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Radio Network Management in Cognitive LTE-Femtocell Systems

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Abstract

There is a strong uptake of femtocell deployment as small cell application platforms in the upcoming LTE networks. In such two-tier networks of LTE-femtocell base stations, a large portion of the assigned spectrum is used sporadically leading to underutilisation of valuable frequency resources.

Novel spectrum access techniques are necessary to solve these current spectrum inefficiency problems. Therefore, spectrum management solutions should have the features to improve spectrum access in both temporal and spatial manner. Cognitive Radio (CR) with the Dynamic Spectrum Access (DSA) is considered to be the key technology in this research in order to increase the spectrum efficiency. This is an effective solution to allow a group of Secondary Users (SUs) to share the radio spectrum initially allocated to the Primary User (PUs) at no interference.

The core aim of this thesis is to develop new cognitive LTE-femtocell systems that offer a 4G vision, to facilitate the radio network management in order to increase the network capacity and further improve spectrum access probabilities.

In this thesis, a new spectrum management model for cognitive radio networks is considered to enable a seamless integration of multi-access technology with existing networks. This involves the design of efficient resource allocation algorithms that are able to respond to the rapid changes in the dynamic wireless environment and primary users activities. Throughout this thesis a variety of network upgraded functions are developed using application simulation scenarios. Therefore, the proposed algorithms, mechanisms, methods, and system models are not restricted in the considered networks, but rather have a wider applicability to be used in other technologies.

This thesis mainly investigates three aspects of research issues relating to the efficient management of cognitive networks: First, novel spectrum resource management modules are proposed to maximise the spectrum access by rapidly detecting the available transmission opportunities. Secondly, a developed pilot power controlling algorithm is introduced to minimise the power consumption by considering mobile position and application requirements. Also, there is investigation on the impact of deploying different numbers of femtocell base stations in LTE domain to identify the optimum cell size for future networks. Finally, a novel call admission control mechanism for mobility management is proposed to support seamless handover between LTE and femtocell domains. This is performed by assigning high speed mobile users to the LTE system to avoid unnecessary handovers.

The proposed solutions were examined by simulation and numerical analysis to show the strength of cognitive femtocell deployment for the required applications. The results show that the new system design based on cognitive radio configuration enable an efficient resource management in terms of spectrum allocation, adaptive pilot power control, and mobile handover. The proposed framework and algorithms offer a novel spectrum management for self-organised LTE-femtocell architecture.

Eventually, this research shows that certain architectures fulfilling spectrum management requirements are implementable in practice and display good performance in dynamic wireless environments which recommends the consideration of CR systems in LTE and femtocell networks.

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Finally, my deepest gratitude goes to my husband *'Anwer'* for his devotion, love, support, patience, and steady encouragement. I want to thank him from my heart for everything he has done.

Declaration

I hereby declare that the research documented in this thesis is my own unaided work, both in conception and execution. Information derived from the published and unpublished work of others has been acknowledged in the text and references are given in the list of sources. The thesis itself was composed and originated entirely by myself in the Wireless Networks and Communications Centre, Electronic and Computer Engineering Department, School of Engineering and Design at Brunel University.

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List of Abbreviations

3G	Third Generation
3GPP	3rd Generation Partnership Project
4G	Fourth Generation
ACK	ACKnowledgement
AD	Administrative Domain
AN	Access Network
AODV	Ad hoc On-Demand Distance Vector
APC	Area Power Consumption
BE	Best Effort
BER	Bit Error Rate
CAC	Call Admission Control
CFS	Cognitive Femtocell Systems
CN	Correspondent Node
CoA	Care-of Address
CR	Cognitive Radio
CRM	Cognitive Resource Management
CRN	Cognitive Radio Network
CSCC	Common Spectrum Control Channel
CSG	Closed Subscriber Group
CSMA/CA	Carrier Sense Multiple Access with Collision Avoidance
CTS	Clear-to-Send
CW	Contention Window
DC	Direct Current
DHCP	Dynamic Host Configuration Protocol
DL	Downlink
DL-DPCH	Downlink Dedicated Physical Channel
DSA	Dynamic Spectrum Access
DSL	Digital Subscriber Line
EPC	Evolved Packet Core
FA	Foreign Agent
FBS	Femtocell Base Station

FCC	Federal Communications Commission
FEC	Forward Error Correction
FIFO	First In First Out
FN	Foreign Network
FUE	Femtocell Users Equipment
GBR	Guaranteed Bit Rate
HA	Home Agent
HeNB	Home Evolved Node-B
HNB-GW	Home Node B- Network Gateway
HSDPA	High Speed Downlink for Packet Access
HSPA	High-Speed Packet Access
HTTP	Hypertext Transfer Protocol
Hz	Hertz
IF	Intermediate Frequency
IP	Internet Protocol
IPTV	Internet Protocol Television
ISD	Inter Side Distance
LTE	Long Term Evolution
M/M/1	Markov/Markov/1 Queue
MAC	Medium Access Control
MANET	Mobile Ad-Hoc Network
MH	Mobile Host
MIMO	Multiple Input Multiple Output
MIPv6	Mobile Internet Protocol Version 6
MLB	Mobility Load Balancing
MN	Mobile Node
MUE	Mobile User Equipment
NET	Network
NRTPS	Non- Real-Time Polling Services
OFDM	Orthogonal Frequency Division Multiplexing
OPNET	Optimized Network Engineering Tool
PDU	Protocol Data Unit
PHY	Physical Layer

PQ	Priority Queuing
PRBs	Physical Resource Blocks
PU	Primary User
QoS	Quality of Services
QPSK	Quadrature Phase-Shift Keying
RAN	Radio Access Network
RBR	Requested Bandwidth Range
RF	Radio Frequency
RNC	Radio Network Controller
RSRP	Reference Signal Received Power
RSS	Received Signal Strength
RTPS	Real Time Polling Services
RTS	Request-to-Send
SDR	Soft Defined Radio
SINR	Signal-to-Interference-Noise-Ratio
SNR	Signal-to-Noise-Ratio
SU	Secondary User
TDA	Transmission Data Attributes
TV	Television
UDP	User Datagram Protocol
UE	Users Equipment
UGS	Unsolicited Grant Service
UL	Up Link
UMTS	Universal Mobile Telecommunications System
VoIP	Voice over IP
WiMax	Worldwide Interoperability for Microwave Access
WLANs	Wireless Local Area Network

List of Publications

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Chapter 1

Introduction

1.1 Motivation

An important feature of Long Term Evolution/Third Generation Partnership Project (LTE/3GPP) systems is that it allows a distributed implementation of femtocells to meet a variety of service requirements by end users. The femtocell access points, denoted as Home evolved Node-B (HeNB) in 3GPP, are low cost, low-power, plug-and-play cellular base stations that provide local broadband connectivity. These HeNBs will need to possess adaptive/cognitive facilities to meet the deployment requirements [1].

Current wireless networks are characterised by a static spectrum assignment policy where government agencies allocate wireless spectrum to licensed holders on a long term basis for large geographical regions. The limited available spectrum and inefficient spectrum utilisation make it necessary to develop a new communication paradigm to exploit the existing wireless spectrum opportunistically. To address these critical problems, the Federal Communications Commission (FCC) recently approved the use of unlicensed devices in licensed bands [2] and this trend is likely to be repeated in other countries in Europe and around the world. Future wireless communication systems will be characterised by the coexistence of several different radio access technologies like Universal Mobile Telecommunications System (UMTS), LTE, LTE-Advance, and Worldwide Interoperability for Microwave Access (WiMax), Wireless Local Area Network (WLANs), and femtocell, as shown in Figure 1.1.

Figure 1.1: 4G cellular networks

There is a strong motivation to introduce cognitive adaptation functionalities to base-stations so they can re-configure their transmission characteristics to connect to variable numbers of users' requests, other base-stations, and respond to other dynamic changes in the Radio Frequency (RF) environment. For instance, as the number of wireless links in a LTE network is likely to be high, a fixed-scheduling mechanism will not achieve the required level of LTE efficiency in the long term [3]. The solution will be the Cognitive Radio (CR) which is a radio system that is aware of its operational and geographical environment. It has ability to sense the spectrum holes and learn from the spectrum previous experience using long-term monitoring in order to dynamically adapt its transmission parameters such as modulation, power, and frequency to access the available free spectrum. The Software Defined Radio (SDR) is the core technology of the CR that provides the flexibility and adaptability to improve efficiency of spectrum access. The CR can make decision about its radio operating behavior by mapping the leaned information against predefined objectives [4].

A very popular scenario of CR is opportunistic spectrum access, whose principle is temporal, spatial, and geographic "reuse" of licensed spectrum as shown in Figure 1.2. In this way, unlicensed Secondary User (SU) can be permitted to use the licensed spectrum, provided that it does not interfere any of the Primary Users (PUs) in the band. Therefore, CRs employ Dynamic Spectrum Access (DSA) to all available channels especially Television (TV) bands in order to improve the effective use of free channels using flexible spectrum access [5].

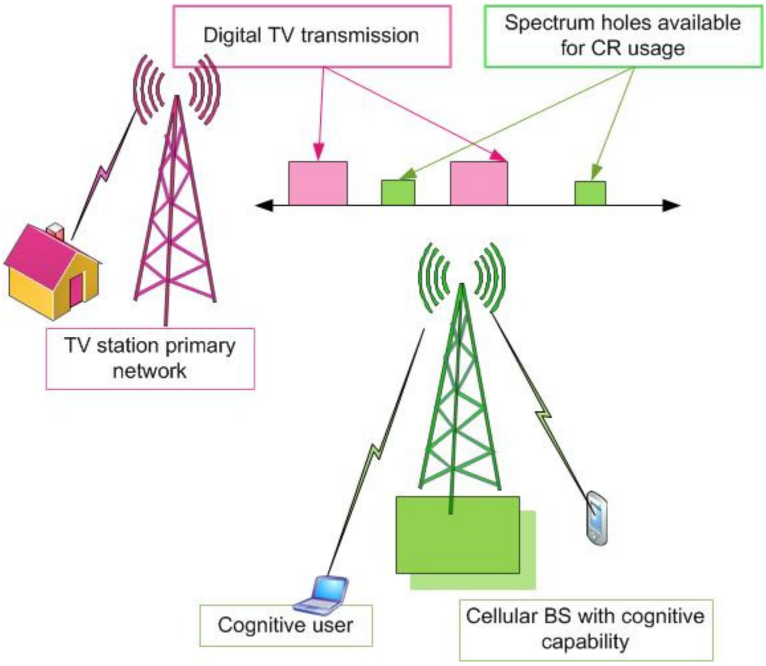

Figure 1.2: Cognitive radio system scenarios

Incorporating CR into femtocell has the potential to improve the macrocell capacity and spectrum efficiency. Despite the fact that a cognitive femtocell network can improve the performance of the macrocell network, the co-existence of the two networks can lead to interference problems. The two types of interferences that can occur between these domains are: cross layer which take place between femtocell and macrocell areas and co-layer which happens between femtocell and femtocell domains [6].

The motivation behind this research is to address wireless radio management for cognitive LTE-femtocell network deployments. The goal is to increase the spectrum access and data deliver rates using the same frequency bandwidth with the lowest possible power consumption metrics. This provides a flexible, adaptive and reconfigurable solution that interconnects this tired network to offer real time correspondence for subscriber to any available access node.

1.2 Problem Statement

There are many obstacles and problems that need to be resolved in order to obtain an efficient cognitive system of large/small scale based converged LTE-femtocell networks. This thesis deals with the radio system management of cognitive femtocells deployed in LTE network. Specifically, the study addresses the problem of spectrum access, power allocation control, as well as handover aspect in cognitive radio networks.

