (e.g. re-use 3) zones. At network planning stage, re-use resources are defined and set for the outer zones in the individual cells. This is a one-time process to make the base stations aware of their partitions per zone before hand and there are no further updates or signalling required in that sense. UEs in each zone will be identified, grouped, and scheduled accordingly. Load balancing can take place by mutual negotiations between base stations. In [46], the authors propose a frequency sharing mechanism that uses frequency reuse coupled with pilot sensing to reduce cross-tier/co-channel interference between macrocell and femtocells. In this scheme, FFR of 3 or above is applied to the macrocell. When a F-BS is turned on, it senses the pilot signals from the macro and discards the sub-band with the largest received signal power, and thus uses the rest of the frequency sub-bands resulting in an increased SINR for MUEs. In [47] a semi-dynamic inter-cell interference coordination (ICIC) scheme for multi-cell OFDMA systems is proposed. The objective of this scheme is to strike a balance between ICI minimization and frequency reuse factor (FRF) maximization. Non-overlapping Cell-edge user groups are formed based on users’ geometry, then a bandwidth allocation strategy is applied, which includes both orthogonal resource and non-orthogonal resource, into several ranks according to traffic load in neighboring groups.

In [48], an adaptive scheme is presented to minimize downlink interference caused by the FBSs in the vicinities of a macrocell. The proposed scheme adopts frequency re-use radio resource hopping or orthogonal FFR radio resource allocation based on the density (e.g., high or low) and location information (e.g., inner region or outer region) of the F-BSs. The location information of the F-BSs may be obtained and maintained within the network through using registered physical address associated with the broadband IP

(Internet Protocol) address that a F-BSs uses. The proposed scheme only deals with the cross-tier interference posed by the femtocells located (inner region) near the M-BS. If the F-BS is situated in a high dense inner region, then orthogonal sub-channels are adopted by the F-BSs. Otherwise, the F-BS selects a sub-channel arbitrarily, utilizes it for a certain period of time, and then hops to other subchannels. The proposed scheme reduces downlink cross-tier interference.

However the schemes described above use a fixed partitioning, which would cause a loss in throughput performance due to inefficient use of the bandwidth resources. A dynamic partitioning scheme (in both time and frequency domain) can be used for bandwidth sharing which minimizes cross-tier and co-tier interference.

As a result, a radio resource management scheme for each femto-network shall be able to “autonomously” utilize the radio resources not occupied by the Macro-network so as to mitigate interference while providing QoS guarantees. Cognitive approach seems to be a good alternative for self-configuration and self-organization strategy.

2.4.4.4 Cognitive Approach

Cognitive Radio (CR) presents itself as a set of concepts and technologies that enable radio equipments to have the autonomy and the cognitive abilities to become aware of their environment as well as of their own operational abilities. Thus it is a device that has the ability to collect information by sensing and that can use the past observations on its surrounding environment, in order to improve its behavior consequently. Therefore the equipment adapts its behavior to the local context. Cognitive radio approach based on distributed spectrum sensing can be used for interference mitigation in femtocell networks. With different levels of cognitive capabilities, Femto-BS adopts different allocation approaches [49] to achieve different levels of spatial reuse. Different interference avoidance schemes based on CR have been suggested in the literature [50–69]. Below are some of the most cited ones.

2.4.4.4.1 Frequency scheduling scheme: Frequency scheduling scheme is specially considered as Inter-cell interference mitigation by means of a cost/Utility function (CF/UF).

The allocation of UEs to resources is done by the scheduler that takes into consideration QoS of the service, channel quality of the UEs (interference, path-loss) and data rate achieved by the UEs so far. This scheduler evaluates a cost/utility function for all eligible combinations of users and resources. The combinations leading to (a minimum cost / a maximum utility) function value are scheduled for transmission.

In [67], an interference handling method from close-by macrocell mobile stations is proposed. It is required to handle the received interference by avoiding the use of their frequency resources at the femtocell network and utilized the spectrum resources efficiently. This scheme utilizes the result of spectrum sensing in terms of energy detection with respect to the distance as availability of scheduling information. In [68] authors propose an interference-aware (IA) scheduling algorithm where scheduling decisions are made based on system performance maximization instead of intracell performance maximization. The proposed scheduler is structurally related to the non-interference aware Proportional Fair (PF) scheduler. They propose a signaling framework for TDD systems that enables distributed IA scheduling. In which, the receivers transmit a small broadcast interference report after reception of data, which allows other transmitters to become active on the corresponding resources only in the case when it is beneficial for the overall system performance. They sketch the signaling implementation and characterize the overhead caused. The performance of IA scheduler are evaluated in numerical examples, it's also compared to both PF scheduler and the global optimum transmission schedule obtained by a centralized scheduler having full system-wide information. In [69], authors formulate the resource allocation problem as a utility optimization and develop a distributed algorithm for joint power control and user scheduling in response to channel conditions.

In [55], authors design and implement one of the first resource management systems, FERMI, for OFDMA-based femtocell networks. As part of its design, FERMI (i) provides resource isolation in the frequency domain (as opposed to time) to leverage power pooling across cells to improve capacity; (ii) uses measurement-driven triggers to intelligently distinguish clients that require just link adaptation from those that require resource

isolation; (iii) incorporates mechanisms that enable the joint scheduling of both types of clients in the same frame; and (iv) employs efficient, scalable algorithms to determine a fair resource allocation across the entire network with high utilization.

It should also be mentioned that a tight interplay exists between the scheduler and the transmit power restriction schemes themselves. A first attempt to define scheduling policies prioritizing the cell-edge UEs into the sub-bands with lower interference levels has shown the interest of this approach. Further studies should consequently investigate this interplay deeper in order to reveal the full potential of this kind of resource management techniques. Moreover, the impact of adaptive transmit power on their performance should be further addressed as well. Furthermore a cost based scheduler algorithm with self-adaptive weight settings is recommended in order to maximize the total system throughput and keep at the same time the percentage of unsatisfied users below the predefined limit.

2.4.4.4.2 Q-LEARNING schemes: Due to the fact that femtocells are non-cooperative with no mutual communication/ coordination, femtocells need to self-organize by gradually learning from their environment (through trials and errors), and adapt their strategy until reaching convergence. Existing research on Reinforcement-Learning (RL) [58] and heuristic issue have been carried out in cognitive radio networks (e.g., see [58, 61–63]). In [62], the authors focused on the resource competition in a spectrum auction system, where the channel allocation is determined by the spectrum regulator. In [62], a distributed opportunistic spectrum access for cognitive radio using correlated equilibrium and no-regret learning was studied in which mutual communication among secondary users is assumed. Therefore, a Q-learning based algorithm was investigated in [57] and [61] in the context of network selection for heterogeneous wireless networks, and channel selection in multi-user cognitive radios, respectively. Due to the fact that there is no mutual communication among different femtocells, many traditional learning techniques (e.g., fictitious play, Nash-Q learning, and evolutionary games [60]) cannot be used since they need information to be exchanged among players (e.g., exchanging their action and payoff information).

In [58] A distributed Q-learning algorithm is proposed in which each Base Station (FBS) gradually learns (by interacting with its local environment) through trials and errors, and adapt the channel selection strategy until reaching convergence. The proposed Q-learning algorithm is cast into high level and low level sub-problems, in which the former finds in a decentralized way the channel allocation through Q-learning, while the latter computes the optimal power allocation. In [64] a multi-agent learning approach is examined, based on distributed Qlearning, where femtocell base stations control their transmit power, such that the femtocell capacity is maximized, while the aggregated downlink interference generated at macro users receivers is maintained within acceptable limits. The distributed Q-learning algorithm is carried out at the femto nodes, in the way that the interference is controlled at each resource block. It consists to integrate multi-user scheduling in the operation of the macrocell network, so that instantaneous changes, with 1 ms granularity, are encountered in the perception that the femtocell agents get of the environment under observation. In [65], authors furthered the study by introducing the concept of logit equilibrium (LE) and present its interpretation in terms of the trade-off faced by femtocells when experimenting several actions to discover the network, and taking the action to maximize their instantaneous performance. the algorithm proposed relies on the observations of the signal to interference plus noise ratio (SINR) of all active communications in both macro and femtocells when they are fed back to the corresponding base stations. Based on such observations, femto base stations learn the probability distributions over the feasible transmit configurations (frequency band and power levels) such that a minimum time-average SINR can be guaranteed in the macrocells, at the equilibrium.

Even as cognition and learning have received a considerable attention from various communities in the past, the process of knowledge transfer, i.e., teaching over the wireless medium has received fairly little attention to date. indeed, when multiple femtocells are densely deployed in a building environment, the network is no longer stationary, since it consists of other nodes who are similarly adapting dynamically. This may generate oscillating behaviors that not always reach an equilibrium and that are not yet fully understood, even by machine learning experts. The dynamics of learning may thus be long and complex in terms of required operations and memory, with complexity increasing

with an increasing observation space. A possible solution to mitigate this problem, to speed up the learning process and to create rules for unseen situations, is to facilitate expert knowledge exchange among learners.

2.4.5 Security

Securing transmissions is one of the biggest concerns in wireless communications since their broadcast nature allows illegitimate users to receive a copy of the transmitted signal.

Shannon's pioneering work [70] inspired some approaches based on cryptography that tries to make it more difficult for illegitimate users to decode the received signal. But cryptography started to show its limitations in the last decade due to the fact that it is mostly based on calculation power which is growing exponentially. In fact, a code that was seen unbreakable in the 70's and took years to find the key, can be now easily broken and its key found in minutes or even seconds.

Physical layer security approaches overtake the computational power limitation since they are based on whether a positive data rate can be supported, and this is not depending on the type of the decoding method the eavesdropper uses.

These approaches have been studied in [71],[72] and [73] based on previous works in [74]. In fact, for the Gaussian channel, secrecy rate has been defined in [74] as the difference between the capacity at the legitimate receiver (destination) and that at the illegitimate receiver (eavesdropper). Also, it has been shown that this rate can be positive if the channel to the illegitimate receiver is noisier than the channel to the legitimate receiver.

The proposed Best Second Hop algorithms do not achieve the optimal security results. In fact, when sending a message from a Source (S) to a Destination (D) through a set of Relays (R), the choice of the best second hop means the choice of the best R-D channel. This does not guarantee that the channel between R^* (R^* is the relay that ensures the best second hop) and an eventual Eavesdropper (E) is weak enough to not let E intercept the transmitted message. A better relaying algorithm needs to be studied in order to ensure a better secrecy level.

Relaying techniques are used to improve the performance of relay-based wireless networks. Cognitive networks received close attention in [75]. Performance Selective

OFDMA has been studied in [76]. Switch and Examine Combining (SEC) performance was studied as a diversity scheme in [77].

2.4.6 Spectrum Sharing

The need to improve the Quality of Service (QoS) of communication in cellular networks played an important role in developing the femtocell technology. This technology has the ability to cover users with a low power, low cost and short range.

There are several research works have been published. The authors in [78] have overviewed the 3GPP LTE and the characteristic of femtocell. Their work included the description of mobility support in 3GPP LTE, the handover procedure in LTE and the deployment scenario of femtocell.

Spectrum sharing introduces a cognitive aspect to femtocells networks. In fact, the idea of multiple users sharing the same spectrum can resolve a lot of optimization and energy efficiency issues.

Every femtocell will have a Primary User (PU the owner of the box) and one or more Secondary Users (SU). The device can manage the connected users' data transmissions in an optimal way with taking into consideration the following parameters: user priority (PU has a higher priority than SU) and spectrum availability (available resource blocks and remaining data to transmit).

In [79], the author proposed a cross-layer protocol of spectrum mobility (layer2) and handover (layer3) in cognitive LTE networks. With the consideration of the minimum expected transmission time in cognitive LTE networks.

The idea is to observe the spectrum occupied ratio to predict the probability of the resource reclaiming by PUs to perform the spectrum mobility on the serving evolved Node B (eNB) or the handover procedure to the new eNB. Their goal is to calculate the minimum expected transmission time when selecting a new spectrum, where the spectrum is in serving eNB or the next eNB.

In [80] it proposed a new green handover protocol that is designed in two-tier OFDMA macrocell-femtocell networks. The green handover protocol can intelligently switch on

the radio communication and association processing or wake up from the idle mode of a femtocell. The smart decision of the wake up operation is based on the fact that the remaining data of a mobile host can be completely uploaded through the wake up Femto-cell.

A Handover decision algorithm in [81] is combined the values of received strength from a serving macrocell and target femtocell in the consideration of large asymmetry in their transmit powers in macrocell to femtocell handover scenario.

In [82], the handover procedure between the femtocell and macrocell has been proposed to be modified. A new handover algorithm based on the UE's speed and Quality of Service (QoS) is proposed. Three different velocity environments have been considered in the algorithm i.e., low speed is between 0 km/h and 15 km/h, medium speed is between 15 km/h and 30 km/h and high speed is higher than 30 km/h. In addition, the real-time and non-real-time traffics have been considered as QoS parameters.

The table 2.2 summarizes the previously studied protocols. The assessment was done on the following four aspects: *User Velocity*, *Signal Strength*, *Transmission Time* and *Energy Efficiency*.

Protocol	Yuh-Shyan [79]	Yuh-Shyan [80]	Ulvan [81]	Zhang [82]
User Velocity	No	No	No	Yes
Signal Strength	No	No	Yes	No
Transmission Time	Yes	Yes	No	No
Energy Efficiency	No	Yes	No	Yes

Table 2.2: Spectrum mobility algorithms summary.

Conclusion

Femtocell Networks are a windfall for telecommunication operators and their consumers. In fact, they come as a solution for several ICT issues such as energy consumption and coverage, but also brings its lot of challenges i.e., security and interference management. In following chapters, the challenges will be discussed and appropriate solutions proposed.

Chapter 3

Energy Saving by Handover

Classification in Femtocells Network

3.1 Introduction

A femtocell is a radio equipment connected to an ADSL line, which aims to improve the quality of the telecommunications network in customers' homes and / or in places that do not support the coverage of macro SBs (Station basis). The diameter of the cell coverage can range from 10 to 100 meters, and can be used interchangeably by its owners and other subscribers of the telecommunications operator. This solution raises several challenges, such as: management of interference, security of personal data, self-organization and especially energy consumption.

We focused our work on the issue of saving the energy consumed by femto-cells. In this paper, we introduce an energy efficient solution, to the cited issue, based on the removal of unwanted mobility events by classifying them according to their probabilistic importance in the context of BWA (Broadband Wireless Access) networks. We derived the analytical model of the solution, then we implemented simulations to validate the analytical results and we observed an agreement. The results confirm the advantage of our solution in reducing energy consumption.

In this chapter, we introduce an energy efficient solution which reduces energy consumed by femto-cells based on the removal of unwanted mobility events by classifying them according to their probabilistic importance in the context of BWA (Broadband Wire-

less Access) networks. The rest of this chapter is organized as follows: the Section 3.2 details the system model. The handover probability and consumed energy expressions of the introduced solution are derived in section 3.3 . Section 3.4 presents the simulation setup and the numerical results. Finally, conclusions are drawn in section 3.5.

3.2 System Model

3.2.1 Main Scheme

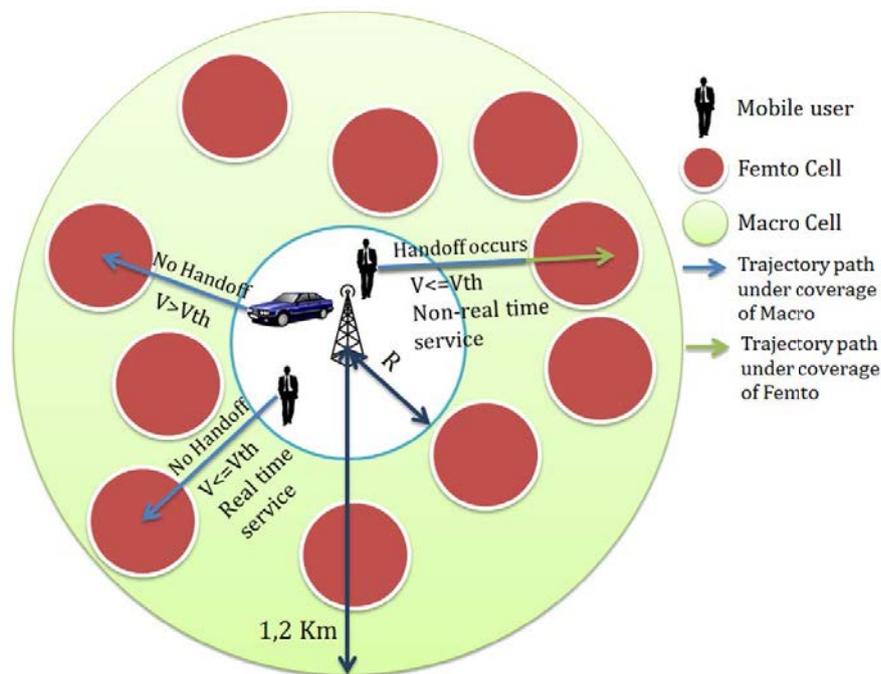


Figure 3.1: System Model.

We consider a BWA Network composed by a macro base station (BS), multiple femto BSs and user equipments (UE). The disposition of the different components is showed by the figure 3.1. The coverage radius of the macro BS is 1.2 Km . The femto BSs are disposed randomly inside the coverage of the macro BS. We assume the following:

- No femto BSs inside the coverage of radius R because the Received Signal Strength (RSS) of the UE inside this area is considered high. Mobile users are deployed randomly under the coverage of the macro BS with different velocity and undergoing varied service types.

- The femto BSs are initially considered to be in the *idle* mode with all the pilot transmissions and associated radio processing disabled. They consume a low power sniffer P_{sniff} which allows the detection of an active call originating from a UE under its coverage to the macro BS.
- When a femto BS detects an active call, it changes to *active* mode and requests the macro BS to handoff the newly originated call to it. Thus, the femto BSs are active only when any UE is undergoing an active call, which thereby enhances the energy conservation.

The possible use cases described in figure 3.1 are:

- **Case 1:** *The mobile user is moving at a high velocity.* Conventional handoff is not applied when a mobile user is moving with a very high velocity. As a user moves with a very high velocity it undergoes huge number of macro/femto handoff within a very short period of time. The overhead of the macro BS thus increases unnecessarily. We consider a velocity threshold 'Vth' of 10 Kmph. If a user's velocity 'V' is higher than Vth, unlike conventional scenario the user will not undergo handoff. Thus the unnecessary handoff is eliminated and improved QoS is guaranteed.
- **Case 2:** *The mobile user is undergoing a real-time service.* When a user is moving while undergoing a real-time connection, multiple handoffs degrades the QoS. Hence, no handoff is triggered for them in order to maintain the QoS. Thereby unnecessary handoff count decreases and improved QoS is assured to the real-time users.
- **Case 3:** *The femto BS is in active mode* We propose an algorithm for saving the energy consumed by the femto BS by counting the number of unnecessary handoffs. This algorithm is detailed in 3.2.2.

3.2.2 Power Saving Algorithm.

The figure 3.2 shows the proposed power management algorithm. The objective is to minimize the number of unwanted mobility events related to fast connection/disconnection cycle of users passing by the coverage territory of the femtocell BS.