The spectrum obtainable by any network operator is limited compared with growing capacity for Fourth Generation (4G) networks. In addition, the predicted new available spectrum gained from users reallocation such as digital TV, will still be insufficient due to the increase of users and applications. Therefore, 4G radio access technologies may be able to provide higher data rates and more users' connections through more developed technologies. LTE and full 4G services may seem flatter and more predictable because they are based on universal IP and packet switching. However, there should be a consideration for more local access systems (such as cognitive femtocells) that can handle local transmission opportunities in order to increase the overall LTE network performance.

The efficiency of spectrum sharing increases when deploying femtocell within macrocell networks. At the same time, spectrum sharing is not in fact unique to femtocell networks, but is also relevant for macrocell networks. Since the number of femtocells could be much higher than the number of macrocells in a certain area, this kind of spectrum allocation requires an efficient spectrum trading to attain an efficient and fair spectrum utilisation [7]. The difficulty of the devoted spectrum formation is that the usage of radio spectrum is not efficient enough and the operator has to reserve a particular spectrum for the femtocell base station. Accordingly the highest risk of spectrum unavailability across the whole system would be resulted from unsuccessful deployment configuration of base stations.

The cognitive femtocell systems may be assigned to operate in their own devoted spectrum which is separated from the macrocell base stations. This deployment is referred to the "dedicated channel" deployment. However, the performance of this solution is limited by the assigned bandwidth, which makes it unreasonable application especially in dense femtocells environments. As a result, a practical solution turns out to be the co-channel sharing where femtocell and macrocell networks share all available spectrums as one common pool. Dynamic spectrum nature of cognitive radio may require good channel conditions with interference avoidance, which means that in the case of dead zone coverage, QoS cannot be guaranteed due to the variations in channel conditions. To mitigate interference in the co-channel deployment, dynamically power adapting schemes are necessary for femtocell networks to effectively alleviate any interference for systems employ Orthogonal Frequency Division Multiplexing (OFDM) technique [8].

The other challenge that is facing cognitive radio systems is the growing number of wireless technologies that may force more usage for power in future systems. In a typical wireless cellular network, the radio access part accounts for up to more than 70 present of the total energy consumption [9]. Therefore, increasing the energy efficiency of LTE-femtocell radio networks is very important to meet the challenges raised by the high demands of traffic and increased numbers of users.

The main obstacle in femtocell networks is due to the fact that an increased number of smaller cells [10] results in a proportional increase in the numbers of occurred handovers. The users moving between Femtocell Base Stations (FBSs) increase the technological challenges of real time services and re-connection procedures. Therefore, a successful FBS deployment should be combined by reducing the unjustified frequent handovers.

The above challenges mentioned are the main driving points for the contributions of this research and the developed algorithms given in the following chapters.

1.3 Aims of Research

The aim of this thesis is to investigate the key issues that enable efficient spectrum management and increase the network capacity using new cognitive LTE-femtocell techniques. The aims of this research are addressed through the following objectives:

- The aim of the first part of this research is to investigate the management of radio resources in order to improve the spectrum allocation performance. In this regard, three novel algorithms for spectrum sensing, spectrum access decision and scheduling are proposed for utilising the unused spectrum while avoiding collision between femtocell and LTE users. These provide a better and flexible modelling for radio coexistence between multi-access system that is composed of different transmission functionalities and technologies.

- The second part of the thesis presents novel power management algorithms to improve the network capacity for outdoor users using the proposed cognitive system. The new power controlling schemes adjust the power of transmission by adapting the size of the coverage areas according to the position of the mobile end users in relative to the femtocell base station. The aim is to increase the power savings of the system and reduce the interference between various domains in such heterogonous mobile network.

- The third part of the thesis is to improve the mobility management between LTE and femtocell networks by introducing a new entity named Call Admission Control (CAC) at the femtocell base station. The CAC mechanism proposes a local handover management that is able to reduce unnecessary handovers between femtocell and LTE base stations. This is performed using Markov chain [11] process that handles the call arrival as a function for mobile speed transitions. The aim is to reduce the time of connection consumed during admission of mobile user moving between femtocell and macrocell domains.

1.4 Methodology

The cognitive management system involves various operations in different network layers, which are cooperating with each other. Therefore, it is difficult to derive a stringent mathematical optimal solution to evaluate the system performance. In this research, advanced approaches are used with novel proposed algorithms alongside mathematical models for each of the investigated topics. The performance of the given solutions are evaluated at the system level and compared with existing literature solutions. The interactions among these proposed solutions also add difficulties in the numerical modelling and the system evaluation of the network performance. This motivates the use of system simulations using the Optimised Network Engineering Tools (OPNET) simulator that provides multi-options for examining wide sized networks with many project nodes.

The system design for model evaluations involves two different networks coexisting together as primary and secondary systems. This generates a wireless environment of dynamic spectrum access that is similar to the anticipated proposals for future heterogeneous networks. In this method, the primary users can access the spectrum at any time as the licensed spectrum occupiers. While, the cognitive network composing of LTE-femtocell nodes can access the spectrum on temporarily occasions whenever the primary system is offline.

This thesis proposes a novel system management design for cognitive femtocells. The new system considers the information from both Physical (PHY) sensors and Medium Access Control (MAC) layers as the factor inputs for the proposed algorithms. Jointly, a new entity named “channel allocation” is incorporated with the MAC layer to perform the spectrum access decisions and resource allocation actions. The development in the MAC layer includes also the solution to reduce the power consumption of femtocell BS transmission with developed pipeline models. The handover solution for reducing the unnecessary redundant handovers is installed at the Network (NET) layer to perform the admission control of call arrival.

The ultimate goal is to explore different configurations to achieve the seamless communications in the future converged 4G systems networks and propose efficient coexistence solutions.

1.5 Thesis Novel Contributions

This thesis addresses the task of supporting new system for cognitive LTE-femtocell wireless networks. It provides different procedures with special focus on: spectrum management algorithms, developed power control model, and a new handover mechanism. The following figure highlights the main contributions of the new cognitive femtocell system functioning, as follows:

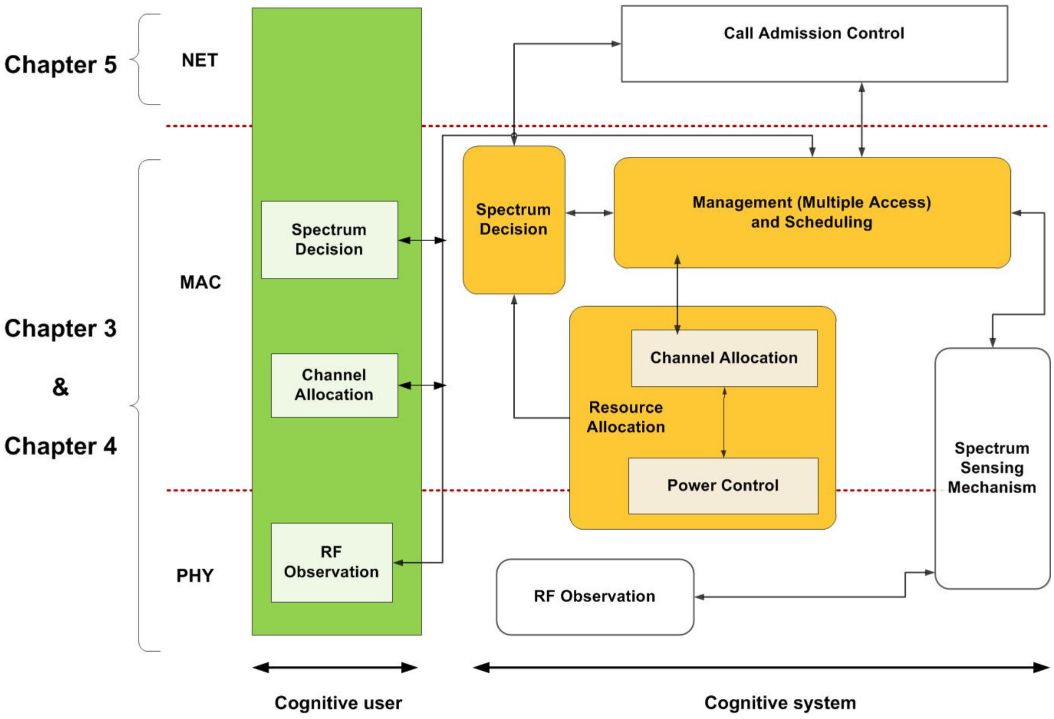

Figure 1.3: Complete system diagram of research contributions

The following are the main features of spectrum management functions:

Spectrum Sensing**:** the cognitive radio makes observations of the RF (Radio Frequency) spectrum and captures their information to determine and detect which of the TV channels are occupied and which are free. The free channels represent white space that can be used by the cognitive radio network.

Management: this function can communicate with all CR users within its coverage and decide the spectrum availability of its coverage. The observed information of each CR user will pass to the cognitive base station or exchanged with its neighbours, and then spectrum availability is determined accordingly. This function it has ability to contract between different layers and organised the tasked between them. Moreover, it includes new scheduling policy that has ability to delegate management of resource policy to users using Round Robin (RR) algorithm.

Resource Allocation: Based on the QoS monitoring results, CR users select the proper channels (channel allocation) [12] and adjust their transmission power (power control) [13] to achieve QoS requirements as well as resource fairness. Especially in power control, sensing results need to be considered so as not to violate the interference constraints.

Spectrum Decision: Based on spectrum availability and the information that are collected form the cognitive sensor, the spectrum decision unit decides on the best spectrum band among the available bands according to the QoS requirements of the applications. The main functionalities required for spectrum decision are spectrum characterisation, spectrum selection, and reconfiguration.

Call Admission control: The CR network is responsible for processing the handover call requests from mobile end users. Admission control strategy will decide, at the time of call arrival, whether or not a new call should be accepted by the system.

1.5.1 Novel Spectrum Resource Management Model

In this thesis, novel spectrum management functionalities such as spectrum sensing, spectrum access, and spectrum decision, are introduced as shown in the Figure 1.2. One main challenge in CR networks is to integrate these functions in the layers of the protocol stack. Therefore, the CR users can communicate reliably over a dynamic spectrum environment. In this task, novel algorithms for optimal spectrum allocation system and the overall network management framework are researched in order to solve the spectrum efficiency problem.

Management unit is interacting with the distributed resources using the new installed functions (e.g., power control, spectrum allocation, and scheduling). This is also used in later contributions in order to achieve the goals of the thesis. More specifically, first the unit exploit various spectrum bands using upgraded sensing technique in order to maximise spectrum access efficiency. Secondly, the new scheduling strategy process is considered based on round robin method to balance the interchange between cognitive femtocell and their clients subject to channel variability.

Finally, the framework design of the resource management has the ability to check the domain network for new available resources, and gets comprehensive information about the radio channel resource availability using the RF observation unit. Therefore, the resource management algorithms can efficiently increase the capacity of the network.

1.5.2 Spectrum Allocation Technique

New channel allocation function is introduced to identify the Quality of Service (QoS) requirements and white space available for transmissions using priority queuing. Here, the priority is determined based on the data rate requested by an application, with minimum BER threshold of 10^{-3} in order to achieve an efficient spectrum utilisation. This type of spectrum allocation compares BER requirements of all applications in the queue before allocating any sub-band to a certain application. Based on this model, different applications are assigned to different spectrum queues and transmission decision choice between them is made whenever the investigated a channel that matches the QoS requested by one of applications.

1.5.3 New Power Management Approaches

The new cognitive management system should target self-organised, self-configuration operations, cooperative network, and seamless power consumption across multiple operators. This certainly leads to flexible and intelligent network management. The optimisation algorithms that intelligently control the power of the cognitive femtocell are proposed to reduce the power consumed in link formulation. The algorithm periodically updates the pilot power configuration based on the distance and the moving mobile user position. Then, the cell coverage planning function is applied to evaluate the cognitive coverage area and set the optimum LTE cell size.

1.5.4 Novel Mobility Management Mechanism

In this thesis, a novel mobility management mechanism is proposed for cognitive femtocell networks to enable seamless handover between LTE-femtocell arrangements considering user speed. The proposed CAC addresses a two level-value of threshold which leads to maximise capacity with minimum switching latency. This is performed by allowing mobile users with low and medium speeds to connect to the femtocell BS while mobile users at higher speeds are assigned to the LTE macrocell BS. This leads achieving seamless heterogeneous handovers by saving the resources and time consumed for unnecessary handovers.

This new CAC mechanism involves the identification of the mobile users' ground speed through calculating the distance and time of signal delays between the femtocell BS and the moving mobile user. In this way, whenever a cognitive femtocell receives a handover request from a UE, the cognitive femtocell BS makes a decision to accept or reject the handover after comparing user speed with a given threshold. This mechanism allocates a new handover call to a selected femtocell BS based on the threshold that is classifies mobiles into three groups low, medium, and high speeds. However, the proposed mechanism not only considers user speed, but also takes the outstanding capacity of the femtocell and LTE BSs into account to decide a suitable network. Based on this scheme, the mobility management performance evaluation shows an improved performance for the chosen mobile users' speeds over the traditional handover schemes.

1.6 Thesis Organisation

This thesis mainly addresses the aforementioned challenges of cognitive femtocell deployment in 4G wireless systems. The work presented in this thesis is organised into six chapters with three chapters for the novel contributions. The first chapter is introducing the thesis contributions, viewpoints and the motivations for the research. The research goal of this thesis is stated according to the requirements of cognitive femtocell networks and resource management.

Each chapter starts with a brief introduction that highlights the main contributions and provides an overview of that chapter. There are also related work sections in each of the analysis chapters on the research topics, and technical solutions and challenge aspects that are analysed in these chapters. In each of the analysis chapters a technical solution or concept is evaluated using a system model and compared to existing work. At the end of each chapter, a brief conclusion and list of references is presented. The remainder of this thesis is organized as following:

Chapter 2: Explains the technical challenges of the proposed cognitive system for this research in terms of PHY and MAC layer models respectively. This chapter starts by presenting the technical requirements and deployment feasibility for the network systems. Then, the existing and future types of network coexistence models are introduced and described in terms of value networks.

Chapter 3: In this chapter, a novel spectrum resource management system is designed in order to precisely produce various adaptation techniques and the analysis of various aspects of wireless femtocell systems is presented. This chapter discusses in detail various aspects including analysis of different types of resource management systems. A novel spectrum management functions, spectrum sensing, scheduling and decision algorithms are applied to ensure the service quality, enhanced resources allocation and to prevent waste of transmission power.

Chapter 4: This chapter first highlight the limitations of the existing power controlling approaches and then address a new adaptive power management algorithm. A novel power consumption modelling that defines a new power metric as the objective optimisation problem is presented and successfully evaluated. Then, numerical results show that deploying femtocells can significantly improving the daily energy consumption.

Chapter 5: Describes the proposed mobility management scenarios using a novel handover mechanism that reduces the numbers of unnecessary handovers. The mechanisms used to manage both challenges of maintaining communications among multiple base stations, and mobile network components. A detail of new call admission control methodology is explained based on mobile velocity and received signal strength. Moreover, Markov chain method is presented for the managing the call arrival admission.

Chapter 6: Present the summary, major conclusions and a discussion on the limitations in its current state and offers a number of possible areas for future research.

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Chapter 2

Background and Technical Challenges in Cognitive LTE Femtocell Systems

This chapter presents the technical background that motivates the research case studies of this thesis. It starts with a demonstration of the evolution of 4G wireless networks. The development towards the LTE network framework is described in detail. Then a survey is given for the impact of deploying femtocells with various access techniques while interconnected to the macrocell base station. The cognitive radio technologies and their wireless coexistence challenges are discussed to allow a reconfigurable interfacing to LTE-femtocell network models. Next, the state of on-going femtocell research efforts are discussed with special focus on the key technical challenges of managing cross-tier radio interference, resource allocation, QoS assurance, multi-tier spectrum access, and how to provide power control over the cognitive femtocell based LTE backbone network. The challenging requirements for effective mobility management are presented to devise solutions in later chapters. The chapter is concluded with a short summary.

2.1 Introduction

The 4G mobile broadband systems are expected to solve outstanding problems of Third Generation (3G) systems and to provide a wide variety of new services, by handling the predicted traffic volumes and meet constantly increasing user data rate demands in an approachable manner. The term 4G is used broadly to include several types of wireless access communication systems, not limited by cellular telephone systems. 4G is projected to provide high speed; high capacity low cost per bit, and IP based services. 4G is all about an integrated, IP global network that is based on an open system approach [1]. Increased the adjustable bandwidth demand of mobile clients, will force operators to optimise the way the capability of a base station is utilised. Unlike in previous generations, the ability of a base station to effectively satisfy the service demand of all its mobile clients would be highly limited and will mostly depend on its infrastructure restrictions, as well as on the service distribution among its mobile clients. However, the successful deployment of 3G cellular networks worldwide, the attention of the mobile industry is now motivated on the beyond 3G evolution of the wireless broadband systems in order to satisfy the end users. The upcoming 4G cellular broadband system is predicting potentially a smooth integrate of these new technologies in order to support effective seamless communication at high speed data rate supported with global roaming and user modified personal services [2].

There are three different potential approaches in developing the future 4G networks. Firstly, is to increase the cell capacity using new techniques such as LTE which is replacing the WiMAX backbone stations. Secondly, is to improve the spectral efficiencies using reconfigurable technologies such as the CR and advanced antenna systems. The third approach is to develop new architectures for mobile networks that help to achieve an autonomous communications. A combination of these technologies and arrangements, if not all three, will lead to the new generation of efficient 4G networks that can be deployed to deal with huge traffic requirements and various corresponding technologies. Figure 2.1 illustrates the various given solutions for future standardisation of 4G systems. The future networks employ an IP-based environment for all traffic requests counting voice, video, and broadcasting media that can access landline and wireless networks. This is integrated in the future 4G solutions and its applications. Together with intelligent terminals, 4G can provide easy access to the broadband services and understanding of the personal downloading profiles.

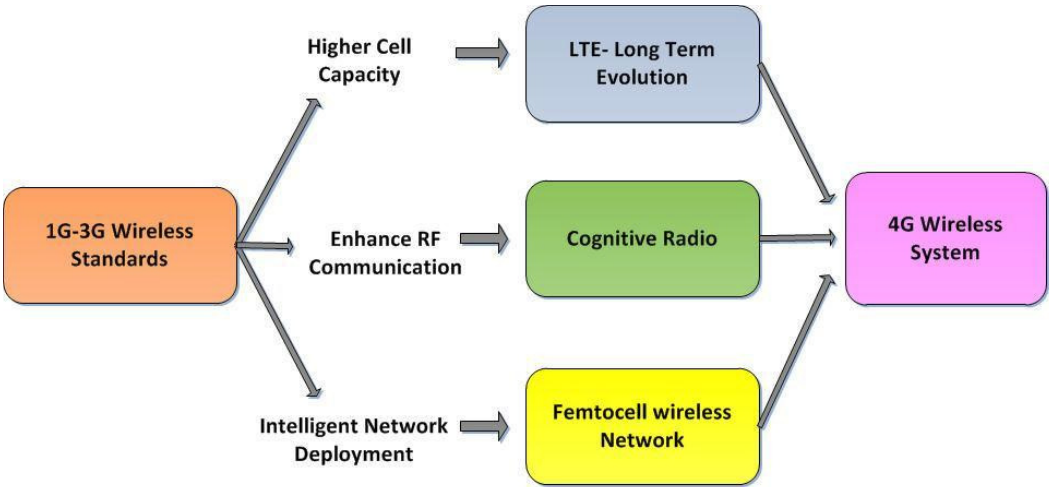


Figure 2.1: Future 4G systems with different technical applications

This allows uninterrupted coverage for a user that changes terminals or switches unnoticeably between the underlying fixed and mobile networks. This is very important for ad-hoc networking and for a mobile user that travels among different terminals of a single network or with the terminals of third parties. In short, a 4G network provides its individual users with full control over privacy and costs. This is a natural extension of the current technologies of broadband Internet and 3G mobile networks like UMTS.

This chapter addresses the key technical challenges encountering suitable femtocell system deployment management. There are so many requirements for keeping femtocell costs as low as possible for effectively competing against the ubiquitous Wi-Fi technology. The main challenge for the femtocell deployments is the interference with the macrocell base station. Other femtocell functions are addressed, including resource management, spectrum allocation management, providing QoS over an Internet backhaul and allowing access to femtocells [3]. Handover and mobility are also very important aspects in femtocell networks as there are different types in femtocell handover from/to macrocell. Furthermore, power consumption is very important consideration to be taken into account in the next generation wireless networks.

2.2 Current Standardisation

Just as for any other new technology, industry standardisation is a very important factor from both the market acceptance and economy of scale (i.e., ecosystem) perspectives. Femtocells are no exception [4]. Early in 2008, the UMTS femtocell standardisation topic gained tremendous interest from many mobile operators, and efforts to find a way to have the capability incorporated into UMTS Release 8 began with great intensity. During April 2009, the Third Generation Partnership Project (3GPP) in collaboration with the femto-forum and the broadband forum released the world's first femtocell standard. This standard covers different aspects of femtocell deployments including the network architecture, radio interference, femtocell management, provisioning, and security [5]. Concurrently, a number of operators-AT &T (USA), O2, and Motorola (Europe) and Softbank (Japan)-are conducting femtocell trials prior to market.

The 3GPP is the primary international standards organisation dealing with mobile networks using the GSM/UMTS and LTE family of air interface technologies. Therefore 3GPP has been linking the standards of UMTS femtocells [6]. Although the standardisation efforts are still on-going process, the current applicable technologies are the inspiring guide to develop any models for the future.

2.3 Long Term Evolution (LTE) Technology

Fourth generation technology is structured to meet the essential requirements for increased capacity and improved network performance. LTE is intended to provide high data rate, low latency, and packet optimised. Meanwhile, there is no circuit switched domain in LTE, voice connectivity is based on Voice over Internet Protocol (VoIP) on top of packet switched IP-protocol. LTE supports a wide range of bandwidths from 1.25 MHz to 20 MHz. The 20 MHz bandwidth gives peak data rate of 326 Mbps using 4x4 Multiple Input Multiple Output (MIMO). For uplink, MIMO currently is not realised, so the uplink data rate is limited to 86 Mbps. Being an evolution of LTE, LTE-Advanced should be backwards compatible in the sense that it should be possible to deploy LTE-Advanced in spectrum already occupied by LTE with no impact on existing LTE terminals [7].

LTE offers important developments over previous technologies such as High-Speed Packet Access (HSPA) and Universal Mobile Telecommunications System (UMTS) by presenting a novel PHY layer and improving the central network. The main reasons for these modifications in the Radio Access Network (RAN) system design are the demand to provide higher spectral efficiency, lower time delay, and more multi-user flexibility than the currently deployed networks. In the development and standardisation of LTE, as well as the implementation process of equipment manufacturers, simulations are necessary to test and optimise algorithms and procedures. This has to be performed on both, the physical layer (link-level) and in the network (system-level) context [8].

2.3.1 LTE-OFDM Technique

In LTE and LTE-Advanced networks, Orthogonal Frequency-Division Multiplexing (OFDM) [9] has been chosen as the multiple access method since it can provide high data rates and spectrum efficiency. In OFDM the whole bandwidth is divided into small sub-carriers or parallel channels which is then used for transmission with a reduced signaling rate. These sub-carriers are orthogonal to each other which mean that they consist of a set of individual sub-carriers and there is no inter sub-carrier interference between them. Each subcarrier frequency is chosen so that an integral number k of cycles in a symbol period. The subcarrier frequency is shown in the equation given below,

$$f_{sc} = k\,\Delta f \tag{2.1}$$

where Δf is the sub-carrier spacing. They do not need to have the same phase, so long integral number of cycles in symbol time T.