- If the number of unwanted events is lesser of equal to a predefined threshold value ' $n1$ ' within a period ' $t1$ ', the femtocell increases its power to the value ' $P1$ ' to enlarge its coverage and resets the unwanted events counter for the new configuration.
- If the number of unwanted events is greater of equal to a predefined threshold value ' $n2$ ' within a period ' $t2$ ', the femtocell reduces its pilot power to a value ' $P2$ ' to reduce its coverage and resets the unwanted events counter for the new configuration.
- Else, the femtocell keeps its power consumption to a value ' $P3$ ' and resets the unwanted events counter for the new configuration.

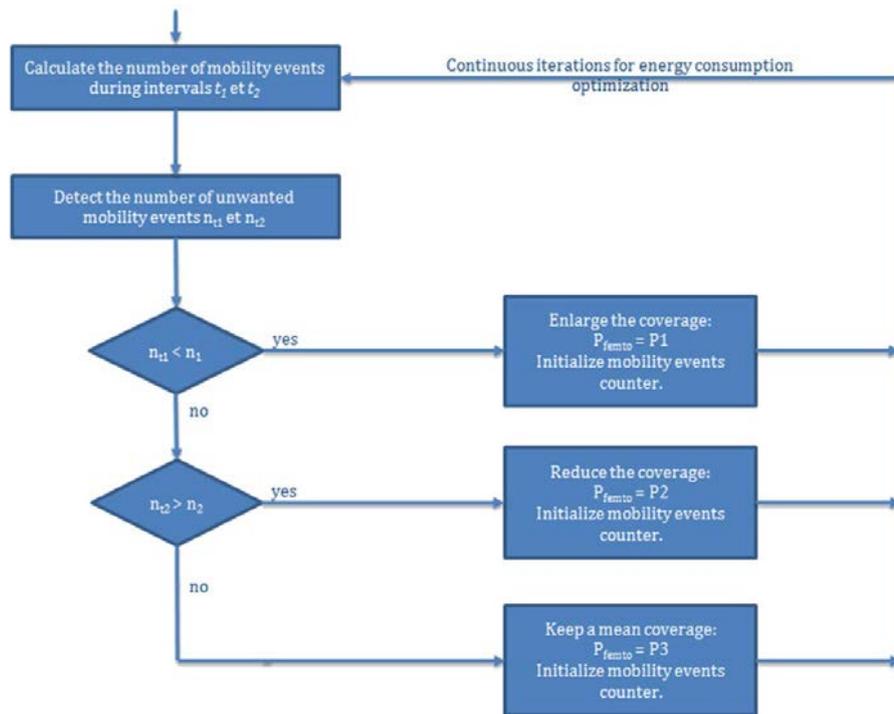


Figure 3.2: Power saving algorithm

3.3 Performance Analysis

In this section the performance of the proposed algorithm in terms of energy consumption is studied.

We consider hierarchical WiMax networks in which there are multiple femtocell BSs and only one macro BS. The latter receives the handover request directly from the user. The state of this type of networks changes upon admission or termination of a service.

Moreover, we suppose that the above mentioned type of networks can admit or terminate only one type of service at a particular moment. Thereby, the future state of the hierarchical networks depends only from the last state and not from the previous ones.

In [83], the author modeled the hierarchical networks as a continuous-time Markov chain with λ as *Pareto* distribution arrival rate and μ the dwell time which refers to the time spend by a user while connected to the femtocell in a specific state. From the model, the author could draw a state diagram from which he calculated the necessary parameters to calculate the consumed energy by a femtocell during the period of one month.

The first step was to define the speed upper bound for our proposal. Given a mobile user UE with an average speed v and traversing a two-tier network (for a distance δ), a valid handover occurs if: the time that the mobile will spend in the femtocell is long enough to compensate for the data loss due to the switching overhead. This means that:

$$v < v_{th} = \frac{\Delta (R_{femto} - R_{macro} - \rho)}{(R_{femto} - \rho) T_h}, \quad (3.1)$$

where, v_{th} is the speed upper bound, T_h is the handover delay, R_{femto} is the throughput of the femtocell and R_{macro} is the throughput of the macrocell. ρ is a hysteresis factor introduced to avoid handover when the two competing cells have negligible bandwidth difference.

Then we calculate the handover probability, 'HO_Prob', which is used to compute the probability that the femtocell is in 'active' state like shown in the equation 3.2.

$$Prob(active) = 1 - \exp(-\rho) * HO_Prob, \quad (3.2)$$

where, $\rho = \lambda/\mu$ for a specific service is called 'network load'. From 3.2, it trivial to deduce the probability (equation 3.3) that the femtocell is in 'idle' state because the author considers only two possible states: *active* or *idle*.

$$Prob(idle) = 1 - Prob(active). \quad (3.3)$$

From the equations 3.2 and 3.3, the author modeled the consumed energy of a femto-cell for a period of one month. The equation is:

$$E = (P_{Active} * Prob(active) + (P_{Sniff} + P_{Idle}) * Prob(idle)) * 3600 * 24 * 30 \quad (3.4)$$

where, P_{Active} is the energy consumed by the femtocell in the 'active' state, P_{Sniff} is the energy consumed by the 'Sniffer' which is needed to detect calls to the femtocell and P_{Idle} is the energy consumed by the femtocell at the *idle* state.

However, we can easily notice that the equation 3.4 does not take into account the adaptatif aspect of the femtocell. In fact, limiting the stated of the cell to two complimentary states does not guarantee an optimal exploitation of the resources, thus, no energy efficiency.

Our contribution consists on the introduction of new states to which the femtocell can switch:

- **Active-minimal:** The femtocell consumes the minimum of energy in order to reduce its coverage. It switches to this state when the number of unwanted mobility events exceeds the maximal threshold.
- **Active-average:** The femtocell consumes more energy to increase its coverage but it does not reach its maximum power. This state is activated when the number of unwanted mobility events is at a tolerable level (between the minimal and maximal thresholds).
- **Active-maximal:** It is the maximal consumption level. The femtocell switches to this state when the number of unwanted mobility events is lower than the minimal threshold.

As cited earlier in this section, the author in [83] calculated the handover probability from the state diagram he modeled. However, in order to implement our solution, we needed a handover probability formula that is in function of the number of users attached to the femtocell. This is why we opted for the model proposed in [84], where the author took into account the number of connected and leaving users for a given period of time.

The author made the following assumption: the dwell time of a connected user is exponentially distributed. Thus, the probability of one user leaving the femtocell during a period of time T is [84]:

$$P_{leave1} = 1 - \exp(-\mu T), \quad (3.5)$$

where, μ is the average dwell time of user connected to the femtocell.

Therefore, the probability of l users, among Z connected users, leaving the femtocell during a period of time T is described as following [84]:

$$P_{leave}(l) = (P_{leave1})^l \cdot (1 - P_{leave1})^{Z-l} \binom{Z}{l}, \quad (3.6)$$

where, the first term indicated the probability of the l first users leaving the femtocell. The second term shows the probability that the rest of the users, $Z-l$, stay connected to the same cell. The last term represents the possible combinations of l leaving users among Z connected users.

From the equation 3.6, the probability of each possible state of the femtocell could be calculated:

- **Active-minimal:** $P_{leave}(l \geq n2)$.
- **Active-average:** $P_{leave}(n1 < l < n2)$.
- **Active-maximal:** $P_{leave}(l \leq n1)$.

where, l is the number of leaving users, $n1$ and $n2$ are respectively the minimal and maximal thresholds of unwanted mobility events number that may occur to the connected users.

The probability that the femtocell is in *idle* state can be easily deduced:

$$Prob(idle) = 1 - (P_{leave}(l \geq n2) + P_{leave}(n1 < l < n2) + P_{leave}(l \leq n1)) \quad (3.7)$$

After the specification of the states to which the femtocell can switch and the calculation of the corresponding probabilities starting from 3.6, the energy consumption of a femtocell during the period of one month is inspired from 3.4 and described as following:

$$E = (P1 * P_{leave}(l \leq n1) + P2 * P_{leave}(l \geq n2) + P3 * P_{leave}(n1 < l < n2) + (P_{Sniff} + P_{Idle}) * Prob(idle)) * 3600 * 24 * 30, \quad (3.8)$$

where, l is the number of handovers during a period of time T . $P1$, $P2$ and $P3$ are respectively: the maximal power, the minimal power and the average power.

It is clear that, from the equation 3.8, our solution covers multiple states of the femto-cell which enables different thresholds of power consumption in function of the number of unwanted mobility events that occurs during a specific period of time. Thus, our proposition insures analytically a better energy efficiency than the described solution in [83].

3.4 Numerical Results

In this section, the numerical results of the implemented simulations of the solution proposed earlier in the section 3.2.2 is presented. The different figures are interpreted and conclusions drawn.

3.4.1 Simulation Setup

The table 3.4.1 resumes the parameters and values we used in order to achieve performance simulations. Common femtocellular networks parameters were used: the number of connected users is fixed to 20 and the minimal and the maximal number of unwanted mobility events thresholds are respectively 2 and 10.

3.4.2 Simulation Results

The simulations were implemented using Matlab version 7.12.1 (R2011a).

The figure 3.3 shows the handover probability in function of the number of leaving users from the femto-cell during the simulation time with $Z=20$ connected users. It is clear that when the number of leaving users increases, the handover probability increases too.

When analysing the figures 3.4 and 3.5, it is clear that our solution 'Seifeddine' produces better performance in terms of energy efficiency while taking into account the un-

Variable	Description	Value	Unit
P1	Power consumed when $l \geq n2$	0.1	mW
P2	Power consumed when $l \leq n1$	0.07	mW
P3	Power consumed when $n1 < l < n2$	0.08	mW
P_Idle	Power consumed in 'Idle' mode	0.06	mW
P_Sniff	Power consumed in 'Sniffer' mode	0.003	mW
Z	Number of connected users to a femtocell	20	N/A
n1	Minimal number of unwanted mobility events	2	N/A
n2	Maximal number of unwanted mobility events	10	N/A

Table 3.1: Simulation parameters

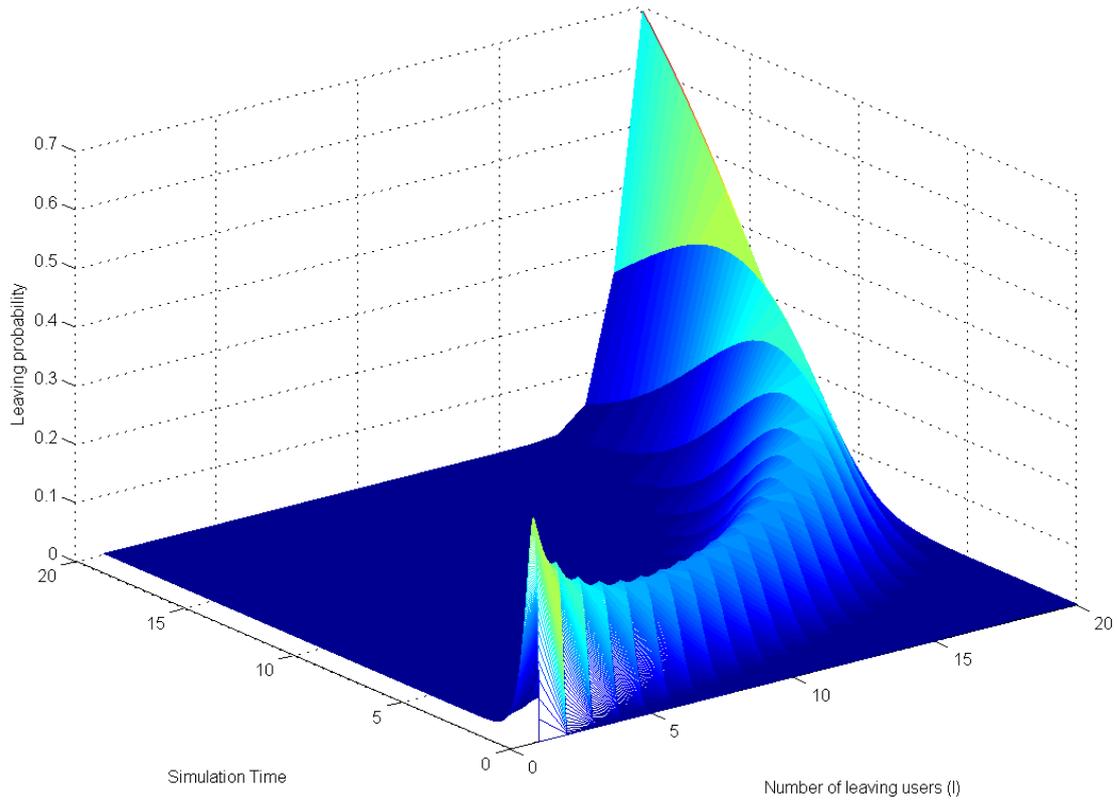


Figure 3.3: Handover probability.

wanted mobility events.

The figure 3.5 emphasizes the adaptive nature of a femtocell energy consumption. In fact, when the number of leaving users is less than or equal to $n1 = 2$, the consumed energy is equal to $P1 = 0.1mW$. When the number of leaving users is greater than or

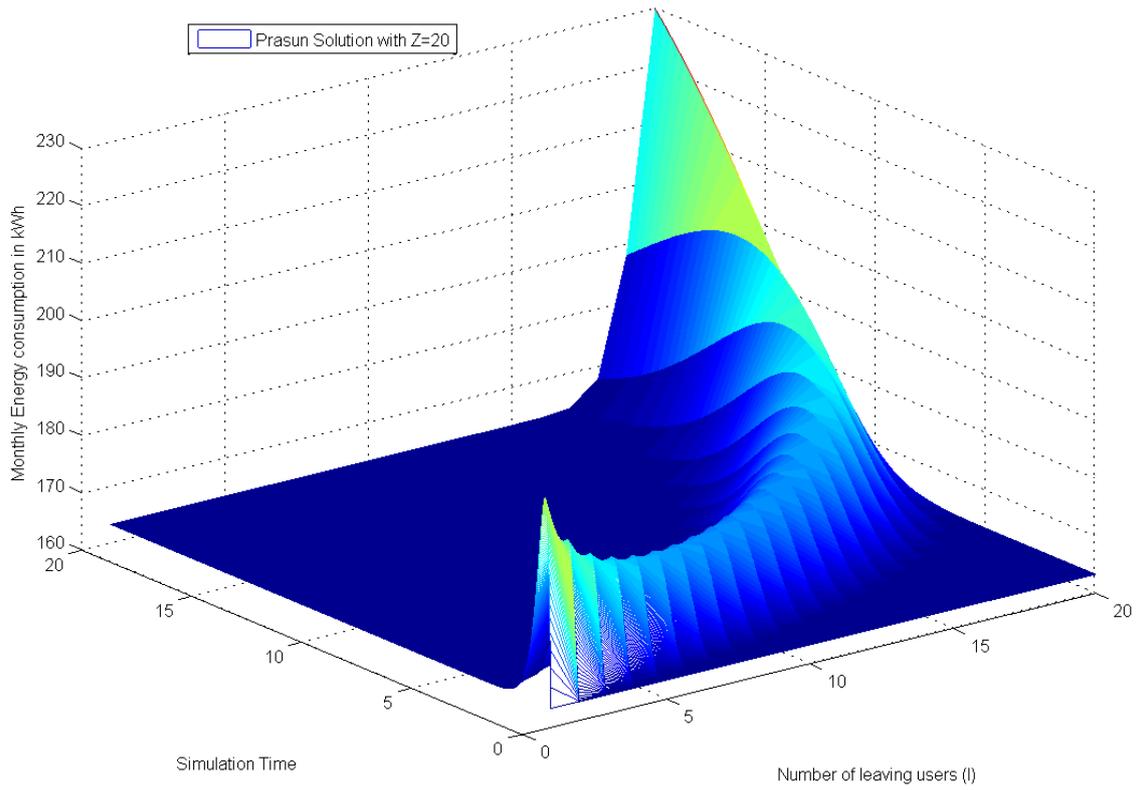


Figure 3.4: Prasun solution energy consumption[83].

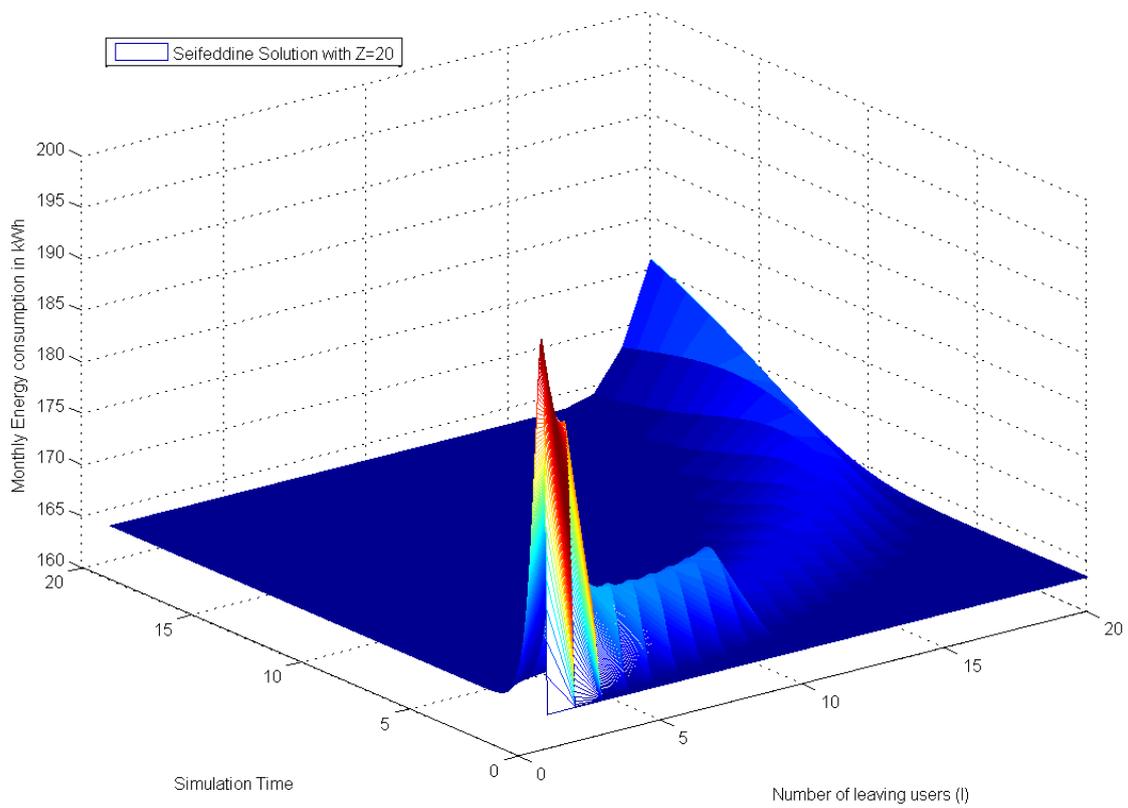


Figure 3.5: Seifeddine solution energy consumption.

equal to $n2 = 10$, the consumed energy is equal to $P2 = 0.07mW$. Else, the consumed energy is equal to $P3 = 0.08mW$.

This adaptive scheme offers a better QoS for the processing of the handovers because there is an attempt to distribute the resources optimally between users: connected and new.