Sub-carrier is first modulated with a data symbol of either 1 or 0, the resulting OFDMA symbol is then formed by simply adding the modulated carrier signal. In LTE and LTE-Advanced techniques, orthogonal OFDM is chosen as the multiple access process since it can deliver high data rates and spectrum efficiency. In LTE systems that are based on OFDM, users are multiplexed in time and frequency by means of a scheduler that dynamically allocates subcarriers to different users at different time instances according to predefined scheduling metrics. Therefore, the OFDM based multiple transmissions by means of cognitive radio stations have been known as an efficient system to meet the requirements of future cognitive wireless networks [9].

OFDM is a spectral efficient transmission structure that divides a high bit rate data stream into several parallel narrowband low-bit-rate data streams often called sub-carriers. This partition is made in the way that sub-carriers are orthogonal to each other which eliminates the need of non-overlapping sub-carriers to avoid inter-carrier interference. The first carrier is selected so that its frequency contains an integer number of cycles in a symbol period as shown in Figure 2.2.

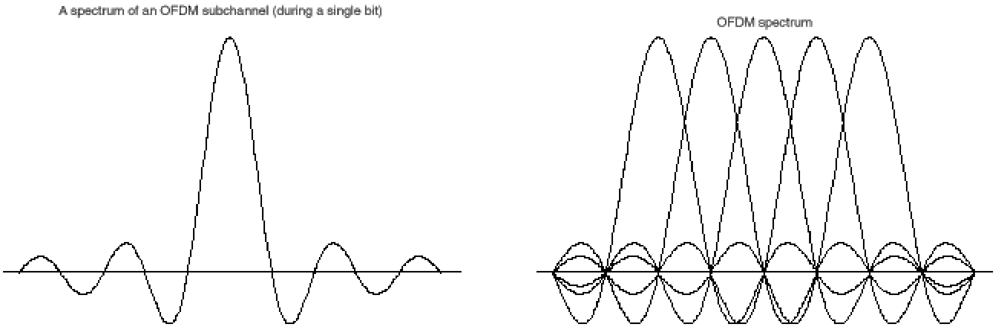


Figure 2.2: Time-frequency representation of OFDM sub-carrier

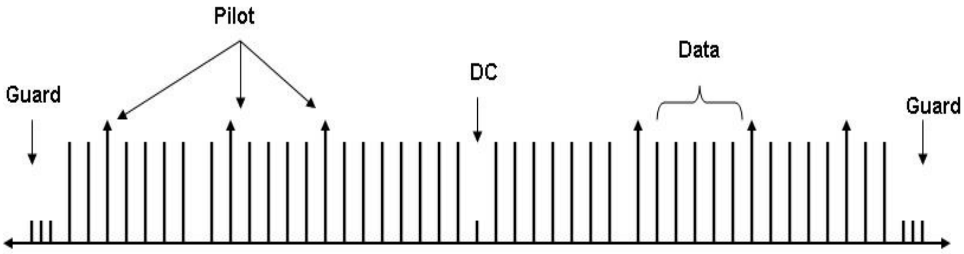
In order to make sub-carriers orthogonal to each other, adjacent sub-carriers are spaced by [9]:

$$BW_{sc} = \frac{BW}{N_{sc}} \qquad (2.2)$$

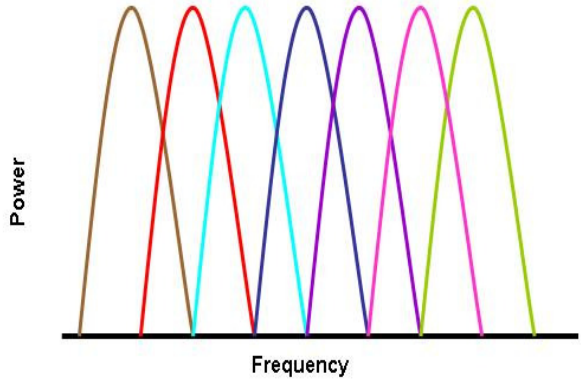
Where BW denotes the nominal bandwidth of high-bit-rate data stream, and N_{sc} refers to the number of sub-carriers.

The OFDM offers high spectral efficiency by allowing the overlapping of the spectrum of the sub-carriers. In order for this to work, the Inter-Carrier Interference ICI between sub-carriers must be mitigated. This is achieved by making the sub-carriers mutually orthogonal. The orthogonality between sub-carriers is maintained by carefully selecting the spacing between the sub-carriers and the savings of bandwidth with OFDM compared to a conventional system with the same sub-carrier bandwidth.

OFDM as shown in Figure 2.3 divides the frequency bandwidth in narrow orthogonal sub-parts called sub-carriers. The sub-carriers include data carriers, pilot carriers and a Direct Current (DC) sub-carrier. The data carriers are used to carry data; the pilot carriers are used for channel sensing purposes and the DC mark the centre of the channel. The conventional system uses a guard band between adjacent sub-carriers. On the other hand, the spectra of the OFDM sub-carriers overlap, leading to higher spectral efficiency.



OFDM Sub - carriers



Orthogonal Frequency Division

Figure 2.3: Frequency bandwidth of OFDM

Each subcarrier is modulated with conventional modulation scheme such as Quadrature Amplitude Modulation (QAM) or Phase Shift Keying (PSK) at a low symbol rate. The orthogonally of the sub-carriers means that each sub-carrier has an integral number of cycles over a symbol period consequently, there is a difference of an integral number of cycles between any two sub-carriers over a symbol period. This ensures that the spectrum of each sub-carrier has a null at the centre frequency of each of the other sub-carriers in the system [10].

OFDMA is an excellent choice of multiplexing scheme for the 3GPP LTE downlink. Although it involves some complexity in terms of bandwidth resource scheduling, it is vastly superior to packet transform approaches in terms of efficiency and latency. In OFDMA, users are allocated a specific number of sub-carriers for a programmed amount of time. These are referred to as Physical Resource Blocks (PRBs) in the LTE specifications. PRBs thus have both a time and frequency dimension. Allocation of PRBs is handled by a scheduling function at the 3GPP base station (eNodeB) [11].

LTE frame structure is 10 ms in duration as shown in Figure 2.4. Each frame is divided into 10 sub-frames, each sub-frame being 1.0 ms long. Each sub-frame is further divided into two slots, each of 0.5 ms duration. Slots consist of either 6 or 7 OFDM symbols, depending on whether the normal or extended cyclic prefix is employed.

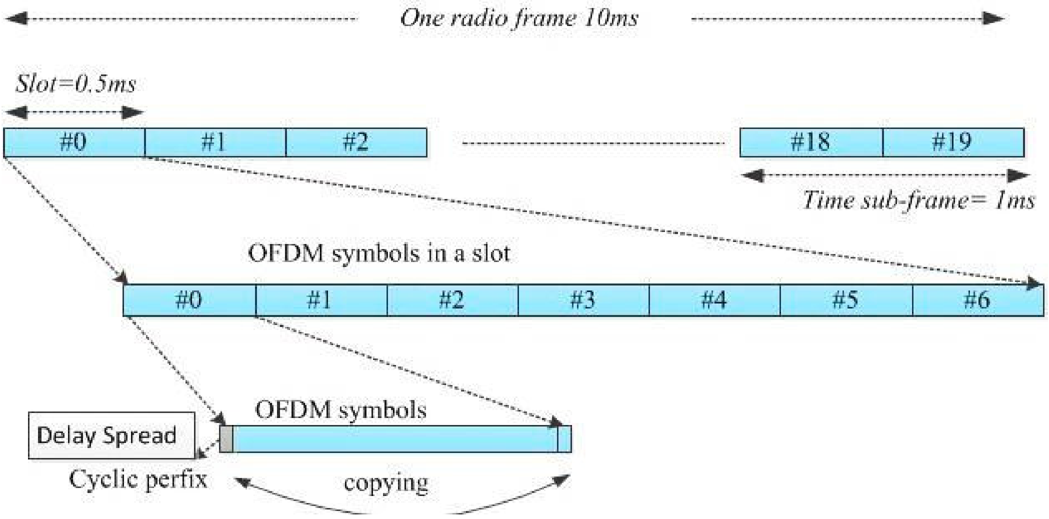


Figure 2.4: LTE frame structure

LTE uplink requirements differ from downlink requirements in several ways. Not surprisingly, power consumption is a key consideration for UE terminals. Single Carrier – Frequency Domain Multiple Access (SC-FDMA) is well suited to the LTE uplink requirements. The basic transmitter and receiver architecture is very similar (nearly identical) to OFDMA, and it offers the same degree of multipath protection [11].

2.4 Femtocell Networks

Femtocell is an economical solution to provide high speed indoor communications instead of the conventional macro-cellular networks. Especially, cognitive femtocell is considered in the next generation cellular network such as 3GPP LTE and WiMAX802.16e systems. Although the femtocell has great advantages to improve coverage for outdoor/indoor users, the interference and mobility management problems are critical issues in the operation of such networks.

Recent surveys have predicted that 50 present of phone calls and 70 present of data services will happen indoors. In next generation systems, more intelligent devices will appear, and the contents of their services will require more network capacity than the services that exist today [12]. Since it is expensive to serve indoor customers with increased service demands from macrocells base stations, new solutions for improving the indoor coverage/capacity are required. According to the femtocell working procedures, the femtocell unit adapts its coverage area to avoid harming other transmitting services in the area by serving around 4-8 customers. However, this definition does not include limits for the number of expected femtocells in a certain area. In other words, the growth of the number of FBSs may impact network performance by consuming all locally available resources without centralized mapping to the spectrum access function.

FBSs are low-power base stations operating in the licensed spectrum that can integrate mobile and Internet technologies within the home using optical fibre connection or Digital Subscriber Line (DSL). FBSs can be deployed outdoor as a relay station or indoors to provide exclusive access to the subscriber. For instance, instead of an operator owning all base stations in a city area, femtocells base stations could be acquired by individuals or small organisations. Femtocell deployment network architecture is illustrated in Figure 2.5.

A femtocell unit generates a signal to the personal mobile equipment's and connects this to the operator's network through the Internet. This allows the improvement of coverage and capacity for each user within their hotspot coverage area. Applications, and services should be delivered at the appropriate security levels and finally, several "green" aspects like necessary power or energy levels needed, activation or deactivation of power consuming devices etc., should be considered in order to achieve future environment friendly networks and infrastructures.

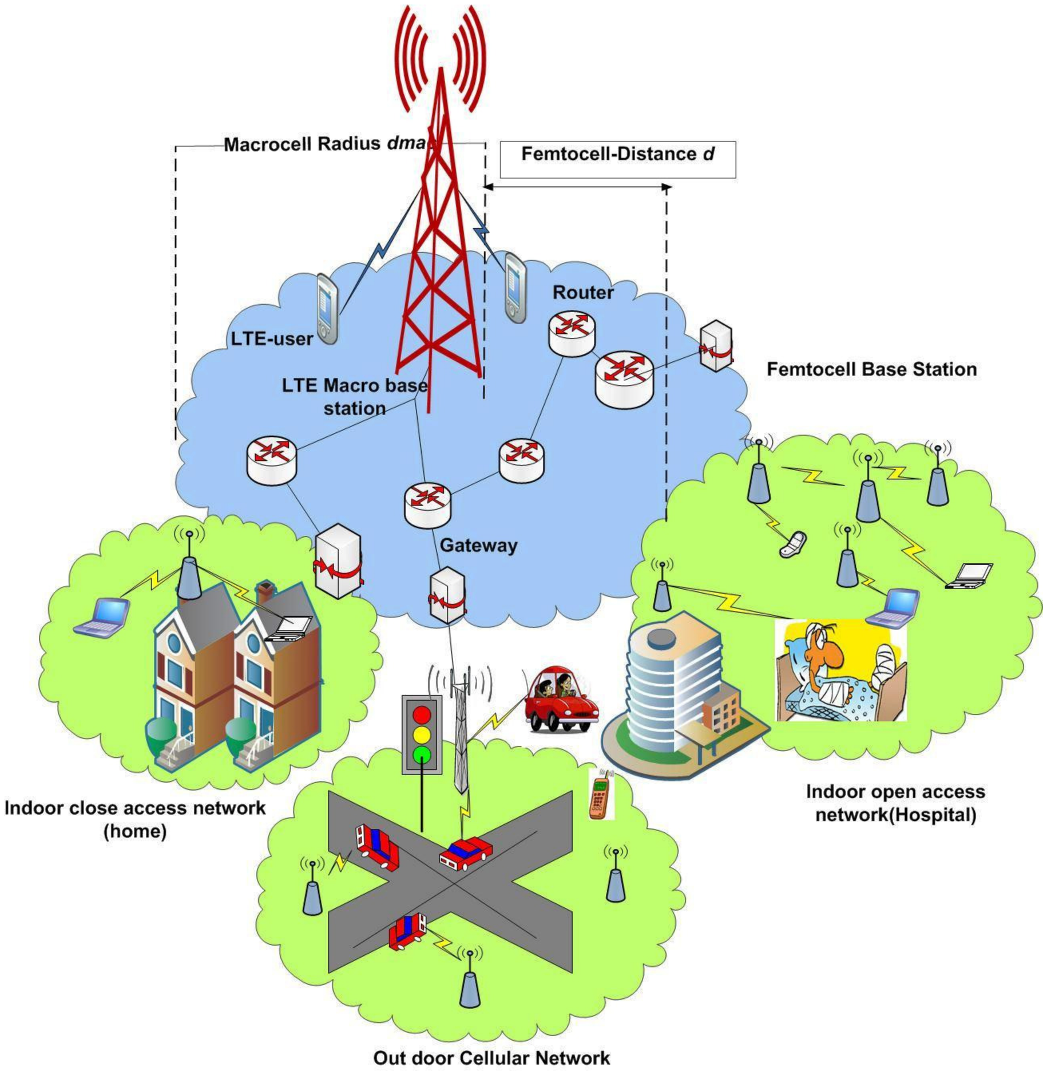


Figure 2.5: Femtocell deployments in 4G wireless systems

2.4.1 The Need for Small-Cell Base Station

The two major limitations of wireless communication are range and capacity. If a service provider wants to improve coverage, either they install a macrocell and provide high power, or they can use a smaller base station that provides coverage only up to a few hundred meters also provide high data rates, at lower power. Even from an economics point of view, femtocells have been found to provide a low cost solution compared to installing higher power macrocells to provide the same quality of service. The goal of femtocells is to provide reliable communication using existing broadband Internet connection. There are three main reasons for requiring femtocells in the current cellular services as shown in Figure 2.6.

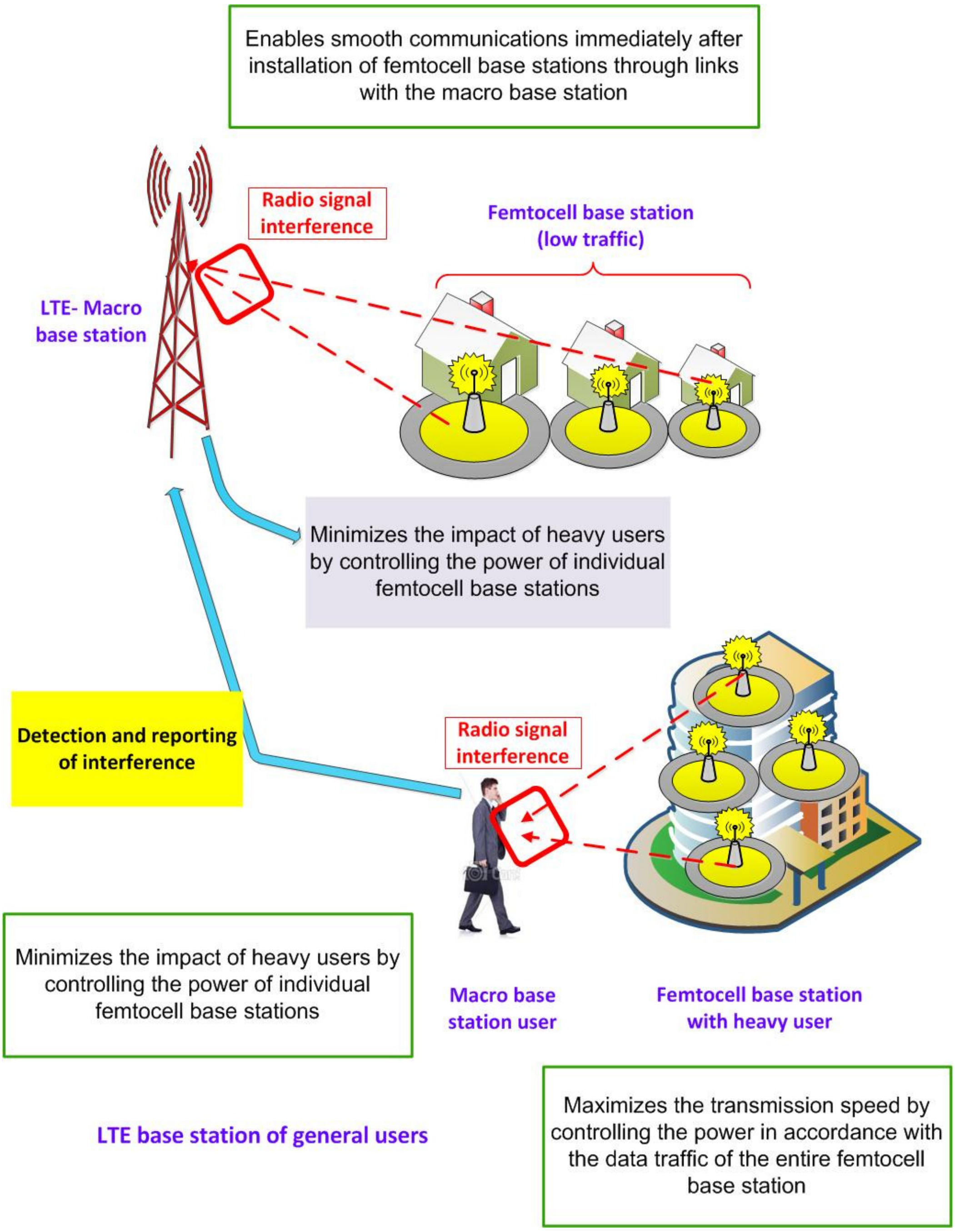


Figure 2.6: Femtocell knowledge developed

- ***Coverage:*** As macrocells cannot deliver good indoor coverage, femtocells can provide strong signal strength indoors. The coverage of femtocells is limited to a few hundred meters or less, which be within the setting of a home or an office. As the distance between the transmitter and the user is now smaller, it leads to higher received signal strength.

- ***Capacity***: Reduced distance between the femtocell and the end user, leads to a higher received signal and femtocells can serve few users, they can devote a larger portion of their resources (transmit power & bandwidth) to each sub-scriber. Then, there is less number of users using the same spectral resources which saves more resources for other users [3]. In other words, the user almost gets a private bandwidth from a shared bandwidth.

- ***Power:*** the increasing number of mobile users leads to a huge load on the macrocellular base stations. The deployment of femtocells will divert many users from macrocell to the femtocell stations in order to reduce the load on macrocells [13]. In addition, a balance can be maintained with the end users effectively using shared macrocells-to-femtocells infrastructure either outdoors or at indoors.

2.4.2 Femtocell Deployment Aspects

Fourth Generation broadband wireless mobile networks, specifically LTE and beyond, are considering issues related to the deployment of femtocells [14]. The feasibility of femtocells deployment in cellular network is studied by the standard development organisations like 3GPP [15]. The deployment of femtocell, low power base stations, together with predictable sites is often believed to greatly lower energy consumption of cellular radio networks since the communication distance is decreased, less power per bit is needed and available spectrum resources are shared between fewer users.

The impact of access control for femtocells is particularly substantial in the integrated macrocell-femtocell deployment scenario. For example, when the macrocell and femtocell networks share the same carrier, this heterogeneous deployment scenario is expected to be the standard rather than the exception, since macrocell network operators possibly will not have any other choice to obtain as much user volume as they can from their costly spectrum by deploying co-channel femtocell systems.

In applied deployment of femtocell systems, the location of FBSs in a random and uncoordinated fashion is unavoidable and may generate high interference scenarios and dead spots particularly in wireless environment [16]. The impact of interference on macro/femto cell User Equipment (UEs) depends on the power, bandwidth utilisation, femtocell density, as well as the access control methods of co-channel femtocells. The impact of interference is caused by femtocells on macrocell capacity and coverage for High Speed Downlink for Packet Access (HSDPA) systems and there are a few mitigation techniques variation of control channel power, power zone isolation, and adaptive power control [17].

2.4.3 Access Mechanisms

Femtocell systems are deployed using one of the following three methods [18]. The scenario for femtocell deployed as open, close, and hybrid access base stations is shown in Figure 2.7.

2.4.3.1 Close Access Method

A femtocell can be positioned in close access network areas, such as homes or offices, which mean that the FBS is providing services to fewer clients, and only registered mobiles can have access to such a femtocell and the macro-user has no access to the FBS. From the description of close access, only users who are listed in the allowed access list of the FBS are granted access to the base station. The main reason for this type of deployment is to guarantee user knowledge when they are within coverage of the FBS. However, one critical issue arises with the deployment of this method when an unsigned user enters the femtocell coverage and that user is not on the allowed access list because it is close access system.

Generally, the visiting macro-user to the femtocell coverage area will still attempt to access the FBS due to the fact that close FBS pilot power signal is usually much higher than macrocell BS pilot signal within the FBS coverage. Nevertheless, this effort will not be successful due to the fact that visiting macro-users are not on the allowed access list of the FBS. This method has the advantage of decreasing the number of handovers in this particular network and that each user can get a high data rate for being close to the femtocell station because of the limited number of users.

2.4.3.2 Open Access Method

Femtocell base stations are deployed in open areas like airports or hospitals. Any user has the right to access these FBSs and there is no need for registration in this case. Complete open access occurs when any user become close to the BS, as long as UE is in the coverage of the femtocell, if of course, there is resource capacity available on it. While appropriate for an operator-owned femtocell deployment, a completely open access scheme may prevent, in the residential femtocell case, an entitled user to connect to its FBS due to capacity being used up by macrocell users [19]. Apparently, open access is beneficial to network operators, by providing an inexpensive way to expand their network capacities by leveraging third-party backhaul for free. Open access also reduces macro-to-femto interference by letting strong interferers simply use the femtocell and coordinate with the existing users through it. However, unwanted handover may be increased for many users entering and leaving such femtocells, causing a noticeable decline in the quality of service [20].

2.4.3.3 Hybrid Access Method

The approach of open and close access methods for femtocells applications are likely to occur in some cases. In such a model, the unregistered subscribers are allowed to access the femtocell base station, but only for limited usage of resources. Hybrid access is based on the limited amount of resources that are available to all users, as shown in Figure 2.7, while the rest are operated in a closed subscriber’s group manner. When the access method blocks the use of femtocell resources to a subset of the users within its coverage area, a new set of interfering signals is implicitly defined in such an area. Hence, the deployment of closed subscriber’s group femtocells makes the problem of interference mitigation even more complex.

Hybrid access methods reach a compromise between the impact on the performance of subscribers and the level of access granted to nonsubscribers. Therefore, the sharing of femtocell resources between users and non-users’ wants to be finely tuned, otherwise, subscribers might feel that they are paying for a service that is to be exploited by others. The influence on subscribers must thus be minimised in terms of performance [21].