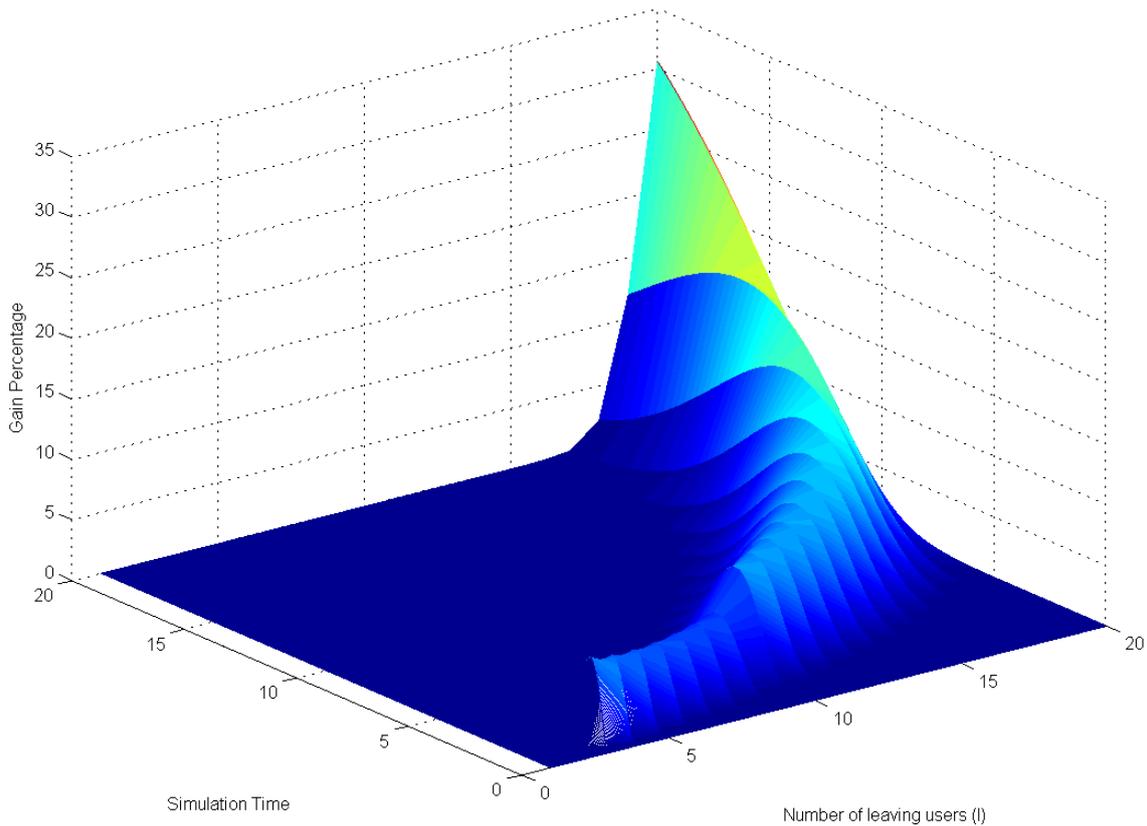


Figure 3.6: Energy gain of our solution compared to Prasu solution.

The figure 3.6 shows a considerable gain in the energy consumed by our solution compared to the Prasu solution [83] that do not adapt its energy consumption.

This gain is due to the fact that the energy consumed by the femtocell is adapted to the actual context and is decreased when the number of unwanted mobility events exceeds the predefined threshold.

The figure 3.7 shows the monthly energy gain of our solution in function of the number of femtocells. It is clear that the more the femtocells are, bigger is the energy gain.

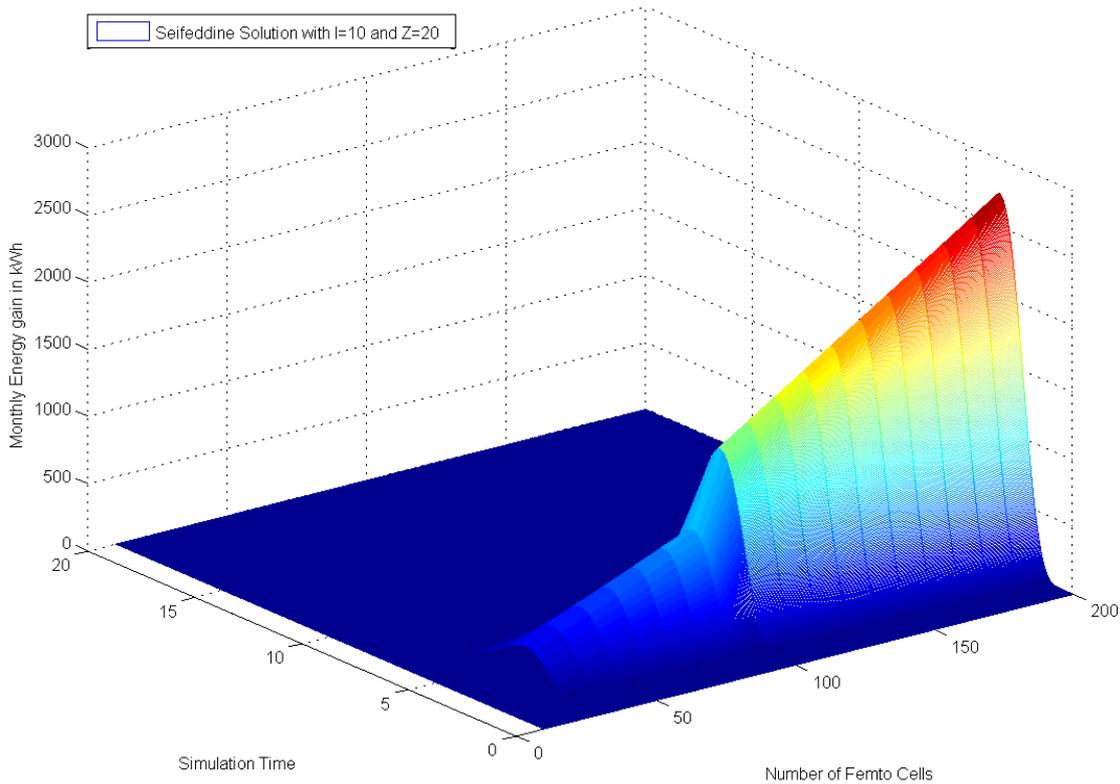


Figure 3.7: Energy gain of our solution in function of the number of femtocells.

3.5 Conclusion

The objective of this chapter was to find a way to minimize the energy consumption of femtocells in macro/femto-cellular BWA networks. After a documentation phase, we could determine where our contribution can lead us to the above mentioned objective. In fact, the handovers classification by their probabilistic importance and their nature: wanted or unwanted, allowed us to achieve a minimal gain of 5% in energy consumption compared to another solution in literature.

We elaborated the mathematical model of our solution from which we could demonstrate, with the help of the implemented simulations, that we achieved our goal by finding a way to minimize the energy consumption of femtocells.

The subject treated in this chapter is considered by specialists as one of the most sensitive topics in the field of telecommunications since it deals with energy management which is a universal problem.

Chapter 4

Spectrum Mobility Management

4.1 Introduction

Cellular networks have experienced unprecedented growth in recent years. The increase in the data usage, the emergence of new applications, the requirements in terms of Quality of Service (QoS), and the growth of bandwidth demand have led to the creation of a variety of new technology standards. The Long Term Evolution (LTE) is one of them. It is the 3.9 G or also called super 3G network proposed by the Third Generation Partnership Project (3GPP), which provides broadband not only for fixed stations but also for mobile ones [85].

In LTE networks, Femtocell have proposed as an efficient solution to provide benefits not only to operator's cellular networks but also to users. Indeed, they offer to operators an infrastructure with a low-cost and can significantly reduce energy transmission infrastructure through low power [86][87][88].

They provide a more effective coverage which allows users to move from one cell to another without a rupture of the communication. This concept is called handover, which becomes a fundamental process in cellular networks [89].

Femtocells bring also a set of challenges and difficulties which constitutes an interesting research field that can lead to new studies, such as: interference management (Inter-Femtocells but also between Femtocells and Macrocells), mobility (handover management), energy efficiency, security (the device belongs to his owner, so he can intercept its data), etc.

We have identified two types of Femtocells users: primary user (PU) who is the subscribed user (the legit owner) of the Femtocell and secondary user (SU) who is not the owner of the Femtocell. PU can access the resources of the Femtocell anytime and anywhere while SU can only access the spectrum not used by PU.

When the PU requests the radio spectrum resources used by the SU, the SU detects the request and moves immediately away the current radio spectrum resources and search another free radio spectrum resources. If it finds free radio spectrum resources, the SU will switch to them and continues the communication; Otherwise it will find neighboring Femtocell that has free radio spectrum resources and switch to it through the Handover procedure.

The key challenge of constructing a Cognitive Radio system is to detect spectrum holes and assign them to appropriate users. Therefore, besides the conventional network management functions like admission control, congestion control, and handover, a CRN must implement at least two additional functions:

- Spectrum sensing: detecting spectrum holes in the licensed spectrum bands.
- Spectrum sharing: deciding proper spectrum allocation scheme among existing PUs and SUs. This is also called the spectrum assignment.

The main contribution presented in this chapter is improving the spectrum sharing through new decision making algorithm that will optimize spectrum usage and reduce the number of unnecessary Handovers. The proposed algorithm aims to reduce the expected transmission time within the dwell time of SU in the coverage of a Femtocell.

The rest of this chapter is organized as follows; Section 4.2 overviews the system architecture and the basic ideas of the proposed scheme. Section 4.3 describes the proposed algorithm of spectrum switching and Handover. Simulations results are presented in Section 4.4. Section 4.5 concludes this paper.

4.2 Basic Ideas

4.2.1 LTE Architecture

Long Term Evolution (LTE) is the 3.9G generation cellular network that is being developed and specified by 3GPP Release 8 as very high flexible for radio interfacing. LTE

promises to provide greatest rate up to 300 *Mbps*.

LTE network architecture was designed with a focus on Macrocells, Femtocells being are latively new addition to the existing components. Figure 4.1 illustrates the relevant components of the LTE network architecture. The Serving Gateway (SGW) supports user data and provides routing and forwarding functionality between eNodeBs (eNBs) or Home e NodeBs (HeNBs) and the Packet Data Network (PDN). It also acts as the mobility anchor during Handovers between LTE and other 3GPP systems. All base stations Data Network (PDN) through the SGW for control signaling.

The Mobility Management Entity (MME) is the key control node for LTE access network. It provides the control plane function for mobility between LTE and other access networks, and is responsible for choosing the right SGW for a UE and for authenticating them.

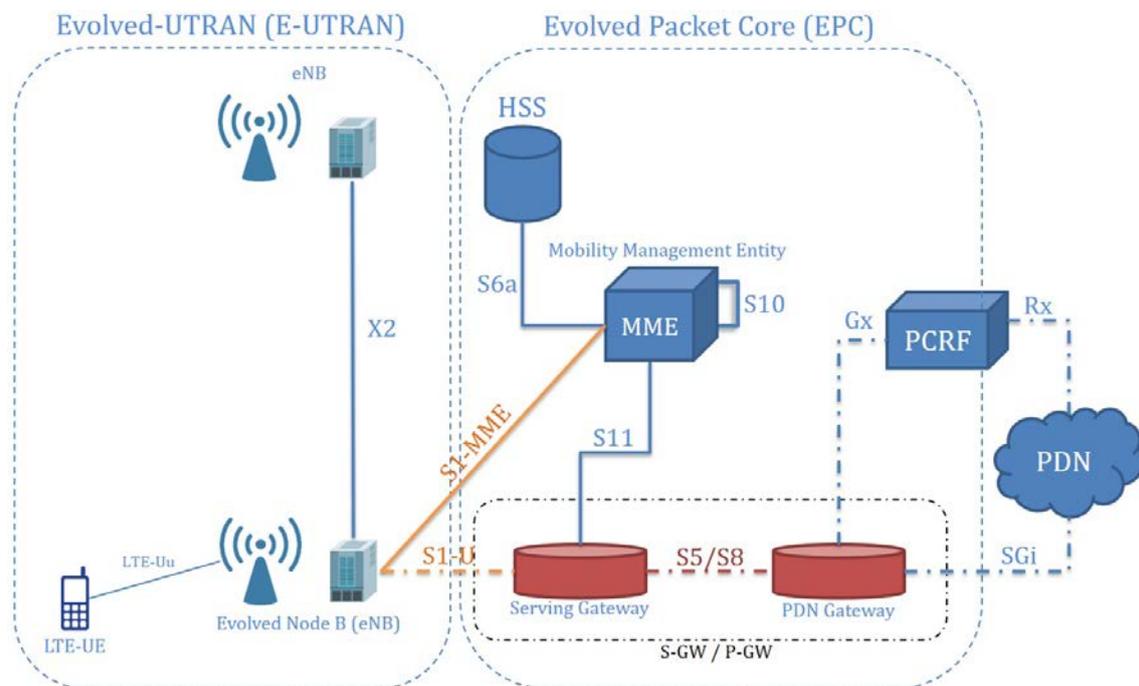


Figure 4.1: LTE Architecture.

The Femtocell concept can be applied on different cellular system it has been discussed in LTE network by the name of Home e-NodeB (HeNB). Femtocell is a small cellular base station, a low-power wireless access point designed for use in residential

environment. This technology is a promising solution for operators to improve network performance in terms of mobility, resources distribution and coverage optimization issues in cellular networks [86][89][90].

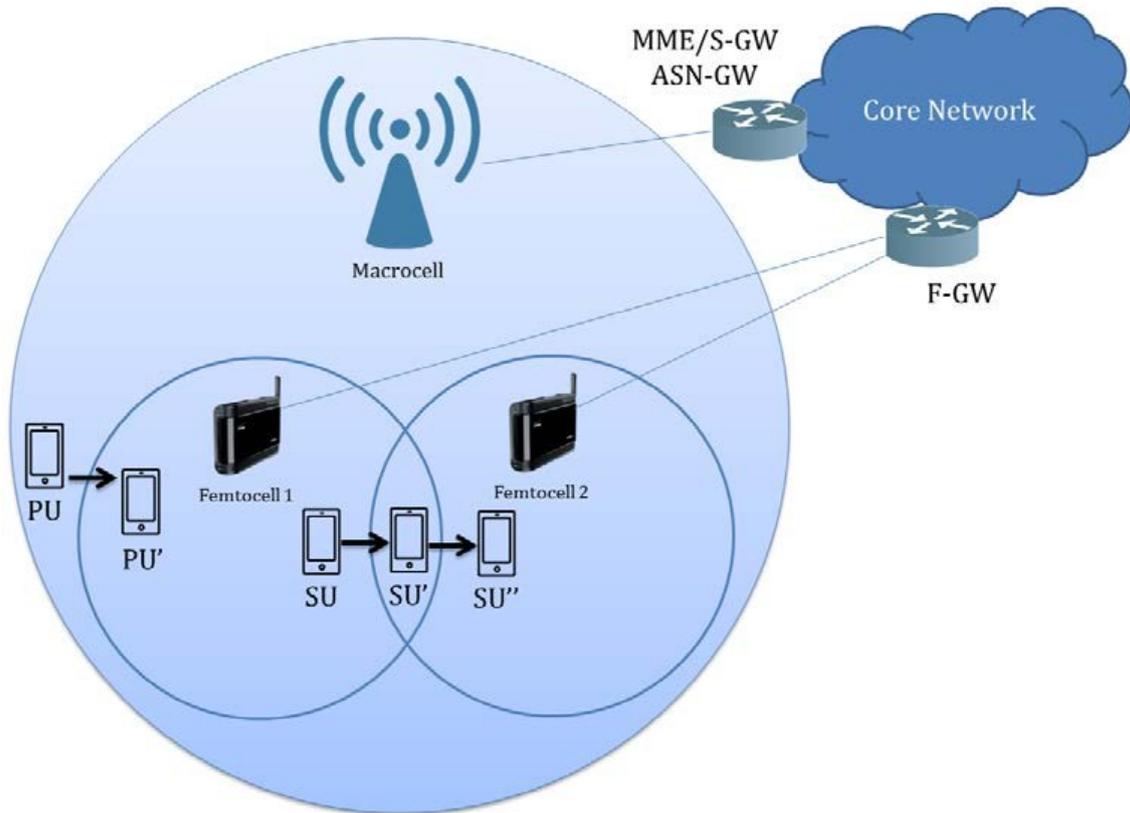


Figure 4.2: System Model.

The system model used in this paper is illustrated in Figure 4.2. There are two types of Femtocell users: Primary User or PU and Secondary User or SU. Generally, open access Femtocells will lead to a decreased performance of primary user's QoS, especially when the number of second users is too high, due to the sharing of resources and the heavy interference conditions.

Furthermore, in closed mode, it may be that the Macrocell coverage will not be sufficient to satisfy the quality of service (QoS) requirements of the secondary users. Hence, it is important that Femtocells can optimally balance their access control mechanisms. One solution is that SU can access the spectrum not used by PUs.

4.2.2 Proposition Context

Cognitive radio can improve spectrum efficiency through intelligent spectrum management technologies by allowing secondary users to temporarily access primary users' non-utilized licensed spectrum. In order to enhance spectrum management, cognitive radio systems require many capabilities such as spectrum mobility (or spectrum handover) [85].

Spectrum mobility occurs when the high-priority PUs appear at its licensed band occupied by the SUs. Spectrum mobility procedures aim to help the secondary users to vacate the occupied licensed spectrum and find suitable target channel in the same Femtocell to resume the unfinished transmission. If SU is in the overlapped area between two adjacent Femtocells, the SU can make a spectrum mobility (at layer 2) if enough resources exist or Layer 3 handover to a new Femtocell. Most of existing protocols [91] only consider the spectrum mobility issue.

The work presented in this chapter has focused on two main axes:

1. In case of no overlapping cells, the UE can only make spectrum switching to the best available spectrum hole SHi in the same Femtocell. In this case, we propose to select the best sub-channel by the SU. This sub-channel is defined as the one having the maximum SNR for the link between the Femtocell and the SU while satisfying to interference threshold for the primary users.
2. In case of overlapping cells, a choice must be done (according to some criteria) between spectrum or Femtocell handover. In case of no sufficient resource with the current Femtocell, a switching to another one is necessary.

Secondary users need to select the appropriate target Femtocell among many candidates by taking into account the amount of remaining data to transmit, the available resources of the target cell and new femto power level (with respect to green networking). In fact, most of energy consumption of the telecommunication networks is caused by the base stations. In addition, in a high density Femtocell deployment, the signaling overhead due to frequent physical handovers causes the decrease of network performance.

Following these considerations, we propose a novel handover decision algorithm in Femtocell cognitive networks.

4.2.2.1 Case of no-Overlapping: Proposed Spectrum Switching Algorithm

When SU is not in the overlapped area, SU is only attached to one Femtocell. Spectrum mobility issues arise when the primary user appears at the channels being occupied by the secondary users.

The secondary users need to return the occupied channel because the primary users have the preemptive priority to access channels. Spectrum handover techniques can help the interrupted secondary user vacate the occupied licensed channel and find a suitable target channel to resume its unfinished data transmission OFDM system has been introduced to enhance the flexibility of the CR network, where individual carriers can be switched off for occupied frequencies by the primary transmitter or for interfering sub-channels.

Two conditions can determine the existence of a spectrum opportunity: the reception at the secondary receiver being successful, and the transmission from the secondary transmitter being harmless to the primary. This means:

- The interference levels of the links between the Femtocell and the primary users have to be lower than a given interference threshold denoted by I_{th}
- In case of spectrum switching scheme, for each sub-channel where the threshold constraint is respected the sub-channel with the higher SNR is selected.