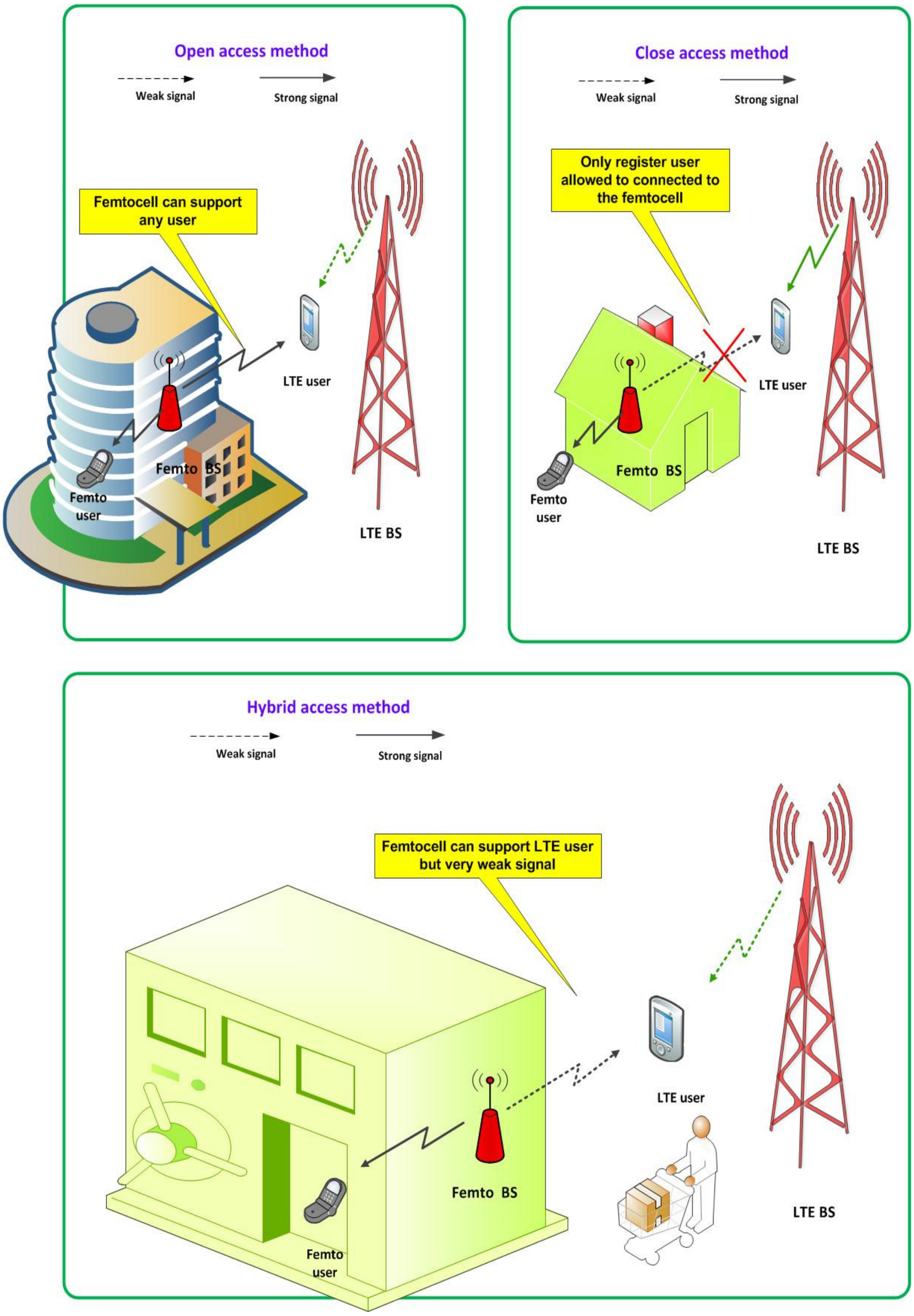


Figure 2.7: Femtocell access methods

The hybrid access method in OFDMA femtocell networks consists of managing the sharing of the OFDMA resources (frequency and time) between subscribers and nonsubscribers. Therefore, these resources have to be defined. In OFDMA the systems sub-channels contain a series of sub-carriers, which can be adjacent or pseudo randomly distributed across the spectrum in order to exploit either multi-user or frequency diversity and the choice of either one or the other channelisation mode depends on the accuracy of the channel state information [22].

2.5 Cognitive Radio Technique

Cognitive radio network has recently emerged as a promising technique to improve the utilisation of the existing radio spectrum. Cognitive radio is an intelligent wireless communication system that is aware of its surrounding environment, and uses the methodology of understanding-by-building to learn from the environment and adapt its internal states to statistical variations in the incoming radio frequency by making corresponding changes in certain operating parameters (e.g., transmit power, carrier frequency, and modulation strategy) in real-time, with two primary objectives in mind: (i) highly reliable communication whenever and wherever needed and (ii) efficient utilisation of the radio spectrum [23], as shown in Figure 2.8.

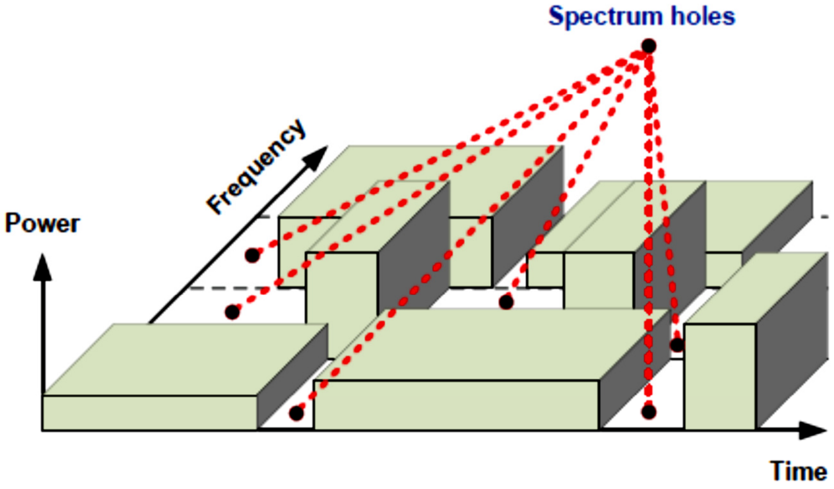


Figure 2.8: Spectrum opportunities for cognitive radio

A radio is adaptive when it can autonomously modify its operating parameters in response to the characteristics of the environment in which it finds itself. For instance, a radio that modifies Intermediate Frequency (IF) filter characteristics in response to the characteristics of the channel it is using may be considered adaptive. In other words, an adaptive radio must be able to make changes to its operating parameters such as power level, modulation, frequency, etc. An 802.11a radio exhibits a level of adaptively as it is able to sense the Bit Error

Rate (BER) of its link and adapts the modulation to a data rate and a corresponding Forward Error Correction (FEC) that sets the BER to an acceptable level for data applications [24]. The different protocols in MAC, networks, transport and application layers should be adaptive to the variation in the CR environment. On the other side, a CR module is used to establish the interfaces among the different layers and control the protocol parameters based on intelligent algorithms [25].

The cognitive radio can be programmed to transmit and receive on a variety of frequencies and to use different transmission access technologies supported by its hardware design. Therefore, cognitive radio can offer a novel way of solving spectrum underutilisation. It does so by sensing the radio environment with a two-fold objective identifying those sub-bands of the radio spectrum that are underutilised by the primary (i.e. legacy) users. However, in order to achieve these goals in an autonomous manner, multiuser cognitive radio networks will have to be self-organising.

2.5.1 Cognitive Networks Functions

Although there are many scenarios for the coexistence between primary and secondary networks, it is mandatory to achieve a certain level of cooperation to prevent any interference resulting from the contention between the cognitive and primary networks or between the cognitive networks. This situation becomes even more complicated in a heterogonous wireless environment composed of many two types of networks primary and secondary. Thus, cooperative schemes are necessary to guarantee seamless communications and to achieve optimal spectrum access. The IEEE 802.11 networks perform the listen to talk operations in transmissions. Therefore, they are the best available standards to simulate the future cognitive network with zero inferences. However, there are several studies about the differences between the traditional networks and the cognitive capabilities and they have been reviewed in [26, 27].

The mental processes of a cognitive radio based on the cognition circle are depicted in Figure 2.9. Cognition is illustrated at the example of flexible radio spectrum usage and the consideration of user preferences. The ability of cognitive radio of adapt and learn from past behavior is particularly important in sight of the fact that understanding the interactions between layers is difficult. However, there is a several protocol architectures incorporate adaptation, but often no discussion is given to intelligence, learning, or pro-active adaptation.

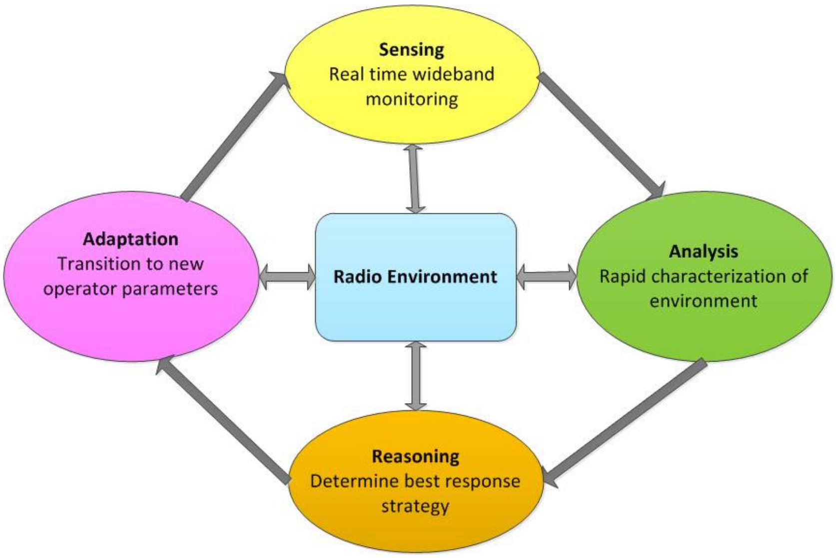


Figure 2.9: Cognitive radio operations

2.5.1.1 Spectrum Sensing

A cognitive radio can sense spectrum and detect “spectrum holes” which are those frequency bands that are not used by the licensed users or having limited interference within them. Spectrum sensing can be performed in either centralised or distributed ways. In centralised spectrum sensing, a central unit, also called sensing controller, is in charge of the sensing process. The sensing information is shared with the different secondary users using a control channel. The cooperative spectrum sensing is more accurate and can reduce the primary signal detection time [28].

2.5.1.2 Spectrum Sharing

Spectrum sharing techniques are generally focused on two types of solutions, spectrum sharing inside a CR network (intra-network spectrum sharing), and among multiple coexisting CR networks (inter-network spectrum sharing) [29]. Once a proper spectrum band is selected in spectrum decision, communication channels in that spectrum needs to be assigned to a CR user while determining its transmission power to avoid the interference to the primary network (resource allocation). Then, the CR user decides when the spectrum should be accessed to avoid collisions with other CR users (spectrum access).

A cognitive radio could incorporate a mechanism that would enable sharing of spectrum under the terms of an agreement between a licensee and a third party. This function picks up the appropriate MAC protocol to access the spectrum holes. At the MAC layer protocol, the reasonable spectrum sharing between the different users can be guaranteed. Additionally, management between base stations can be achieved in order to avoid the collision with Primary User (PUs) as well as with other Secondary User (SUs) pairs. This can be done by negotiating the spectrum opportunities available to share them on an ad-hoc or real-time basis, without the need for prior spectrum allocation between all users. In a cooperative cognitive radio network, the primary users can lease their spectrum to cognitive radio users for a portion of time and in exchange, they can get the cooperative radio transmission power from the cognitive users. However, the cognitive radio may have algorithms that can allow the sharing of spectrum in terms of arranged agreements between a licenses network. Spectrum sharing plays thereby a significant factor to increase spectrum utilisation.