In our scheme, a set of k femtocells is defined for each sub-channel where the interference threshold constraint is respected. Among this set, in case of spectrum switching the sub-channel with the higher femto-second user SNR is selected.

In an attempt to simplify the performance analysis, the following assumptions are used:

1. The relays are assumed geographically close, so they experience the same average channel statistics.

2. Each relay gathers information about interference channel state.
3. Each sub-channel goes under frequency flat fading, and that all sub-channels are Rayleigh faded and are subject to AWGN with zero mean and variance N_0 .
4. The interference caused by the macro-cell can badly affect the overall system and leads to a transmission cancellation. In order to analyze the performance of the two tier network transmissions, we assume that the macro does not interfere with the Femtocell based on perfect spectrum sensing.

The first step is to obtain the set of sub-channels satisfying the transmission constraint. Mathematically, the probability of satisfying this constraint is given by:

$$P_\alpha = Pr(\gamma_{SU,SH_j} > \delta_{SU,SH}) = \exp \frac{-\delta_{SU,SH}}{\gamma_{SU,SH_j}}. \quad (4.1)$$

In order to average over all possible channel selection, a binomial distribution should be used which is given by:

$$\sum_{j=1}^N = \binom{N}{j} P_\alpha^j (1 - P_\alpha)^{(N-j)}, \quad (4.2)$$

where, $\binom{N}{j} = \frac{N!}{j!(N-j)!}$.

Finally, based on (4.2.1), (4.2.2), the order statistics [92], and the binomial expansion form [93], the PDF of the received SNR within this scheme is expressed as follows:

$$f_1(\gamma) = \sum_{j=1}^N \binom{N}{j} P_\alpha^j (1 - P_\alpha)^{(N-j)} \left\{ P_{NI} \sum_{i=1}^j \frac{\binom{j}{i} i (-1)^{i-1}}{\widehat{\gamma}_{SH,SU}} \exp\left(\frac{-i\gamma}{\widehat{\gamma}_{SH,SU}}\right) + \frac{P_I}{\widehat{\gamma}_{SU,PU}} \exp\left(\frac{-\gamma}{\widehat{\gamma}_{SU,PU}}\right) \right\} + \frac{(1 - P_\alpha)^N}{\gamma_{SU,PU}} \exp\left(\frac{-\gamma}{\widehat{\gamma}_{SU,PU}}\right), \quad (4.3)$$

where, $P_{NI} = 1 - \exp\left(\frac{-I_{th}}{\widehat{\gamma}_{SU,PU}}\right)$ and $P_I = 1 - P_{NI}$ are, respectively, the probability that a Femtocell is not interfering with the primary user, and the probability that a femtocell is interfering with a primary user.

4.2.2.2 Case of Overlapping: Proposed Handover Decision Algorithm

In case of overlapping networks, the SU can make a spectrum mobility following the same method as in Section 4.2.2.1 if enough resources are available in the same femto-cell. However, if this is not possible the SU has to find a new femtocell and need to make a layer 3 handover.

The question that we need to answer to is what femtocell to select and how?

4.3 Proposed Solution

This section presents our handover decision algorithm. The proposed algorithm calculates and evaluated the distance between the *SU* and the neighbor femtocell, the expected transmission time, the dwell time and the power of the neighbor femtocell.

This algorithm makes the decision to perform the spectrum mobility on the current femtocell or handover to the neighbor femtocell. The detailed flow chart of the algorithm is firstly shown in Figure 4.3.

The developed algorithm consists of two phases:

1. The first phase is sensing.
2. The second phase is making decision.

Let t_{req} denote the *SU* service required time, SH_i is the i_{th} spectrum hole, and $P_u(SH_i, t_{req})$ denote the probability of spectrum hole unoccupied by *PUs*.

Let T_{dwell} denote the Dwell Time of the *SU* that maintains the communication with the femtocell where the *SU* is in the femtocell coverage. It is the time period from the *SU* starting to communicate with the femtocell to the *SU* stopping to communicate with the femtocell, where the *SU* is in the coverage of the femtocell as shown in Figure 4.4.

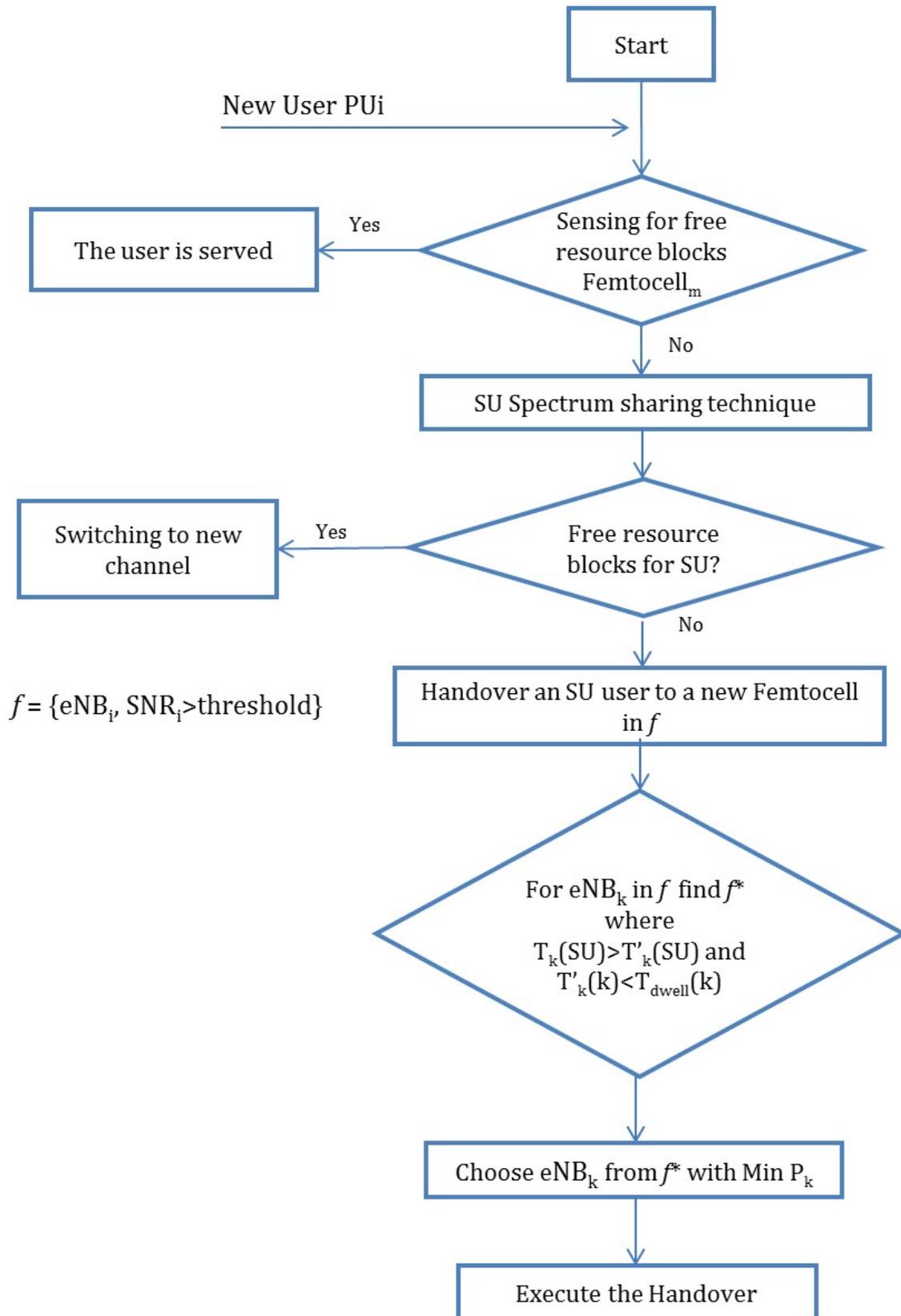


Figure 4.3: Flowchart of the Handover Decision Algorithm.

The function of T_{dwell} is determined by the variation of the signal strength and the distance between the SU and the Femtocell.

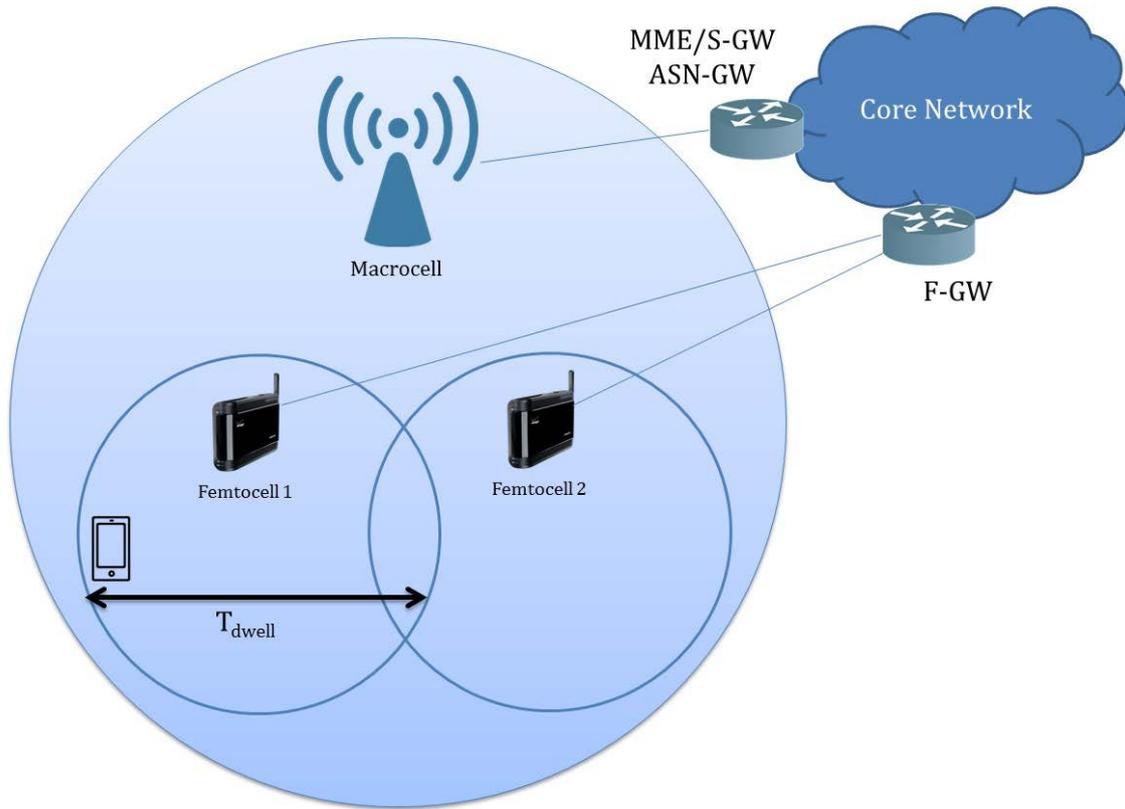


Figure 4.4: The dwell time.

Let $T_E(SH_i)$ denote the expected transmission time of the spectrum hole i (SH_i), for data service of the SU . $T_E(SH_i)$ is determined by the spectrum occupied ratio, the signal strength variation, and the available bandwidth of the spectrum hole.

The higher value of $T_E(SH_i)$ indicates that the SU can perform spectrum mobility or Handover procedure because the SU has the higher probability of resource claimed by PU_s . The smaller value of $T_E(SH_i)$ indicates that the successful data transmission is higher because there are no resources reclaimed by PU_s .

4.3.1 Sensing Phase

Each SU senses all spectrum bands RB_q in the transmission coverage of the current femtocell, where $1 \leq q \leq N$, and N is the maximum number of RB_s . So, the unoccupied adjacent RB_q form a spectrum hole SU_i , where $1 \leq i \leq j$. Therefore, we can obtain a spectrum hole sequence $(SU_1, SU_2, \dots, SU_i, \dots, SU_j)$. The information of the occupied

frequency λ_{mi} is observed and recorded for all RB_q .

Estimation and analysis allows evaluating the information that is used to calculate the distance between the SU and the neighboring femtocell, the expected transmission time $T_E(SH_i)$ and the dwell time T_{dwell} of SU in the coverage of the femtocell E . The power signal received from the current femtocell is also periodically estimated.

4.3.2 Handover Selection Criteria

Depending on the SU received signal from the current femtocell, if the received signal power is higher than the threshold value, SU can perform data transmission through the current femtocell if enough resources for the SU are available. Otherwise, SU cannot perform data transmission through the current femtocell and handover is needed.

To select the best femtocell to handover to, the system follows the rules below:

1. Select the set f of neighboring femtocells eNB_i having $SNR_{eNB_j} > SNR_{Threshold}$ (i.e. received signal at the SU is higher enough) and $d_{UE-eNB_i} > d_{UE-eNB_{current}}$ (i.e the SU is moving to that femtocell)
2. Chose from f the set f^* of femtocells having :
 - The expected transmission time $T_E(SH_i)$ for SU less than the one of the current femtocell. The smaller value of $T_E(SH_i)$ is, the higher successful data transmission will be. This is because that there is no resource reclaimed by any PU . Therefore, each SU evaluates all possible expected transmission times of the SU to determine to move to new eNB .
 - The required time to transmit through the chosen SH_i in the new femtocell must be sufficient for SU data transmission this means that: $T_E(SH_i) < T_{dwell}$

$$f^* = \{f/T'_E(SH'_i) < T_E(SH_i) \text{ , and } T'_E(SH'_i) < T_{dwell}\} , \quad (4.4)$$

3. The chosen Femtocell for handover will be the one from f^* having the minimum transmitting power to respect green vision.

4.3.3 Analytical Evaluation

The expected transmission time $T_E(SU_i)$ is calculated as follows:

1. Let SNR_{dB} represent the received signal between the SU and the current Femtocell and SNR'_{dB} represent the received signal between the SU and the neighboring Femtocell:

$$SNR_{dB} = 10 \log_{10} \left(\frac{P_{Signal}}{P_{Noise}} \right) , \text{ and } SNR'_{dB} = 10 \log_{10} \left(\frac{P'_{Signal}}{P'_{Noise}} \right) , \quad (4.5)$$

2. Let R_i denotes the transmission rate of SH_i that contains m_i RBs . So the bandwidth of SH_i is $m_i \times RB$. The required transmission time t_{req} is:

$$t_{req} = \frac{d_t}{m_i \times RB \times \log_2(1 + SNR_{dB})} , \quad (4.6)$$

where, d_t is the data size.

3. Let R'_j denotes the transmission rate of SH'_j that contains m'_j RBs . So the bandwidth of SH_i is $m_i \times RB$. The required transmission time t'_{req} is:

$$t'_{req} = \frac{d_t}{m'_j \times RB \times \log_2(1 + SNR'_{dB})} , \quad (4.7)$$

where, d_t is the data size.

4. To predict the unoccupied SH_i within a required time t_{req} , the probability of k events happened within a period time T is given by Poisson distribution : $P(k, T) = \frac{(\lambda T)^k}{k!} \exp^{-\lambda T}$, where λ is the proportion of average event happened. If the SH_i contains m_i RBs , the probability of spectrum hole SH_i unoccupied by PU_s within the time period of t_{req} will be:

$$P_u(SH_i, t_{req}) = \prod_{n=1}^{m_i} P_n(0, t_{req}) = \exp^{-\sum_{n=1}^{m_i} \lambda_n t_{req}} . \quad (4.8)$$

If the SH'_j contains m'_j RBs , the probability of spectrum hole SH'_j unoccupied by PU s within the time period of t'_{req} is:

$$P_u(SH'_j, t'_{req}) = \prod_{n=1}^{m'_j} P_n(0, t'_{req}) = \exp^{-\sum_{n=1}^{m'_j} \lambda_n t'_{req}}. \quad (4.9)$$

5. For each spectrum hole SH_i of the current Femtocell, $T_E(SH_i)$:

$$T_E(SH_i) = \frac{d_t}{P_u(SH_i, t_{req}) \times R_i} + (1 - P_u(SH_i, t_{req})) \times T_{L2H}. \quad (4.10)$$

where, T_{L2H} is designed the layer-2 switch time and $(1 - P_u(SH_i, t_{req}))$ is the probability of SH_i that is occupied within the time period t_{req} .

If no PU appears, the transmission time is $\frac{d_t}{R_i}$. So, this time will be interrupted by the appearance of PU . Therefore, the expected transmission time will be extended by $P_u(SH_i, t_{req}) \times R_i$. If the deployment of SH_i by SU_n is interrupted another time by the appearance of a PU , the SU_n can perform the spectrum mobility. This condition is introduced by $(1 - P_u(SH_i, t_{req})) \times T_{L2H}$.

6. If the SU_n is in the overlapped area between the current Femtocell and the neighboring femtocell, the SU_n must calculate also $T'_E(SH'_i)$ for the neighboring Femtocell. $T'_E(SH'_i)$ is given by the following equation:

$$T'_E(SH'_i) = \frac{d_t}{P'_u(SH'_i, t'_{req}) \times R'_j} + (1 - P'_u(SH'_i, t'_{req})) \times T_{L2H} + T_{L3H}, \quad (4.11)$$

where, T_{L3H} is denoted the layer-3 Handover time.

4.4 Simulations Results

To evaluate our algorithm, simulations were implemented using Matlab. The SU is in the overlapped area (Figure 4.5), it can perform the spectrum switching or the handover procedure following schema in Figure 5.1. The proposed scheme is compared with the

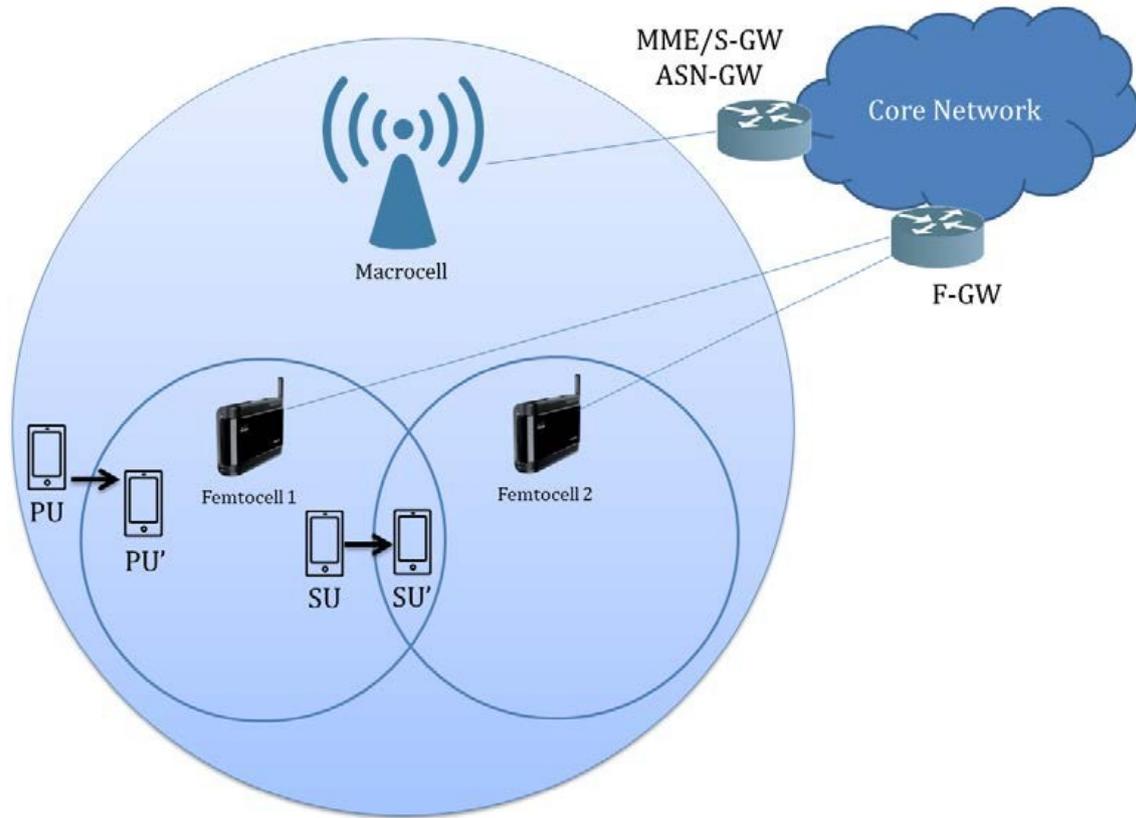


Figure 4.5: The Simulation Topology.

cross layer protocol which is only based on the minimum expected transmission time to perform the spectrum mobility or handover.