2.5.1.3 Spectrum Decision

This function is able to analyse the information that comes from sensing the spectrum. Before making the spectrum access decision, the characteristics of the identified spectrum holes, the probability of the PU appearance and the possible sensing errors should be measured. Once the suitable band is selected, the CR has to optimise the available system resources in order to achieve the required objective. CR networks require capabilities to decide on the best spectrum band among the available bands according to the QoS requirements of the applications. This idea is called spectrum decision and constitutes a rather important but yet unexplored topic.

Spectrum decision is closely related to the channel characteristics and the operations of primary users. Spectrum decision usually consists of two steps: First, each spectrum band is characterised based on not only local observations of CR users but also statistical information of primary networks. Then, based on this characterisation, the most appropriate spectrum band can be chosen. In the other words, the CR user finds the best spectrum band to satisfy user’s QoS requirements (sustainable rate, delay, jitter, average session time, acceptable loss rate, etc) and spectrum characteristics. CR users require spectrum decision at the beginning of the transmission. Through RF observation, CR users characterise available spectrum bands by considering the received signal strength, interference, and the number of users currently residing in the spectrum, which are also used for resource allocation in classical wireless networks [30, 31].

2.5.1.4 Location Identification

The ability to determine the spectrum users' locations in order to identify the appropriate operating parameters such as the power and frequency allowed at surrounding locations is highly required. In bands such as those used for satellite downlinks that are receive-only and do not transmit a data, location technology may be an suitable technique for avoiding interference because sensing knowledge would not be able to identify the locations of nearby receivers.

2.5.1.5 Network Discovery

For a cognitive radio terminal to determine the best way to communicate, it should first learn about available access networks around it by long time monitoring. These networks are reachable either via directed one hop communication or via multi hop relay cognitive nodes. The capability to discover one hop or multi hop located access networks is critical to secure dependable connections.

2.6 Cognitive Network Management

Cognitive radio networks have different modes for managing the access to the spectrum in order to share transmission opportunities between different users. The functionality of such settings and decided by the level of expected collaboration between users and many other technical features for the systems in operation. Thus, a cognitive network may fall within one of three categories: centralised, distributed, and hybrid managements.

2.6.1 Centralised Network Architecture

This mode of cognitive network employs a central entity namely Spectrum broker which plays the essential role of managing the spectrum sharing resources among different wireless generation networks. In this way, the centralised spectrum broker is able to coordinate access to the spectrum in a given area and allocates short term spectrum occupancies to competing wireless service suppliers and end users, as shown in Figure 2.10.

Spectrum broker or server is a central network entity that plays a significant character of spectrum sharing of the resources among wireless heterogeneous networks. In spectrum broker technique [32] server has ability to connect to any network and coexistence of primary and secondary radios in a shared environment in a centralised fashion, local network level brokering mechanism that targets to significantly increase spectrum utilisation while reducing the complexity requirements of cognitive system deployment.

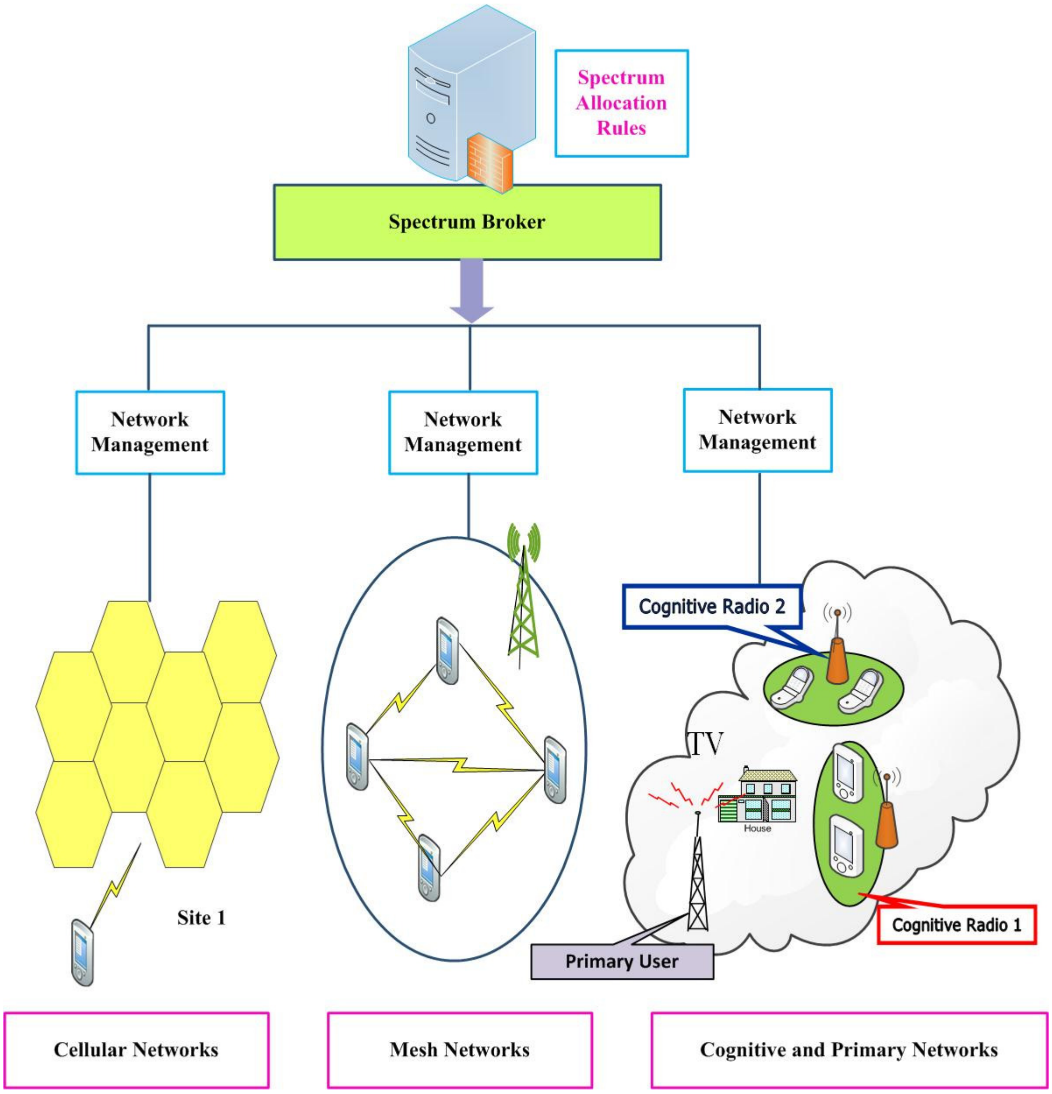


Figure 2.10: Centralised network management architecture

The centralized spectrum server can collate the information about surrounding wireless environment and interference through local measurements from different terminals and then provide offer suggestions to the efficient spectrum use [33].

2.6.2 Distributed Network Architecture

The most common controlling application for cognitive networks assumes the absence of a centralised management infrastructure. This mode of service management namely as distributed management deals with different self-management techniques that are able to decide to access the spectrum in a distributed way, as shown in Figure 2.11.

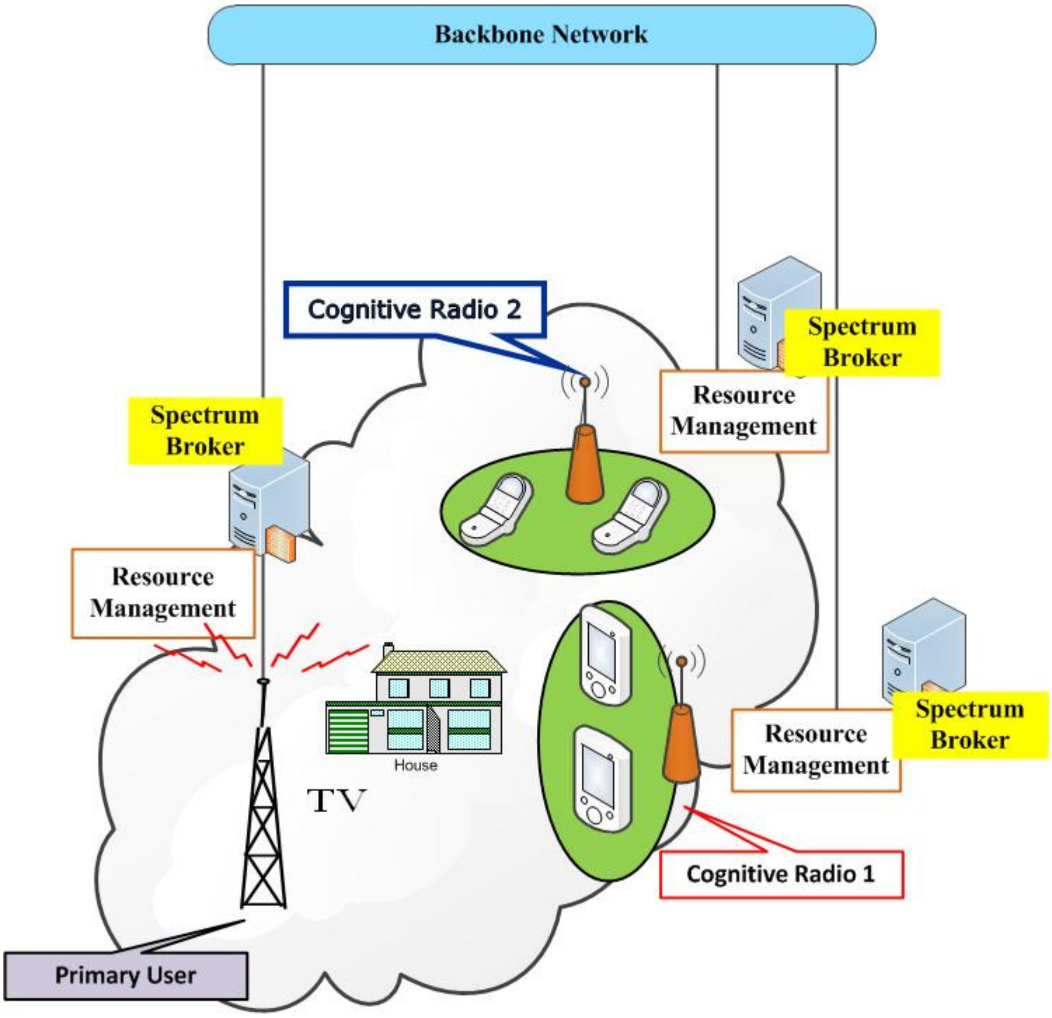


Figure 2.11: Distributed network architecture

Therefore, strategy services for considering dynamic network environments must be adaptive to different operational environments and resource availability. Motivated by this requirement and by previous research in network management [34] and [35] consequently, each cognitive node has the ability to allocate the spectrum opportunities according to local strategies. This spectrum allocation policy is performed based on local negotiating between cognitive nodes in the local area [36]. Thus, local self- organised groups negotiate the assigning of the spectrum holes to any end-users equipment within their groups and surrounding nodes before making final adaptations.

The control process for resource allocation of cognitive networks is performed by the spectrum management entity in the base station node. This entity shares the information which has been collected from both local observation and cooperative sensing to determine where unlicensed users can access the free spectrum on individual basis [37]. In order to transmit in a distributed system, the cognitive node initially starts to broadcast a request to its neighbours within the same domain to avoid any interference. Neighbours are started to join the group and reply to the requester from a coordination or senior cognitive node. The group senior node will be the responsible to decide upon final allocation of the transmission request and informing other neighbours' nodes. The cognitive nodes can exchange information and coordination messages by using a dedicated Common Spectrum Control Channel (CSCC) with higher power and hence larger transmission range via multi-hop routing. In fact, the most probable scenario for a spectrum conflict may occur when two cognitive nodes are willing to transmit at the same time provided by the long-time consumed for issuing a transmission request [38] and [39].