In the following, we illustrate our simulation results for the total transmission time, throughput and the power consumption. The efficient handover algorithm in the femtocell LTE network is implemented with a low transmission time, low power and high throughput.

4.4.1 Total Transmission Time

The simulation results of the total transmission time (TTT) under various data sizes and spectrum hole unoccupied ratio, P_u , for the simulation of overlapping scenario are shown in Figures 4.6, 4.7 and 4.8.

Figure 4.6 shows the TTT under various data sizes ranging from $10Mb$ to $50Mb$ where the P_u is fixed at 0.5. TTT increases with the data size, because more time is needed for more data processing. In contrast, TTT decreases when P_u increases i.e. the number of

holes increases. 4.7 illustrates the effect of TTT with various spectrum hole unoccupied ratio, P_u , ranging from 0.1 to 0.9 where the data size is fixed at $10Mb$.

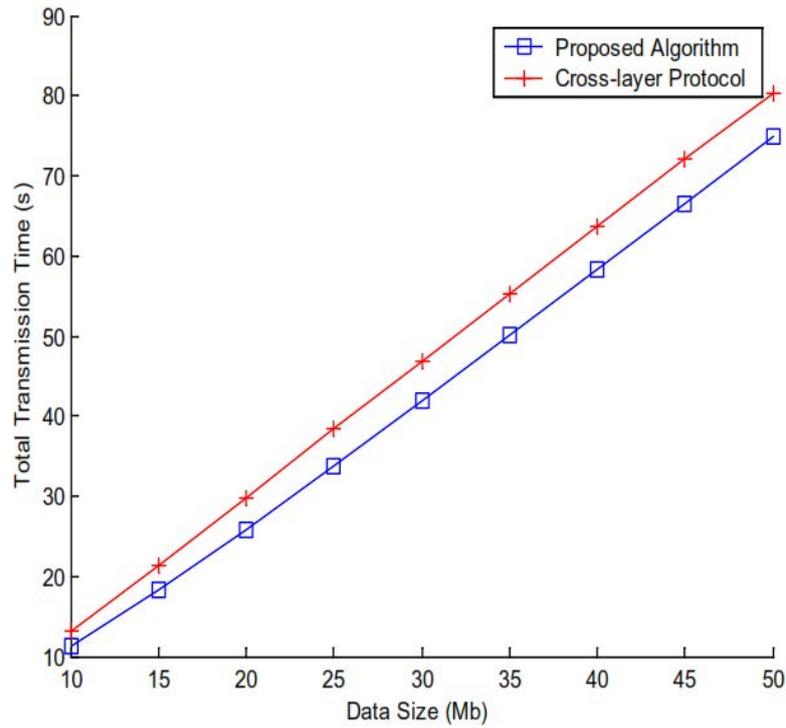


Figure 4.6: Total Transmission Time by data size.

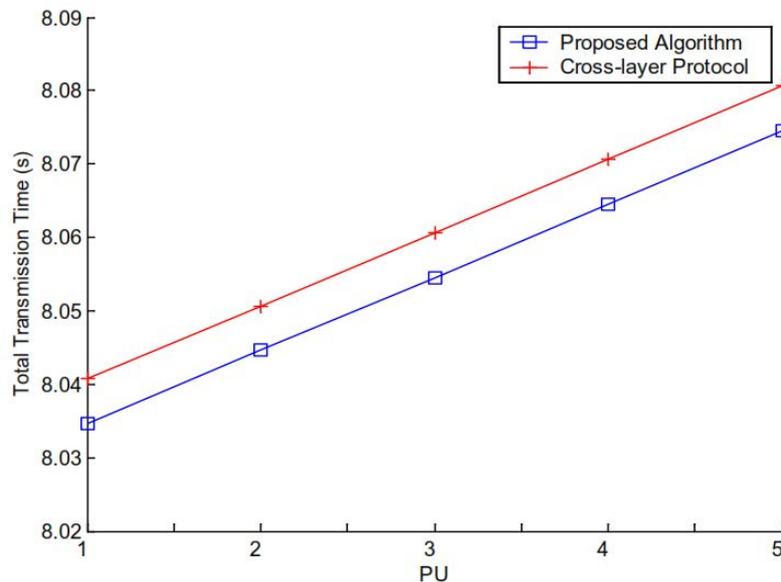


Figure 4.7: Total Transmission Time by P_u .

The great value of the P_u indicates that the SU has more opportunities to utilize the spectrum holes without interruption caused by the appearance of the PU_s ; that's why the transmission time will decrease. The main conclusion here is that our proposed algorithm

is faster in data delivery than the cross layer one. This is because our algorithm adopts a dynamic real-time procedure of spectrum resources detection.

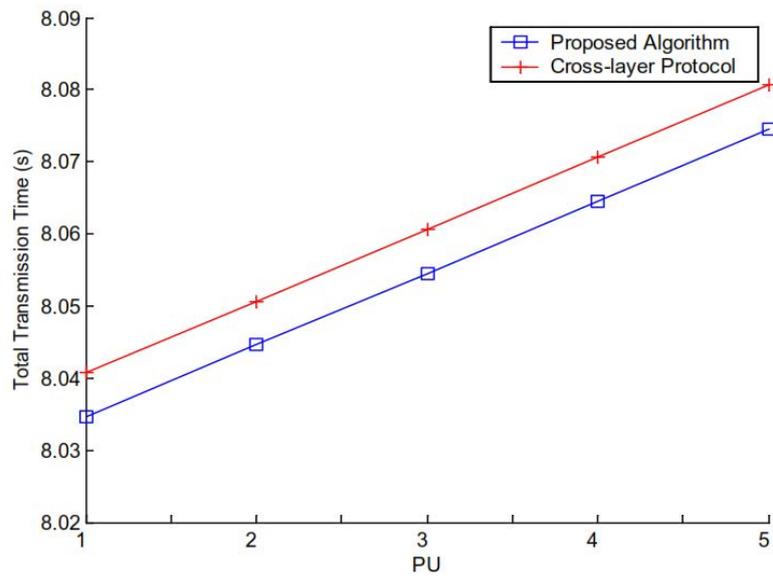


Figure 4.8: Total Transmission Time by PUs.

4.4.2 Throughput

The simulation results of the throughput under various data sizes and the spectrum holes unoccupied ratio P_u for the simulation of the first scenario are presented in Figure 4.9. Due to best total transmission time, the throughput observed by our algorithm is better than the one of the cross-layer protocol.

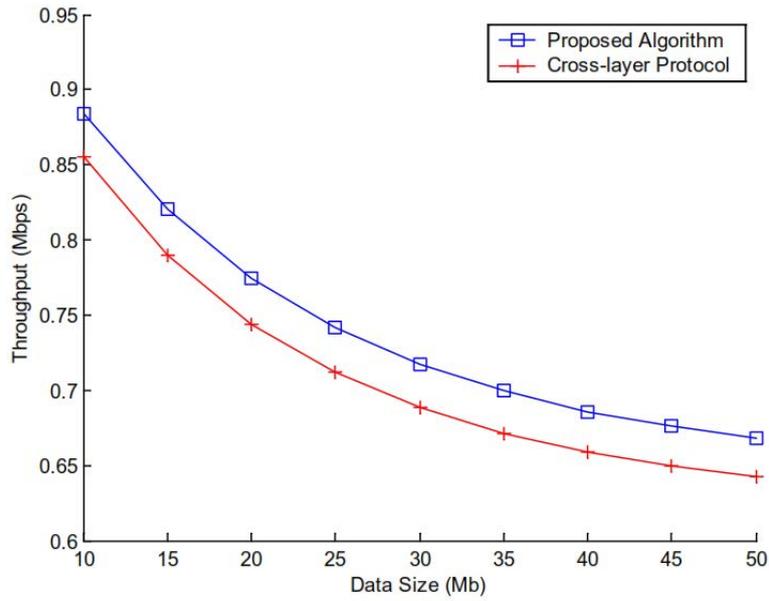


Figure 4.9: Throughput by data size.

4.5 Conclusion

In this chapter, we have proposed a decision handover algorithm in the femtocell-LTE networks. We developed a decision handover algorithm with consideration of the Poisson distribution model of spectrum mobility. This algorithm is based on the minimum expected transmission time within the dwell time of the UE in the coverage of the femtocell.

We have provided the mathematical analysis and the performance simulation to illustrate that the proposed algorithm reduces significantly the expected transmission time and the spectrum mobility ratio.

Chapter 5

Improved Relay Selection Under Secrecy Rate Maximization

5.1 Introduction

Security is one of the major concerns in Telecommunications since the first means appeared. This threat is bigger when it comes to Wireless Networks since the legitimate source, relays and destination are using a channel which is easily accessible: the air. In the femtocells network scenario and since the device is the property of the telecommunication operator's customer, there is a possibility for the latter to intercept the data processed by the device thus become an eavesdropper of every communication handled by the femtocell device.

In this chapter, we propose a best relay selection based cooperative scheme that maximizes the secrecy rate and the QoS at the destination. The best relay is chosen over two steps. In the first step, a sub-group of relays verifying a quality condition on the link between them and the eavesdropper is first chosen. In the second step, the relay among the selected sub-group that has the best link to the destination is selected as the best one. To evaluate the performance of the proposed scheme, we derive the expressions of average secrecy rate, average outage probability, and average BER. Monte Carlo simulations are used to confirm the analytical results and the advantage of the proposed scheme when compared to related works that will be detailed later.

5.2 System Model

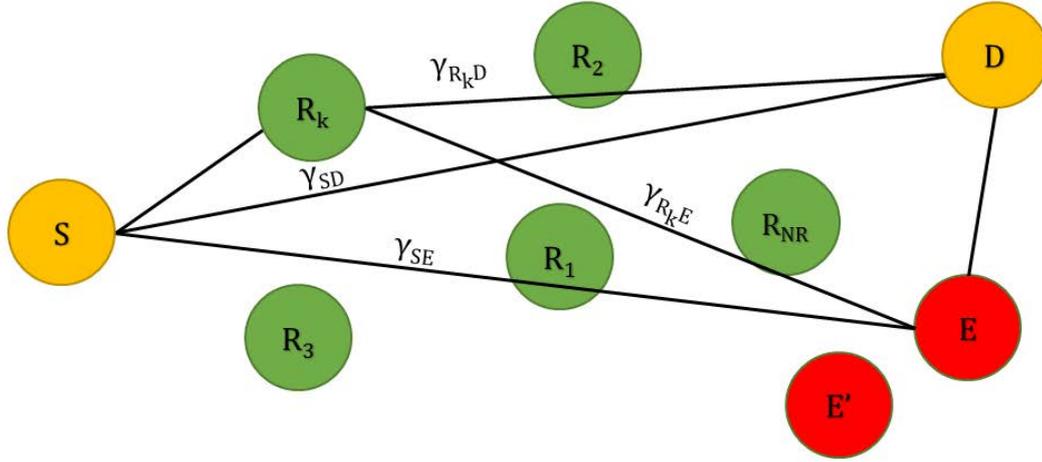


Figure 5.1: System Model.

We consider a distributed wireless cooperative network configuration as depicted in Fig. 5.1, with one source, one destination, one eavesdropper, and N_R relays. The channels between the different nodes in the network are assumed to be independent and identically distributed (i.i.d.) complex Gaussian with unit variance. Hence, the corresponding squared amplitudes of the complex gains are exponentially distributed. The global channel state information (CSI) is assumed to be available at a fusion center for designing the transmission scheme. Global CSI knowledge, including that of the eavesdropper CSI, is possible in cases in which the eavesdropper is a known but unauthorized user. By assuming a high reliability of the first hop, a perfect decode-and-forward (DF) relaying strategy is considered.

To enhance the performances of the introduced cooperative network, we present and detail in the following section the proposed scheme that is named Restricted Best Second Hop (RBSH). In addition, two related schemes, which are named Worst Relay-Eavesdropper Link (WREL), and Best Second Hop (BSH), are presented and used in the performances analysis to evaluate the advantage of the proposed scheme.

5.3 Related and Proposed Schemes

In this section we describe the principle of the related and proposed schemes, and we derive the corresponding probability density functions (PDF) of the received SNR.

5.3.1 Best Second Hop (BSH) Scheme

Within the BSH scheme, the choice of the best relay does not rely on the best relay-eavesdropper link, i.e., the relay that have the strongest link with the destination will be chosen without take into consideration the quality of the link between the best relay and the eavesdropper. In addition, within this scheme, the relays are assumed to perfectly decode the message sent by the source and use the same codeword to send it to the destination, and hence the first link will not be considered in the choice of the best relay. Based on that, the best relay is the one that offers the best received SNR at the destination, which is denoted by γ_{R^*D} and verifies : $\gamma_{R^*D} = \max(\gamma_{R_kD})$, where γ_{R_kD} is the instantaneous SNRs of the links between the k^{th} relay and the destination.

By using the order statistics and the binomial expansion form [94], the PDF of γ_{R^*D} for this method is expressed as follows

$$p_{R^*D}(\gamma_{R^*D}) = \sum_{k=1}^{N_R} \binom{N_R}{k} \frac{k (-1)^{k-1}}{\bar{\gamma}_{RD}} \exp\left(-\frac{k\gamma_{R^*D}}{\bar{\gamma}_{RD}}\right), \quad (5.1)$$

where, $\bar{\gamma}_{RD}$ is the average SNR of the link between a relay and the destination.

Let γ_{SD} , γ_{SE} , and γ_{R^*E} be the instantaneous SNRs of the source-destination link, the source-eavesdropper link, and the best selected relay-eavesdropper link, respectively.

By assuming that all the link experience independent Rayleigh fading, the PDF expressions of γ_{SD} , γ_{SE} and γ_{R^*E} are given, respectively, by

$$p_{SD}(\gamma_{SD}) = \frac{1}{\bar{\gamma}_{SD}} \exp\left(-\frac{\gamma_{SD}}{\bar{\gamma}_{SD}}\right), \quad (5.2)$$

$$p_{SE}(\gamma_{SE}) = \frac{1}{\bar{\gamma}_{SE}} \exp\left(-\frac{\gamma_{SE}}{\bar{\gamma}_{SE}}\right), \quad (5.3)$$

and

$$p_{R^*E}(\gamma_{R^*E}) = \frac{1}{\bar{\gamma}_{RE}} \exp\left(-\frac{\gamma_{R^*E}}{\bar{\gamma}_{RE}}\right), \quad (5.4)$$

where, $\bar{\gamma}_{SD}$, $\bar{\gamma}_{SE}$, and $\bar{\gamma}_{RE}$ are the average SNRs of γ_{SD} , γ_{SE} , and γ_{RE} , respectively.

At the destination, Maximum Ratio Combining (MRC) is adopted and the combined SNR can be written as $\gamma_D^{eq} = \gamma_{R^*D} + \gamma_{SD}$. Due to the independence of γ_{R^*D} and γ_{SD} , the PDF of γ_D^{eq} can be obtained through the convolution of the PDFs of γ_{R^*D} and γ_{SD} as follows

$$p_D(\gamma_D^{eq}) = \int_0^{\gamma_D^{eq}} p_{R^*D}(\tau) p_{SD}(\gamma_D^{eq} - \tau) d\tau. \quad (5.5)$$

After evaluating the integration in (5.5), $p(\gamma_D^{eq})$ can be expressed as

$$p_D(\gamma_D^{eq}) = \sum_{k=1}^{N_R} \binom{N_R}{k} \frac{k(-1)^{k-1}}{k\bar{\gamma}_{SD} - \bar{\gamma}_{RD}} \left[\exp\left(-\frac{\gamma_D^{eq}}{\bar{\gamma}_{SD}}\right) - \exp\left(-\frac{k\gamma_D^{eq}}{\bar{\gamma}_{RD}}\right) \right]. \quad (5.6)$$

At the eavesdropper, the PDF expression of the equivalent received SNR can be derived as as follows

$$\begin{aligned} p_E(\gamma_E^{eq}) &= \int_0^{\gamma_E^{eq}} p_{R^*E}(\tau) p_{SE}(\gamma_E^{eq} - \tau) d\tau \\ &= \frac{1}{\bar{\gamma}_{SE} - \bar{\gamma}_{RE}} \left[\exp\left(-\frac{\gamma_E^{eq}}{\bar{\gamma}_{SE}}\right) - \exp\left(-\frac{\gamma_E^{eq}}{\bar{\gamma}_{RE}}\right) \right], \end{aligned} \quad (5.7)$$

where, $\gamma_E^{eq} = \gamma_{R^*E} + \gamma_{SE}$.

5.3.2 Worst Relay-Eavesdropper Link (WREL) Scheme

The relay selection within WREL scheme is based on the relay-eavesdropper links without take in consideration the link between the relay and the destination. In this scheme the relay that provides the worst received SNR at the eavesdropper is selected to retransmit the message. The instantaneous SNR of the link between the selected relay and the eavesdropper can be evaluated as follows : $\alpha_{R^*E} = \min(\gamma_{R_kE})$, where γ_{R_kE} is the instantaneous SNRs of the links between the k^{th} relay and the eavesdropper.

Consequently, the PDF of the received SNR (α_{R^*E}) for the link between the selected relay and the Eavesdropper is expressed as

$$f_{R^*E}(\alpha_{R^*E}) = \frac{N_R}{\bar{\gamma}_{RE}} \exp\left(-\frac{N_R \alpha_{R^*E}}{\bar{\gamma}_{RE}}\right), \quad (5.8)$$

and the PDF expression of the received SNR for the link between the selected relay and the destination is given by

$$f_{R^*D}(\alpha_{R^*D}) = \frac{1}{\bar{\gamma}_{RD}} \exp\left(-\frac{\alpha_{R^*D}}{\bar{\gamma}_{RD}}\right). \quad (5.9)$$

By using the MRC receiver at the destination, the PDF of the equivalent received SNR ($\alpha_D^{eq} = \alpha_{R^*D} + \gamma_{SD}$) can be derived as follows

$$\begin{aligned} f_D(\alpha_D^{eq}) &= \int_0^{\alpha_D^{eq}} f_{R^*D}(\tau) p_{SD}(\alpha_D^{eq} - \tau) d\tau \\ &= \frac{1}{\bar{\gamma}_{SD} - \bar{\gamma}_{RD}} \left[\exp\left(-\frac{\alpha_D^{eq}}{\bar{\gamma}_{SD}}\right) - \exp\left(-\frac{\alpha_D^{eq}}{\bar{\gamma}_{RD}}\right) \right]. \end{aligned} \quad (5.10)$$

While, the PDF of the equivalent received SNR at the eavesdropper ($\alpha_E^{eq} = \alpha_{R^*E} + \gamma_{SE}$) can be derived as follows

$$\begin{aligned} f_E(\alpha_E^{eq}) &= \int_0^{\alpha_E^{eq}} f_{R^*E}(\tau) p_{SE}(\alpha_E^{eq} - \tau) d\tau \\ &= \frac{N_R}{N_R \bar{\gamma}_{SE} - \bar{\gamma}_{RE}} \left[\exp\left(-\frac{\alpha_E^{eq}}{\bar{\gamma}_{SE}}\right) - \exp\left(-\frac{N_R \alpha_E^{eq}}{\bar{\gamma}_{RE}}\right) \right]. \end{aligned} \quad (5.11)$$

5.3.3 Restricted Best Second Hop (RBSH) Scheme

The best relay selection algorithm within RBSH scheme consists of the following steps:

1. Choose a subgroup ($\Omega = \{R_i | \gamma_{R_iE} < \gamma_{th}\}$) of relays that comply with the condition: $\gamma_{R_iE} < \gamma_{th}$, where γ_{th} is an SNR threshold on below of which, the eavesdropper is considered not listening to the message sent from the i^{th} relay to the destination.
2. Choose the relay among Ω that has the highest received SNR:
$$\beta_{R^*D} = \max(\gamma_{R_iD} | R_i \in \Omega).$$
3. If $\Omega = \{\emptyset\}$, then only the direct transmission link will be used.

The probability that the eavesdropper is not listening to the message sent from a given relay k to the destination can be expressed as follows

$$\begin{aligned} P_{NL} &= P(\gamma_{R_kE} < \gamma_{th}) \\ &= \int_0^{\gamma_{th}} \frac{1}{\bar{\gamma}_{RE}} \exp\left(-\frac{\gamma_{R_kE}}{\bar{\gamma}_{RE}}\right) d\gamma_{R_kE} \\ &= 1 - \exp\left(-\frac{\gamma_{th}}{\bar{\gamma}_{RE}}\right). \end{aligned} \quad (5.12)$$

The next step is to choose from Ω the relay which maximizes the SNR of the second hop γ_{R_iD} . The probability that at least one relay is satisfying the security constraint can be

written, by using the binomial distribution, as follows

$$\sum_{k=1}^{N_R} \binom{N_R}{k} P_{NL}^k P_L^{N_R-k}, \quad (5.13)$$

where, $\binom{N_R}{k} = \frac{N_R!}{k!(N_R-k)!}$, and $P_L (= 1 - P_{NL})$ is the probability that the eavesdropper is listening to the message sent from a given relay. By using the order statistics and the binomial expansion form [94], the PDF of β_{R^*D} under the above mentioned constraint is given by

$$g_{R^*D}(\beta_{R^*D}) = \sum_{k=1}^{N_R} \binom{N_R}{k} P_{NL}^k P_L^{N_R-k} \sum_{i=1}^k \binom{k}{i} \frac{i(-1)^{i-1}}{\bar{\gamma}_{RD}} \exp\left(-\frac{i\beta_{R^*D}}{\bar{\gamma}_{RD}}\right). \quad (5.14)$$

By using an MRC receiver, the equivalent SNR at the destination, denoted by β_D^{eq} , can be evaluated as the sum of β_{R^*D} and γ_{SD} if $\Omega \neq \{\emptyset\}$, and it is equal to γ_{SD} , if only the direct link is used, e.g., $\Omega = \{\emptyset\}$. Consequently, the corresponding PDF can be written as follows

$$\begin{aligned} g_D(\beta_D^{eq}) &= \int_0^{\beta_D^{eq}} g_{R^*D}(\tau) p_{SD}(\beta_D^{eq} - \tau) d\tau + P_L^{N_R} p_{SD}(\beta_D^{eq}) \\ &= \sum_{k=1}^{N_R} \binom{N_R}{k} P_{NL}^k P_L^{N_R-k} \sum_{i=1}^k \binom{k}{i} \frac{i(-1)^{i-1}}{\bar{\gamma}_{SD}\bar{\gamma}_{RD}} \exp\left(\frac{-\beta_D^{eq}}{\bar{\gamma}_{SD}}\right) \int_0^{\beta_D^{eq}} \exp\left(\frac{\tau}{\bar{\gamma}_{SD}} - \frac{i\tau}{\bar{\gamma}_{RD}}\right) d\tau \\ &\quad + \frac{P_L^{N_R}}{\bar{\gamma}_{SD}} \exp\left(\frac{-\beta_D^{eq}}{\bar{\gamma}_{SD}}\right). \end{aligned} \quad (5.15)$$

By evaluating the integral in (5.15), $g_D(\beta_D^{eq})$ can be further simplified to

$$\begin{aligned} g_D(\beta_D^{eq}) &= \sum_{k=1}^{N_R} \binom{N_R}{k} P_{NL}^k P_L^{N_R-k} \sum_{i=1}^k \binom{k}{i} \frac{i(-1)^{i-1}}{i\bar{\gamma}_{SD} - \bar{\gamma}_{RD}} \left[\exp\left(\frac{-\beta_D^{eq}}{\bar{\gamma}_{SD}}\right) - \exp\left(\frac{-i\beta_D^{eq}}{\bar{\gamma}_{RD}}\right) \right] \\ &\quad + \frac{P_L^{N_R}}{\bar{\gamma}_{SD}} \exp\left(\frac{-\beta_D^{eq}}{\bar{\gamma}_{SD}}\right). \end{aligned} \quad (5.16)$$

By respecting the security constraint, when the source is transmitting, the eavesdropper is not getting any information from the best relay. Hence, the total PDF expression of the equivalent received SNR (β_E^{eq}) at the eavesdropper is given by

$$g_E(\beta_E^{eq}) = p_{SE}(\beta_E^{eq}). \quad (5.17)$$

5.4 Performance Analysis

In this section, we evaluate and detail the performance of the related and proposed schemes in terms of average outage probability, average BER, average ergodic capacity, and average secrecy rate.

5.4.1 Outage Probability

An outage is defined as an event in which the equivalent received SNR at the destination is below a given threshold γ_{th} . The expressions of the average outage probability for the different schemes are derived as follows:

5.4.1.1 Outage Probability of BSH Scheme

The average outage probability expression for BSH scheme is derived as follows

$$\begin{aligned} P_{out}^{BSH} &= P(\gamma_D^{eq} < \gamma_{th}) \\ &= \int_0^{\gamma_{th}} p_D(\gamma_D^{eq}) d\gamma_D^{eq}. \end{aligned} \quad (5.18)$$

Based on the PDF expression of γ_D^{eq} in (5.6), and after evaluating the integration in (5.18), P_{out}^{BSH} is given by

$$P_{out}^{BSH} = \sum_{k=1}^{N_R} \binom{N_R}{k} \left((-1)^{k-1} + \frac{(-1)^{k-1}}{k\bar{\gamma}_{SD} - \bar{\gamma}_{RD}} \left[\bar{\gamma}_{RD} \exp\left(\frac{-k\gamma_{th}}{\bar{\gamma}_{RD}}\right) - k\bar{\gamma}_{SD} \exp\left(\frac{-\gamma_{th}}{\bar{\gamma}_{SD}}\right) \right] \right). \quad (5.19)$$

5.4.1.2 Outage Probability of WREL Scheme

Based on (5.18), and the PDF expression of α_D^{eq} in (5.10), the average outage probability expression for WREL scheme is expressed as follows

$$P_{out}^{WREL} = \frac{1}{\bar{\gamma}_{SD} - \bar{\gamma}_{RD}} \left[\bar{\gamma}_{RD} \exp\left(\frac{-\gamma_{th}}{\bar{\gamma}_{RD}}\right) - \bar{\gamma}_{SD} \exp\left(\frac{-\gamma_{th}}{\bar{\gamma}_{SD}}\right) \right]. \quad (5.20)$$

5.4.1.3 Outage Probability of RBSH Scheme

Based on the PDF expression of β_D^{eq} in (5.16), and according to (5.18), the average outage probability expression for BRSH scheme is expressed as follows

$$P_{out}^{RBSH} = \sum_{k=1}^{N_R} \binom{N_R}{k} P_{NL}^k P_L^{N_R-k} \sum_{i=1}^k \binom{k}{i} \left((-1)^{i-1} + \frac{(-1)^{i-1}}{i\bar{\gamma}_{SD} - \bar{\gamma}_{RD}} \left[\bar{\gamma}_{RD} \exp\left(\frac{-i\gamma_{th}}{\bar{\gamma}_{RD}}\right) - i\bar{\gamma}_{SD} \exp\left(\frac{-\gamma_{th}}{\bar{\gamma}_{SD}}\right) \right] \right) + P_L^{N_R} \left[1 - \exp\left(\frac{-\gamma_{th}}{\bar{\gamma}_{SD}}\right) \right]. \quad (5.21)$$

5.4.2 Average Bit Error Rate (BER)

In this section, we derive the expressions of BER for the different schemes. Without loss of generality, the BPSK is the used modulation in this evaluation.

5.4.2.1 BER of BSH Scheme

For BPSK modulation, the average BER expression for BSH scheme is derived as follows [95]

$$P_e^{BSH} = \int_0^\infty Q\left(\sqrt{2\gamma_D^{eq}}\right) p_D(\gamma_D^{eq}) d\gamma_D^{eq}. \quad (5.22)$$

Based on ([95], Eq. A2), we have

$$\int_0^\infty Q\left(\sqrt{2x}\right) \exp(-\mu x) dx = \frac{1}{2\mu} \text{Binc}_{\frac{\mu}{1+\mu}} \left[1, \frac{1}{2} \right], \quad \forall \mu > 0, \quad (5.23)$$

where, $\text{Binc}_{(\cdot)}[\cdot, \cdot]$ is the incomplete Beta function [96], By using the expression of p_D in (5.6), and (5.23), P_e^{BSH} can be derived and expressed as follows

$$P_e^{BSH} = \sum_{k=1}^{N_R} \binom{N_R}{k} \frac{(-1)^{k-1}}{2(k\bar{\gamma}_{SD} - \bar{\gamma}_{RD})} \left(k\bar{\gamma}_{SD} \text{Binc}_{x_{SD}} \left[1, \frac{1}{2} \right] - \bar{\gamma}_{RD} \text{Binc}_{x_{RD}} \left[1, \frac{1}{2} \right] \right), \quad (5.24)$$

where, $x_{SD} = \frac{1}{1+\bar{\gamma}_{SD}}$, and $x_{RD} = \frac{k}{k+\bar{\gamma}_{RD}}$.

5.4.2.2 BER of WREL Scheme

Based on the derivation of (5.24), and the PDF $f_D(\alpha_D^{eq})$, the average BER for WREL scheme is derived as follows

$$\begin{aligned} P_e^{WREL} &= \int_0^\infty Q\left(\sqrt{2\alpha_D^{eq}}\right) f_D(\alpha_D^{eq}) d\alpha_D^{eq} \\ &= \frac{1}{2(\bar{\gamma}_{SD} - \bar{\gamma}_{RD})} \left(\bar{\gamma}_{SD} \text{Binc}_{x_{SD}} \left[1, \frac{1}{2}\right] - \bar{\gamma}_{RD} \text{Binc}_{y_{RD}} \left[1, \frac{1}{2}\right] \right), \end{aligned} \quad (5.25)$$

where, $y_{RD} = \frac{1}{1+\bar{\gamma}_{RD}}$.

5.4.2.3 BER of RBSH Scheme

The average BER of RBSH scheme with BPSK modulation can be derived as follows

$$P_e^{RBSH} = \int_0^\infty Q\left(\sqrt{2\beta_D^{eq}}\right) g_D(\beta_D^{eq}) d\beta_D^{eq}. \quad (5.26)$$

Based on the expression of g_D in (5.16), and (5.23), the average BER of SBSH scheme is expressed as

$$\begin{aligned} P_e^{RBSH} &= \sum_{k=1}^{N_R} \left\{ \binom{N_R}{k} P_{NL}^k P_L^{N_R-k} \sum_{i=1}^k \left\{ \binom{k}{i} \frac{(-1)^{i-1}}{2(i\bar{\gamma}_{SD} - \bar{\gamma}_{RD})} \right. \right. \\ &\quad \left. \left. \left(i\bar{\gamma}_{SD} \text{Binc}_{x_{SD}} \left[1, \frac{1}{2}\right] - \bar{\gamma}_{RD} \text{Binc}_{z_{RD}} \left[1, \frac{1}{2}\right] \right) \right\} \right\} + \frac{P_L^{N_R}}{2} \left(1 - \sqrt{\frac{\bar{\gamma}_{SD}}{1+\bar{\gamma}_{SD}}} \right), \end{aligned} \quad (5.27)$$

where, $z_{RD} = \frac{i}{i+\bar{\gamma}_{RD}}$.

5.4.3 Average Ergodic Capacity and Secrecy Rate

In this section, we derive the expressions of the average ergodic capacity for the different schemes at the destination and the eavesdropper. The derived expressions are used to evaluate the average secrecy rate for each scheme, which is given by the difference between the average ergodic capacity at the destination and the average ergodic capacity at the eavesdropper. The ergodic capacity characterizes the transmission channel. It is defined as the number of bits that can be transmitted without error per unit time and via a unit frequency, e.g., [bps/Hz].

In the following we derive the expressions of the ergodic capacity for the different schemes.

5.4.3.1 Average Ergodic Capacity of BSH Scheme

The average ergodic capacity for BSH scheme at the destination can be derived as follows

$$C^{BSH} = \int_0^{+\infty} \frac{1}{2} \log_2(1 + \gamma_D^{eq}) p_D(\gamma_D^{eq}) d\gamma_D^{eq}. \quad (5.28)$$

Based on ([96], Eq. 4.331.2), we have

$$\int_1^{+\infty} \exp(-\mu x) \ln(x) dx = \frac{-1}{\mu} \text{Eint}(-\mu), \quad \forall \mu > 0, \quad (5.29)$$

where, $\text{Eint}(\cdot)$ is the exponential integral function [96]. By using the change in variable : $v = 1 + \gamma_D^{eq}$ in (5.28), and based on the expression of p_D in (5.6), the average ergodic capacity of BSH scheme can be derived using (5.29) and expressed as

$$C_D^{BSH} = \sum_{k=1}^{N_R} \left\{ \binom{N_R}{k} \frac{(-1)^{k-1}}{2\ln(2)(\bar{\gamma}_{RD} - \bar{\gamma}_{SD})} \left[\bar{\gamma}_{SD} \exp\left(\frac{1}{\bar{\gamma}_{SD}}\right) \text{Eint}\left(\frac{-1}{\bar{\gamma}_{SD}}\right) - \frac{\bar{\gamma}_{RD}}{k} \exp\left(\frac{k}{\bar{\gamma}_{RD}}\right) \text{Eint}\left(\frac{-k}{\bar{\gamma}_{RD}}\right) \right] \right\}. \quad (5.30)$$

At the eavesdropper, and based on the derivation of (5.30), the average ergodic capacity expression is given by

$$C_E^{BSH} = \frac{1}{2\ln(2)(\bar{\gamma}_{RE} - \bar{\gamma}_{SE})} \left[\bar{\gamma}_{SE} \exp\left(\frac{1}{\bar{\gamma}_{SE}}\right) \text{Eint}\left(\frac{-1}{\bar{\gamma}_{SE}}\right) - \bar{\gamma}_{RE} \exp\left(\frac{1}{\bar{\gamma}_{RE}}\right) \text{Eint}\left(\frac{-1}{\bar{\gamma}_{RE}}\right) \right]. \quad (5.31)$$

5.4.3.2 Average Ergodic Capacity of WREL Scheme

By analogy with the derivations of (5.30) and (5.31), the average ergodic capacity expressions at the destination and the eavesdropper are given by

$$C_D^{WREL} = \frac{1}{2\ln(2)(\bar{\gamma}_{RD} - \bar{\gamma}_{SD})} \left[\bar{\gamma}_{SD} \exp\left(\frac{1}{\bar{\gamma}_{SD}}\right) \text{Eint}\left(\frac{-1}{\bar{\gamma}_{SD}}\right) - \bar{\gamma}_{RD} \exp\left(\frac{1}{\bar{\gamma}_{RD}}\right) \text{Eint}\left(\frac{-1}{\bar{\gamma}_{RD}}\right) \right], \quad (5.32)$$

and

$$C_E^{WREL} = \frac{N_R}{2\ln(2)(\bar{\gamma}_{RE} - N_R \bar{\gamma}_{SE})} \left[\bar{\gamma}_{SE} \exp\left(\frac{1}{\bar{\gamma}_{SE}}\right) \text{Eint}\left(\frac{-1}{\bar{\gamma}_{SE}}\right) - \frac{\bar{\gamma}_{RE}}{N_R} \exp\left(\frac{N_R}{\bar{\gamma}_{RE}}\right) \text{Eint}\left(\frac{-N_R}{\bar{\gamma}_{RE}}\right) \right], \quad (5.33)$$

respectively.

5.4.3.3 Average Ergodic Capacity of RBSH Scheme

For this scheme, the average ergodic capacity at the destination is derived as follows

$$C_D^{RBSH} = \int_0^{+\infty} \frac{1}{2} \log_2(1 + \beta_D^{eq}) g_D(\beta_D^{eq} | \beta_D^{eq} = \beta_{R^*D} + \gamma_{SD}) d\beta_D^{eq} + \int_0^{+\infty} \log_2(1 + \beta_D^{eq}) p_{SD}(\beta_D^{eq} | \beta_D^{eq} = \gamma_{SD}) d\beta_D^{eq}. \quad (5.34)$$

After evaluating the integration in (5.34) using (5.29), C_D^{RBSH} can be expressed as

$$C_D^{RBSH} = \sum_{k=1}^{N_R} \left\{ \binom{N_R}{k} \frac{(-1)^{k-1}}{2 \ln(2) (\bar{\gamma}_{RD} - \bar{\gamma}_{SD})} \left[\bar{\gamma}_{SD} \exp\left(\frac{1}{\bar{\gamma}_{SD}}\right) \text{Eint}\left(\frac{-1}{\bar{\gamma}_{SD}}\right) - \frac{\bar{\gamma}_{RD}}{k} \exp\left(\frac{k}{\bar{\gamma}_{RD}}\right) \text{Eint}\left(\frac{-k}{\bar{\gamma}_{RD}}\right) \right] \right\} - \frac{P_L^{N_R}}{\ln(2)} \exp\left(\frac{1}{\bar{\gamma}_{SD}}\right) \text{Eint}\left(\frac{-1}{\bar{\gamma}_{SD}}\right). \quad (5.35)$$

At the eavesdropper, and based on (5.17), and (5.29), the average ergodic capacity can be derived as follows

$$C_E^{RBSH} = \int_0^{+\infty} \frac{1}{2} \log_2(1 + \beta_E^{eq}) p_{SE}(\beta_E^{eq}) d\beta_E^{eq} = \frac{-1}{2 \ln(2)} \exp\left(\frac{1}{\bar{\gamma}_{SE}}\right) \text{Eint}\left(\frac{-1}{\bar{\gamma}_{SE}}\right). \quad (5.36)$$

5.5 Numerical Results

In this section, we present the simulation setup, and the simulation results to evaluate the derived expressions as well as the performances of the different schemes.

5.5.1 Simulation Setup

In the simulation setup, we assume that the average SNR of the direct link is proportional to the average SNR of the second hop as: $\bar{\gamma}_{SD} = 0.2 \bar{\gamma}_{RD}$. The average SNR between the relays and destination is the same as that between relays and eavesdropper. The source and the relays are using a unit transmissions power. The number of relays and the value of interference threshold are varying as shown in the simulation figures.

5.5.2 Simulation Results Interpretation

Fig. 5.2 presents the variations of the average outage probability for the different scheme vs. the number of relays, with $\gamma_{th} = 10$ dB. This figure reveals that the BSH method offers a lower outage probability than the other three methods. This is because, the probability to select the best relay in term of second hop SNR is high within this scheme compared to the other schemes. We notice also that the outage probability of WREL is constant, this is due to the fact that it does not depend on the number of relays, i.e., it is based only on the quality of the selected relay-eavesdropper link.

Fig. 5.3 shows the outage probability behaviors for the different scheme vs. $\bar{\gamma}_{RD}$, with $\gamma_{th} = 10$ dB. As shown in this figure, when the average SNR is below 15 dB, RBSH scheme offers a better result than WRLS scheme since there are relays that are satisfying the security condition. But when the average SNR is higher than 15 dB, RBSH scheme does not offer better results because none of the relays satisfies this condition. BSH scheme outperforms the other schemes. This is because this scheme is not limited by the security conditions as the case in the other schemes.

Fig. 5.4 shows the average BER performance of the different schemes vs. the number of relays. Similar to the outage probability behavior, we remark that the BSH scheme outperforms the other schemes in term of BER, and the WREL scheme presents a constant lowest performance as it does not depend on the number of the relays.

Fig. 5.5 shows the secrecy rates achieved by the three studied methods while changing the number of relays. It is noticeable that RBSH scheme is realizing better secrecy rate than the other two methods. This is because the RBSH scheme is based on the quality of both the best selected relay - destination link and the best selected relay - eavesdropper link, which is not the case for the two other schemes.

Fig. 5.6 shows the secrecy rates achieved by the three methods while changing $\bar{\gamma}_{RD}$. Similar to the outage probability behaviors, when the average SNR is below 12 dB, RBSH scheme offers better results since there are relays that are satisfying the security condition. But when the average SNR is higher than 12 dB, RBSH scheme does not offer better results because none of the relays satisfies this condition.

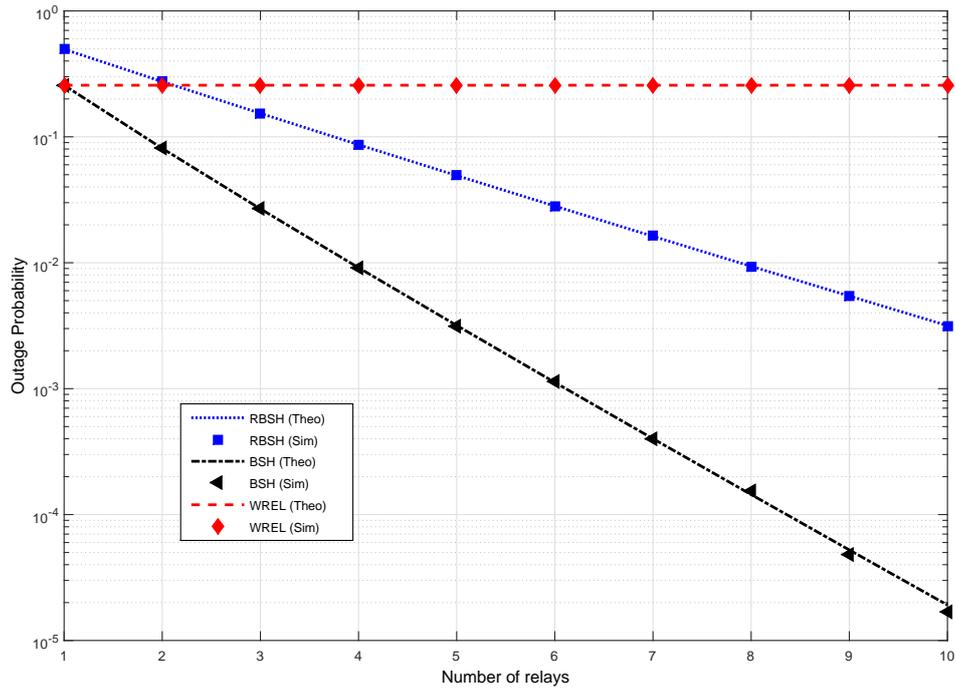


Figure 5.2: Average outage probability vs. number of relays, with $\gamma_{th} = 10$ dB.

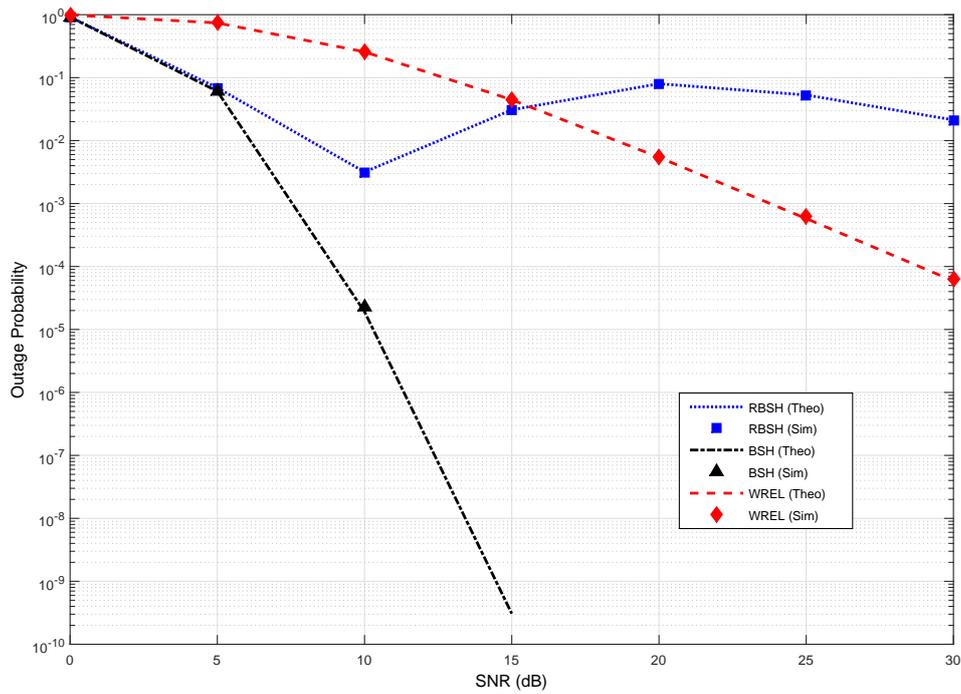


Figure 5.3: average outage probability vs. SNR, with $\gamma_{th} = 10$ dB.

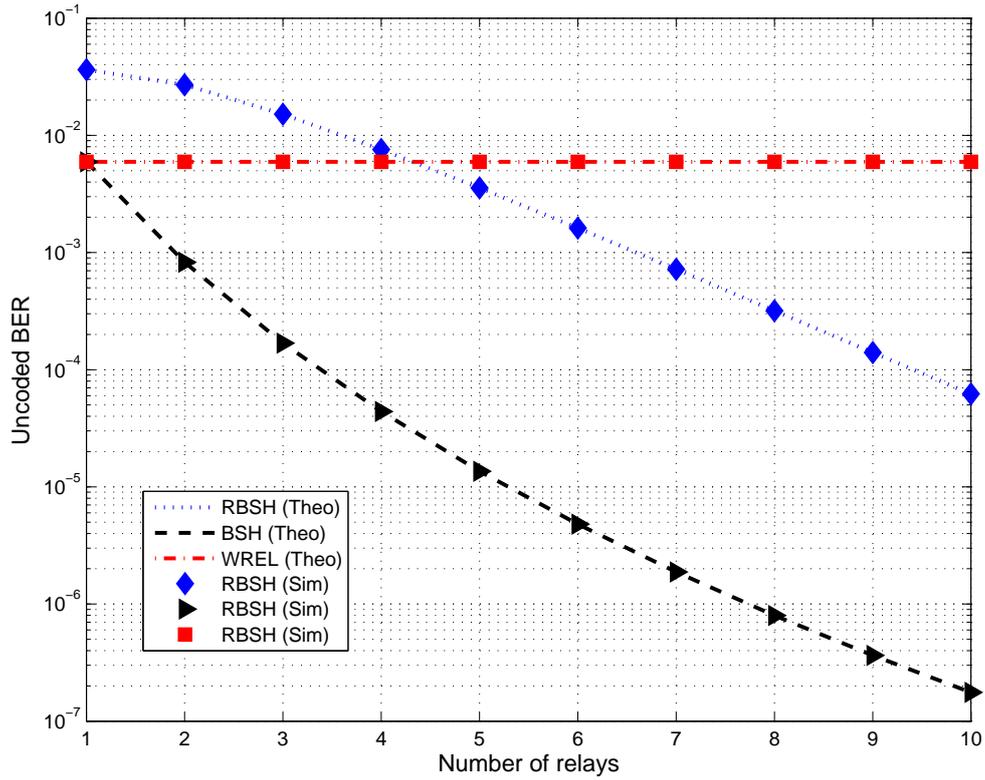


Figure 5.4: Average BER vs. number of relays.

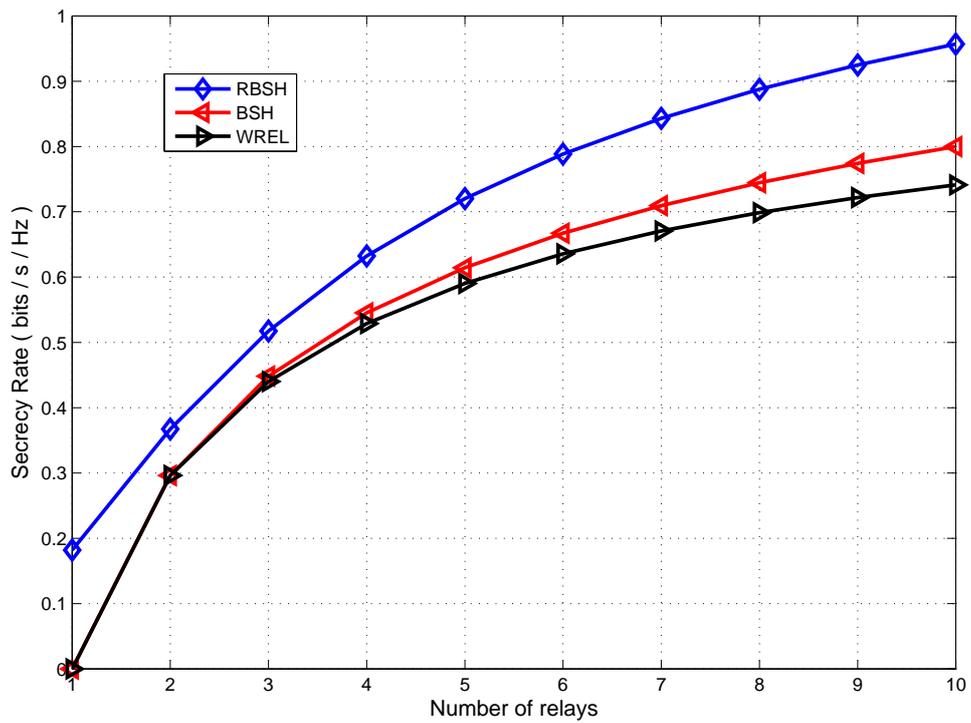


Figure 5.5: Average secrecy rate vs. number of Relays.

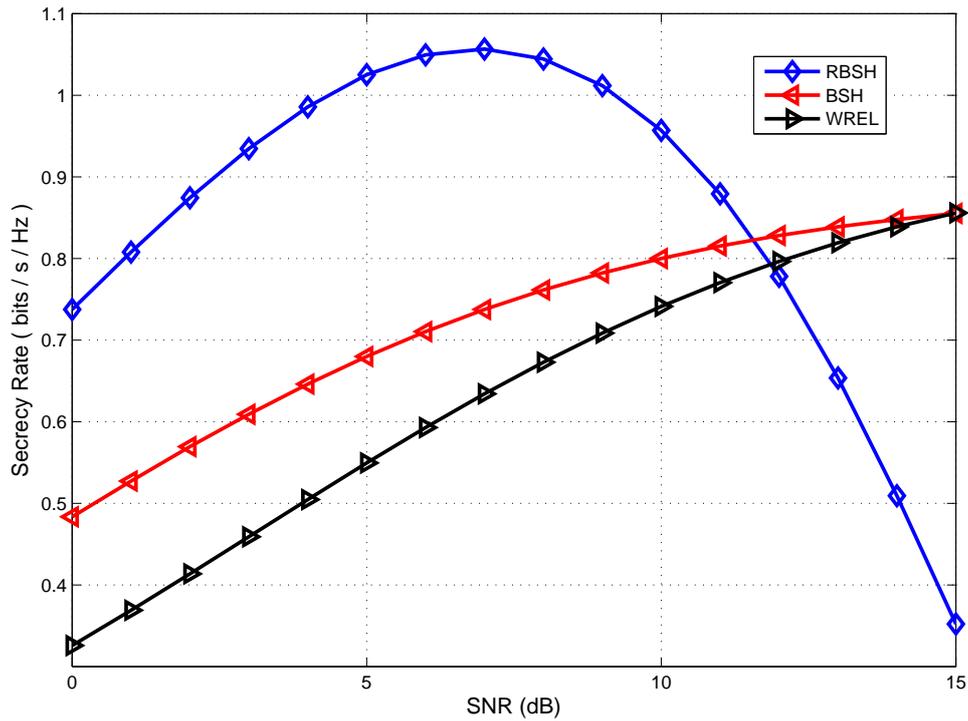


Figure 5.6: Secrecy rate vs. average second hop SNR.

5.6 Conclusion

In this chapter, we have proposed an efficient cooperative communications scheme which maximizes the secrecy rate. The new scheme is based on best relay selection method that maximizes the secrecy rate and benefits from increasing the number of relays under QoS constraint at the destination. Performance analysis have been conducted in terms of secrecy rate, outage probability, and BER. Simulations results have been used to confirm the mathematical derivations and an agreement results have been observed. The results confirm the better secrecy rate of the introduced transmission scheme compared to well established techniques introduced in the literature.

Chapter 6

General Conclusion and Perspectives

6.1 General Conclusion

In this thesis, solutions were proposed to the following femtocell network challenges: energy efficiency, spectrum sharing and security.

The Ph.D. thesis has been structured in 6 chapters:

The first chapter has presented the general introduction of the thesis. It has described the problem statement and the motivations. After that, the contributions of this thesis have been presented and detailed, and which have been mainly focusing on three axis; proposing new handover algorithms or relay selection schemes, deriving closed form expressions of different evaluative performances metrics, and making proper simulations to validate the analytical results. In addition the list of publications during the thesis period has been introduced. Finally, the thesis organization has been presented.

In chapter 2, a study on the communication networks state of the art is made. We detailed the challenges brought by the introduction of the femtocell networks and investigated existing works in the field.

In chapter 3, the objective was to find a way to minimize the energy consumption of femtocells in macro/femto-cellular BWA networks. After a documentation phase, we could determine where our contribution can lead us to the above mentioned objective. In fact, the handovers classification by their probabilistic importance and their nature: wanted or unwanted, allowed us to achieve a minimal gain of 5% in energy consumption compared to another solution in literature.

We elaborated the mathematical model of our solution from which we could demonstrate, with the help of the implemented simulations, that we achieved our goal by finding a way to minimize the energy consumption of femtocells.

The subject treated in this chapter is considered by specialists as one of the most sensitive topics in the field of telecommunications since it deals with energy management which is a universal problem.

In chapter 4, we have proposed a decision handover algorithm in the femtocell-LTE networks. We developed a decision handover algorithm with consideration of the Poisson distribution model of spectrum mobility. This algorithm is based on the minimum expected transmission time within the dwell time of the UE in the coverage of the femto-cell.

We have provided the mathematical analysis and the performance simulation to illustrate that the proposed algorithm reduces significantly the expected transmission time and the spectrum mobility ratio.

We have proposed in chapter 5 an efficient cooperative communications scheme which maximizes the secrecy rate. The new scheme is based on best relay selection method that maximizes the secrecy rate and benefits from increasing the number of relays under QoS constraint at the destination. Performance analysis have been conducted in terms of secrecy rate, outage probability, and BER. Simulations results have been used to confirm the mathematical derivations and an agreement results have been observed. The results confirm the better secrecy rate of the introduced transmission scheme compared to well established techniques introduced in the literature.

6.2 Future Work

When deployed, femtocell networks will count a huge number of devices spread on the residential and industrial maps. The idea is to use this windfall as an opportunity to optimize UEs connections under energy consumption constraint. In fact, femtocells can be used as relays between sources and destinations. The latter can be, UEs or macro/femtocells. Green IT is currently one of the hottest topics in ICT. In fact, Energy efficiency is a key indicator in the communication systems with limited lifetime of the batteries used to supply the wireless devices. Many efforts have been spent on the efficient use of battery energy, especially in wireless sensor network, where battery installed on sensors are limited and replacing them becomes difficult due to inaccessibility of the sensors. Therefore, seeking new source of energy to prolong the lifetime of the energy-constrained wireless network becomes a spotlight.

Recent progress in electronics have revealed that energy harvesting, a process that helps capturing and storing the energy derived from ambient or external sources, is an alternative for prolonging the lifetime of a wireless network and a key enabling technology in the development of wireless sensor networks (WSNs).

Energy harvesting has received significant attention recently, where the surrounding energy can be harvested from a large variety of physical natures, such as solar, vibration, thermal or acoustic energy sources. Apart from the conventional energy harvesting methods, a new emerging solution is to avail ambient RF signals, since RF signals can carry energy and information at the same time. Thus, energy constrained nodes can scavenge energy and process the information simultaneously.

Bibliography

- [1] Prasun Chowdhury, Anindita Kundu, Saha Misra, and Salil K Sanyal, “Load balancing with reduced unnecessary handoff in hierarchical macro/femto-cell wimax networks,” *International Journal of Wireless & Mobile Networks (IJWMN)*, vol. 4, no. 3, 2012.
- [2] M. Rumney, *LTE and the Evolution to 4G Wireless Design and Measurement Challenges*, Agilent Technologies Publication, 2009.
- [3] A. Omri, R. Hamila, M. Hasna, R. Bouallegue, and H. Chamkhia, “Estimation of Highly Selective Channels for Downlink LTE MIMO-OFDM System by a Robust Neural Network.,” *International Journal of Ubiquitous Systems and Pervasive Networks (IJUSPN)*., vol. 2, no. 1, pp. 31– 38, 2011.
- [4] S.Frattasi, H.Fathi, F.H.P.Fitzek, R.Prasad, and M.D.Katz, “Defining 4G Technology from the Users Perspective,” *IEEE Network*, vol. 20, pp. 35–41, 2006.
- [5] Vikram Chandrasekhar and Jeffrey G. Andrews, “Uplink capacity and interference avoidance for two-tier femtocell networks,” *IEEE Transactions on Wireless Communications*, 2009.
- [6] R. Kim, J. S. Kwak, and K. Etemad, “Wimax femtocell: requirements, challenges, and solutions,” *IEEE Transactions on Wireless Communications*, vol. 47, no. 9, pp. 84 –91, 2009.
- [7] A. Barbieri, A. Damnjanovic, T. Ji, J. Montojo, Y. Wei, D. P. Malladi, O. Song, and G. Horn, “The downlink inter-cell interference problem in rel-10 lte femtocell networks,” *IEEE JSAC Special Issue on Femtocell Networks*, 2012.

- [8] A. Ghosh, J. Zhang, J. G. Andrews, and R. Muhamed, *Fundamentals of LTE*. Prentice-Hall, 2010.
- [9] P. Xia, V. Chandrasekhar, and J. G. Andrews, "Open vs. closed access femtocells in the uplink," *IEEE Transactions on Wireless Communications*, vol. 9, no. 10, pp. 3798 – 3809, 2010.
- [10] 3GPP TS 36.300, *Evolved Universal Terrestrial Radio Access (E-UTRA) and Evolved Universal Terrestrial Radio Access Network (E-UTRAN); Overall description; Stage 2*), 2011.
- [11] 3GPP TS 36.816, *Evolved Study on Management of Evolved Universal Terrestrial Radio Access Network (E-UTRAN) and Evolved Packet Core (EPC)*, 2011.
- [12] 3GPP TS 32.500, *Telecommunication Management; Self-Organizing Networks (SON); Concepts and requirements*, 2011.
- [13] 3GPP TS 36.902, *Self-Configuring and Self-Optimizing Network Use Cases and Solutions*, 2011.
- [14] D. Lopez-Perez, A. Ladanyi, A. Juttner, and J. Zhang, "Ofdma femtocells: A self-organizing approach for frequency assignment," *PIMRC*, p. 2202–2207, 2009.
- [15] S. Feng and E. Seidel, "Self-organizing networks (SON) in 3GPP long term evolution," *NOMOR whitepaper*, 2010.
- [16] Nestor Gonzalez and Luis Moron, *Publication Telefonica, Green IT, Green Telecom Networks*, chapter 4, 2009.
- [17] H. Zhou, H. Luo, H. Zhang, C.H. Lo, and H.C. Chao, "A network-based global mobility management architecture," *International Journal of Ad Hoc and Ubiquitous Computing*, vol. 5, no. 1, pp. 1–6, 2010.
- [18] A. Kumar, A.K. Sarje, and M. Misra, "Prioritised predicted region based cache replacement policy for location dependent data in mobile environment," *International Journal of Ad Hoc and Ubiquitous Computing*, vol. 5, no. 1, pp. 55–67, 2010.

- [19] H. Oh, K. Yoo, J. Na, and C. Kim, "A seamless handover scheme in ipv6-based mobile networks," *International Journal of Ad Hoc and Ubiquitous Computing*, vol. 4, no. 1, pp. 54–60, 2010.
- [20] J.M. Moon and D.H. Cho, "Novel handoff decision algorithm in hierarchical macro/femto-cell networks," *Proc. IEEE Wireless Communications and Networking Conference, WCNC*, pp. 1–6, 2010.
- [21] S. Wu, X. Zhang, R. Zheng, Z. Yin, Y. Fang, and D. Yang, "Handover study concerning mobility in the two-hierarchy network," *Proc. IEEE Vehicular Technology Conference, VTC*, pp. 1–5, 2009.
- [22] A. Ulvan, R. Bestak, and M. Ulvan, "The study of handover procedure in lte-based femtocell network," *Proc. IEEE Wireless and Mobile Networking Conference, WMNC*, pp. 1–6, 2010.
- [23] H. Zhang, X. Wen, B. Wang, W. Zheng, and Y. Sun, "A novel handover mechanism between femtocell and macrocell for lte based networks," *Proc. International Conference on Communication Software and Networks, ICCSN*, pp. 228–231, 2010.
- [24] I. Ashraf, Lester T.W. Ho, and H. Claussen, "Improving energy efficiency of femto-cell base stations via user activity detection," *Proc. Communications and Networking Conference, WCNC*, pp. 1–5, 2010.
- [25] H. Claussen, I. Ashraf, and Lester T.W. Ho, "Dynamic idle mode procedures for femtocells," *Bell Labs Technical Journal*, vol. 15, no. 2, pp. 95–116, 2010.
- [26] Yuh-Shyan Chen and Cheng-You Wu, "A green handover protocol in two-tier ofdma macrocell-femtocell networks," *Mathematical and Computer Modelling*, 2012.
- [27] S. Kishore, L. J. Greenstein, H. V. Poor, and S. C. Schwartz, "Soft handoff and uplink capacity in a two-tier cdma system," *IEEE Transactions on Wireless Communications*, vol. 4, no. 4, pp. 1297–1301, 2005.
- [28] A. Damnjanovic, J. Montojo, Y. Wei, T. Ji, T. Luo, M. Vajapeyam, T. Yoo, O. Song, and D. Malladi, "A survey on 3gpp heterogeneous networks," *IEEE Wireless Communications*, vol. 18, no. 3, pp. 10–21, 2011.

- [29] Sahin ME, Guvenc I, Moo-Ryong J, and Arslan H, "Handling cci and ici in ofdma femtocell networks through frequency scheduling," *Consum. Elect. IEEE Transact.*, vol. 55, no. 4, pp. 1936–1944, 2009.
- [30] H. S. Jo, P. Xia, and J. G. Andrews, "Downlink femtocell networks: Open or closed?," *IEEE International Conference on Communications*, 2011.
- [31] Femto Forum, *Interference Management in OFDMA Femtocells*, 2010.
- [32] 3GPP TR 25.820, *3G Home NodeB Study Item Technical Report*, 2011.
- [33] RP-100372, *New Work Item Proposal: Enhanced ICIC for non-CA based deployments of heterogeneous networks for LTE*, 2010.
- [34] V. Chandrasekhar, J. Andrews, Z. Shen, T. Muharemovic, and A. Gatherer, "Power control in two-tier femtocell networks," *IEEE Transactions on Wireless Communications*, vol. 8, no. 8, pp. 4316–28, 2009.
- [35] G. Fodor, C. Koutsimanis, A. Racz, N. Reider, A. Simonsson, and W. Muller, "Inter-cell interference coordination in ofdma networks and in the 3gpp long term evolution system," *J. Comm.*, vol. 4, no. 7, pp. 445–453, 2009.
- [36] G. Boudreau, J. Panicker, N. Guo, R. Chang, N. Wang, and S. Vrzic, "Interference coordination and cancellation for 4G networks," *IEEE Comm. Mag.*, vol. 47, no. 4, pp. 74–81, 2009.
- [37] Serkan Uygungelen, Gunther Auer, and Zubin Bharucha, "Graph-based dynamic frequency reuse in femtocell networks," *VTC*, 2011.
- [38] H. Widiarti, S. Pyun, and D. Cho, "Interference mitigation based on femtocells grouping in low duty operation," *Proc. IEEE 72nd Vehicular Technology Conference Fall (VTC'10-Fall)*, 2010.
- [39] 3GPP R1-105238, *Further Discussion on HeNB Downlink Power Setting in HetNet*, 2010.
- [40] D. Niyato, E. Hossain, and Z. Han, "Dynamics of multiple-seller and multiple-buyer spectrum trading in cognitive radio networks: A game-theoretic modeling approach," *IEEE Trans. Mobile Comput.*, vol. 8, no. 8, pp. 1009–1022, 2009.

- [41] Jia-Shi Lin and Kai-Ten Feng, “Game theoretical model and existence of win-win situation for femtocell networks,” *IEEE ICC 2011 proceedings*, 2011.
- [42] H.-S. Jo, C. Mun, J. Moon, and J.-G. Yook, “Interference mitigation using uplink power control for two-tier femtocell networks,” *IEEE Trans. on Wireless Communications*, vol. 8, no. 10, pp. 4906–4910, 2009.
- [43] Femto Forum, *Interference management in UMTS femtocells*, 2008.
- [44] L. Poongup, L. Taeyoung, J. Jangkeun, and S. Jitae, “Interference management in lte femtocell systems using fractional frequency reuse,” *Proc. 12th International Conference on Advanced Communication Technology*, vol. 2, pp. 1047–1051, 2010.
- [45] Su Huan, Kuang Linling’, and Lu Jianhua, “Interference avoidance in ofdma-based femtocell network,” *IEEE Youth Conference on Information, Computing and Telecommunication*, pp. 126–129, 2009.
- [46] Hongjia Li, Xiaodong Xu, Dan Hu, Xiqiang Qu, Xiaofeng Tao, and Ping Zhang, “Graph method based clustering strategy for femtocell interference management and spectrum efficiency improvement,” *Wireless Communications Networking and Mobile Computing (WiCOM)*, pp. 1–5, 2010.
- [47] T. Kim and T. Lee, “Throughput enhancement of macro and femto networks by frequency reuse and pilot sensing,” *Proc. IEEE International Performance, Computing and Communications Conference (IPCCC)*, p. 390–394, 2008.
- [48] L. G. U. Garcia, K. I. Pedersen, and P. E. Mogensen, “Autonomous component carrier selection: Interference management in local area environments for lte-advanced,” *Communications Magazine, IEEE*, 2009.
- [49] R. Juang, P. Ting, H. Lin, and D. Lin, “Interference management of femto-cell in macro-cellular networks,” *Proc. Wireless Telecommunications Symposium (WTS’10)*, p. 1–4, 2010.
- [50] S. Srinivasa and S. A. Jafar, “The throughput potential of cognitive radio: A theoretical perspective,” *IEEE Commun. Mag.*, vol. 45, no. 5, pp. 73–79, 2007.

- [51] R. Madan, A. Sampath, A. Khandekar, J. Borran, and N. Bhushan, "Distributed interference management and scheduling in LTE-A femto networks," *Proc. GLOBECOM*, p. 1–5, 2010.
- [52] T. Akbudak and A. Czylik, "Distributed power control and scheduling for decentralized ofdma networks," *International ITG Workshop on Smart Antennas (WSA)*, p. 59 – 65, 2010.
- [53] Sahin ME, Guvenc I, Moo-Ryong J, and Arslan H, "Handling cci and ici in ofdma femtocell networks through frequency scheduling," *Consum. Elect. IEEE Transact.*, pp. 1936–1944, 2009.
- [54] P. Jänis, V. Koivunen, and C.B. Ribeiro, "Interference-aware radio resource management for local area wireless networks," *EURASIP J. Wireless Comm. and Networking*, 2011.
- [55] T. Lan, K. Sinkar, L. Kant, and K.J. Kerpez, "Resource allocation and performance study for lte networks integrated with femtocells," *Proc. GLOBECOM*, 2010.
- [56] Mustafa Y. Arslan, Jongwon Yoon, Karthikeyan Sundaresan, Srikanth V. Krishnamurthy, and Suman Banerjee, "Fermi: a femtocell resource management system for interference mitigation in ofdma networks," *MOBICOM*, 2011.
- [57] IST-WINNER II Deliverable 1.1.2 v.1.2, *WINNER II Channel Models*, 2007.
- [58] D. Niyato and E. Hossain, "Dynamic of network selection in heterogeneous wireless networks: an evolutionary game approach," *Proc. 12th International Conference on Advanced Communication Technology*, vol. 58, no. 2, pp. 2651–2660, 2009.
- [59] L. Busoni, R. Babuska, and B. D. Schutter, "A comprehensive survey of multiagent reinforcement learning," *Trans. Systems, Man and Cybernetics*, vol. 38, no. 2, pp. 156–172, 2008.
- [60] Mehdi Bennis and Dusit Niyato, "A q-learning based approach to interference avoidance in self-organized femtocell networks," *GLOBECOM Workshops (GC Wkshps)*, 2010 *IEEE*, 2010.

- [61] D. Fudenberg and D. K. Levine, "The theory of learning in games," *The MIT Press*, 1998.
- [62] H. Li, "Multi-agent q-learning of channel selection in multi-user cognitive radio systems: A two by two case," *IEEE Conference on System, Man and Cybernetics (SMC)*, 2009.
- [63] F. Fu and M. van der Schaar, "Learning to compete for resources in wireless stochastic games," *IEEE Trans. Veh. Technol.*, 2009.
- [64] Z. Han, C. Pandana, and K. Liu, "Distributive opportunistic spectrum access for cognitive radio using correlated equilibrium and no-regret learning," *Proc. of IEEE Wireless Communications and Networking Conference (WCNC)*, 2007.
- [65] Ana Galindo-Serrano, Lorenza Giupponi, and Gunther Auer, "Distributed learning in multiuser ofdma femtocell networks," *VTC*, 2011.
- [66] M. Bennis and S. M. Perlaza, "Decentralized cross-tier interference mitigation in cognitive femtocell networks," *IEEE International Conference on Communications (ICC)*, 2011.
- [67] T. Akbudak and A. Czylik, "Distributed power control and scheduling for decentralized ofdma networks," *International ITG Workshop on Smart Antennas (WSA)*, p. 59 – 65, 2010.
- [68] Sahin ME, Guvenc I, Moo-Ryong J, and Arslan H, "Handling cci and ici in ofdma femtocell networks through frequency scheduling," *Consum. Elect. IEEE Transact.*, vol. 55, no. 4, pp. 1936–1944, 2009.
- [69] P. Jänis, V. Koivunen, and C.B. Ribeiro, "Interference-aware radio resource management for local area wireless networks," *EURASIP J. Wireless Comm. and Networking*, 2011.
- [70] T. Lan, K. Sinkar, L. Kant, and K.J. Kerpez, "Resource allocation and performance study for lte networks integrated with femtocells," *GLOBECOM*, 2010.
- [71] C. E. Shannon, "Communication theory of secrecy systems," *Bell Syst. Tech. J.*, vol. 28, pp. 656–715, 1949.

- [72] Y. Liang, H. V. Poor, and S. Shamai (Shitz), "Secure communication over fading channels," *IEEE Trans. Inf. Theory*, vol. 54, no. 6, pp. 2470–2492, 2008.
- [73] Y. Liang, H. V. Poor, and S. Shamai (Shitz), "Physical layer security in broadcast networks," *Security Comm. Networks*, vol. 2, no. 3, pp. 227–238, 2009.
- [74] R. Liu, T. Liu, H. V. Poor, and S. Shamai (Shitz), "MIMO Gaussian broadcast channels with confidential messages," *IEEE Int. Symp. Inf. Theory (ISIT)*, vol. 56, no. 9, pp. 4215–4227, September 2010.
- [75] A. D. Wyner, "The wire-tap channel," *Bell Syst. Tech. J.*, vol. 54, no. 8, pp. 1355–1387, 1975.
- [76] H. Shamkhia, M. Hasna, and R. Hamila, "Performance analysis of relay selection schemes in underlay cognitive networks with decode and forward relaying," *IEEE International Symposium on Personal, Indoor and Mobile Radio Communications (PIMRC'12), Sydney Australia*, pp. 1552 – 1558, September 2012.
- [77] A. Gouisseem, M. Hasna, R. Hamila, H. Besbes, and F. Abdelkefi, "Optimized selective ofdma in multihop network," *IEEE International Symposium on Personal, Indoor and Mobile Radio Communications (PIMRC'12), Sydney Australia*, pp. 1348 – 1353, September 2012.
- [78] H. Chamkhia, M.O. Hasna, and R. Hamila, "Performances analysis of sec based transmit diversity systems with mrc receivers," *Computing, Communications and Applications Conference (ComComAp), Hong Kong*, pp. 71 – 75, February 2012.
- [79] H. Kwak, P. Lee, Y. Kim, N. Saxena, and J. Shin, "Mobility management survey for home-e-nb based 3gpp lte systems," *Journal of Information Processing Systems*, vol. 4, no. 4, pp. 145–152, 2008.
- [80] Yuh-Shyan Chen, Ching-Hsiung Cho, Ilsun You, and Han-Chieh Chao, "A cross-layer protocol of spectrum mobility and handover in cognitive lte networks," *Simulation Modelling Practice and Theory*, 2010.
- [81] Yuh-Shyan Chen and Cheng-You Wu, "A green handover protocol in two-tier ofdma macrocell–femtocell networks," *Mathematical and Computer Modelling*, 2012.

- [82] A. Ulvan, R. Bestak, and M. Ulvan, "The study of handover procedure in lte-based femtocell network," *IEEE Wireless and Mobile Networking Conference*, pp. 1–6, 2010.
- [83] H. Zhang, X. Wen, B. Wang, W. Zheng, and Y. Sun, "A novel handover mechanism between femtocell and macrocell for lte based networks," *International Conference on Communication Software and Networks*, pp. 228–231, 2010.
- [84] D. López-Pérez, A. Ladanyi, A. Jüttner, and J. Zhang, "Ofdma femtocells: A self-organizing approach for frequency assignment," *IEEE PIMRC (Personal, Indoor and Mobile Radio Communications)*, 2009.
- [85] *Evolved Universal Terrestrial Radio Access (E-UTRA) and Evolved Universal Terrestrial Radio Access Network (E-UTRAN): Overall Description*, 3GPP TS36.300, 2010.
- [86] V. Chandrasekhar and J. Andrews, "Femtocell networks : Survey," *IEEE Communication Magazine*, vol. 46, no. 9, pp. 59–67, 2008.
- [87] S. Carlow and C. Wheelock, *Femtocell Market Challenges and Opportunities*, 2007.
- [88] Jie Zhang and Guillaume de la Roche, *Femtocell: Technologies and Deployment*, 2010.
- [89] Tijane Fatima Zohra BADRI, SAADANE Rachid, Mohammed Wahbi, and Mbarki Samir, "Handover management scheme in lte femtocell networks," *International Journal of Computer Science & Information Technology (IJCSIT)*, vol. 5, no. 3, 2013.
- [90] L. Wang, Y. Zhang, and Z. Wei, "Mobility management schemes at radio network layer for lte femtocells," *IEEE VTC'09*, p. 1–5, 2009.
- [91] M. Hoyhtya, S. Pollin, and A. Mammela, "Performance improvement with predictive channel selection for cognitive radios," *Cognitive Radio and Advanced Spectrum Management (CogART)*, pp. 1–5, 2008.
- [92] Herbert A. David and H. N. Nagaraja, *Order Statistics, 3rd Edition*.

-
- [93] Milton Abramowitz and Irene A. Stegun, *Handbook of Mathematical Functions: with Formulas, Graphs, and Mathematical Tables (Dover Books on Mathematics)*, 1965.
- [94] H. C. Yang and M. S. Alouini, *Order Statistics in Wireless Communications Diversity, Adaptation, and Scheduling in MIMO and OFDM Systems*, Cambridge University Press, 2011.
- [95] D. W. Yue and H. Nguyen, "Orthogonal df cooperative relay networks with multiple-snr thresholds and multiple hard-decision detections," *Eurasip Journal on Wireless Com. and Net.*, vol. 10, 2010.
- [96] I.S. Gradshteyn and I.M. Ryzhik, *Table of Integrals*, 2007.