2.6.3 Hybrid Network Architecture

In this management approach the centralised and distributed models are bridged to create a hybrid spectrum sharing system. The spectrum broker will be the main spectrum governing entity for issuing transmission requites from groups whenever a conflict in accessing the spectrum emerges between neighboured different groups' nodes, as shown in Figure 2.12.

On the other hand, the spectrum access management inside the groups is performed using the distributed model. This means that groups' senior node is the main decision maker for accessing the spectrum in their groups provided by being the contact node with the spectrum broker. The CSCC is used for exchanging the spectrum arrangements for local groups and between the group's' senior node and the spectrum broker. The senior node is chosen by the groups' radios for its long experience and operation in the wireless local area due to negotiations between all group nodes. The main advantage of this model is to allow the spectrum broker to deal with other operators' requests and to reduce the information's exchanged over the CSCC [40].

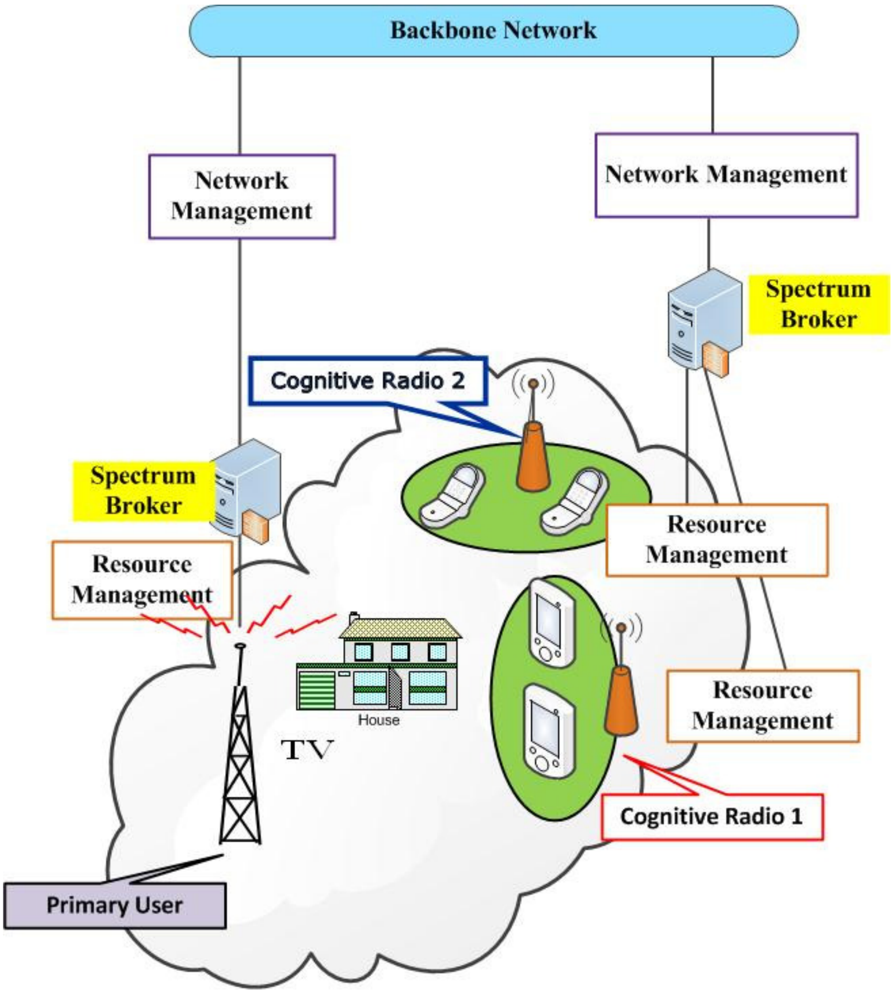


Figure 2.12: Hybrid network architecture

2.7 Cognitive Femtocell in LTE Systems

Cognitive radio interconnection of femtocell networks could be part of future Internet wireless networks. This new coexistence paradigm between cognitive radio and femtocells is based on predefined converge areas of services and the challenge is to combine the capacity of different resources to provide broadband access to both stationary and mobile cognitive users. However, high throughput demands of mobile end users in the future may need more resources than what are currently available for the exiting macrocell networks. Hence, femtocell networks will play a vital role in supporting indoor environments, such as airports, hospitals, or houses. Enhancing data delivery for Internet services could be creating a novel cross layer framework in the gateway router. This improves the cognitive femtocells' flexibility and efficiency in accessing the spectrum. On the other hand, the new design concepts increase system's reconfigurability to respond to real-time changes in the wireless environment [18].

In this research, two-tier networks are considered that consist of overlaying macrocell and cognitive femtocell systems. Within the overlapped coverage areas in such a two-tier system, an User Equipment (UE) has the option to access either macrocell base station or femtocell base station, and it can switch the access tier by performing seamless vertical handover. In this thesis, a user accessing a macrocell BS is called UE, and a user accessed to a femtocell BS is called Femtocell Users Equipment FUE. After obtaining licensed spectrum, wireless cellular operator can adopt different approaches to utilise the spectrum in a wireless overlay network. The principal approach is that two tier networks share the licensed spectrum, such that macrocell and femtocell operate in co-channel frequency reuse. This approach is called spectrum efficiency usage. Other aspects are focusing on resource management to avoid two-tier interference where each radio tier has a more available aggregate of spectrum but suffers higher cross-tier interference. On the other hand, this work will go further in examining the possibility of relay enhanced networks, measuring the potential increase in energy efficiency that deploying a certain number of low powered relay femtocell nodes can provide.

The investigations in the possible energy savings that are possible for cognitive mobile networks by using new framework vision for green management network are considered, as shown in Figure 2.13. This energy saving are obtained by presenting a feature that dynamically places low loaded cells into sleep mode, during which radio circuits are efficiently powered down, decreasing the networks' energy consumption. The main goal of the whole design is to maximise the achievable throughput of the system while minimising the need of cognitive femtocell for the power. In addition, the work has investigated the effect of the deployment of a cognitive femtocell network within the LTE system transmission. The femtocell scheme approved by 3GPP for LTE is implemented and its performance evaluation is investigated in this thesis.

Energy efficient enhancement in wireless communication can be achieved only if improvements are experienced in the whole communication chain for different operational load scenarios. Similarly, the multi-user scheduler should indeed allocate time and frequency resources to minimise the transmission energy cost while meeting QoS requirements of all active users admitted by a base station. The momentary system load plays an important role in the overall optimisation design. Currently deployed base stations are commonly designed so that they can accommodate the traffic demand at peak times. Nevertheless, cell traffic load notably varies during the day. Several researches pointed out that to save energy, base stations should perform a dynamic load and energy state arrangement, which balances extra load on a determined optimal set of base stations, thus maintaining minimum energy consumption [41].

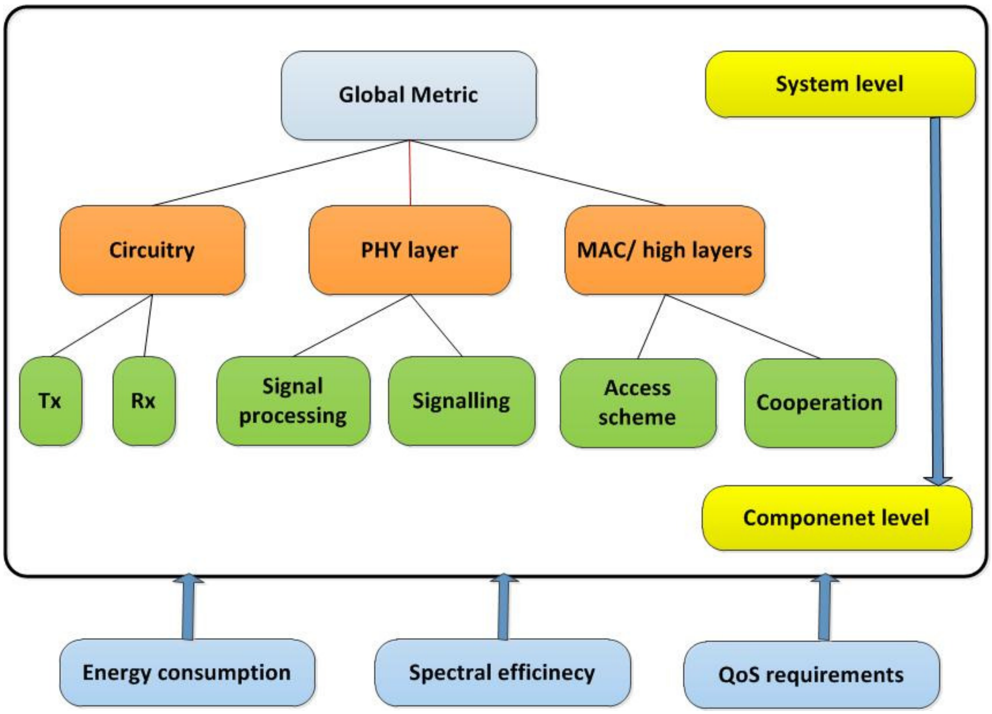


Figure 2.13: Framework for green network management

2.8 Technical Challenges

The following sections indicate the key technical challenges facing functional deployments of femtocell network systems.

2.8.1 Spectrum Decision and Allocation Efficiency

Channel management in the femtocell networks is one of the main features that represent a radical departure from the existing mobile networks. The spectrum technology deployment is growing faster than the determination in spectrum availability. Therefore, as frequency bands or free white holes become more scarce and unavailable for the next generation wireless technologies then a wide range of services will require radio spectrum as a resource to operate properly. This leads to the important investigation of the spectrum efficient utilisation. In the development of the spectrum decision function, several challenges still remain unsolved [31]:

- ***Decision model:*** Spectrum capacity estimation using Signal-to-Noise Ratio (SNR) is not sufficient to characterise the spectrum band in CR networks. Applications require different QoS requirements, thus, the design of spectrum decision function base on spectrum adaptive, and spectrum decision models is still a research issue.

- ***Cooperation with reconfiguration***: CR techniques enable transmission parameters to be reconfigured for optimal operation in a certain spectrum band. For example, even if SNR is changed, bit rate and BER can be maintained by exploiting adaptive modulation instead of spectrum decision. Hence, a cooperative framework with reconfiguration is required in the spectrum decision.

- **Spectrum decision over heterogeneous spectrum bands:** Currently, certain spectrum bands are assigned to different purposes, whereas some bands remain unlicensed. Thus, a CR network should support spectrum decision operations on both the licensed and unlicensed bands.

However, the dedicated channel deployment may not be applicable when femtocells are densely deployed. As a consequence, it may be practical to make macrocell and femtocells share the available spectrum together. Co-channel operation of macrocell and femtocells was considered by dynamically adjusting the transmit power [42]. Assigning orthogonal spectrum resources between the central macrocell and femtocell BSs eliminates cross-tier interference [43]. The orthogonal access spectrum allocation strategy is illustrated in Figure 2.14.

To avoid persistent collisions with neighbouring femtocells in accessing the spectrum, each femtocell can access a random subset of the candidate frequency sub-channels, where each sub-channel is accessed with equal probability. Mobile operators can deploy femtocell base stations that operate on a cross channel or a co-channel basis with existing macrocell. While operating on a dedicated channel is a pragmatic strategy, co-channel operation also has benefits due to the potentially increased spectral efficiency using spatial frequency re-use. On the other hand, co-channel operation may cause more interference between BSs.

Shared spectrum operation may be desirable to operators because of the scarce availability of spectrum and flexibility during deployment [44] with shared spectrum between tiers. However, radio interference between cellular users and femtocell hotspots, and between hotspot users and the macrocell BS, is likely to be the capacity-limiting factor.

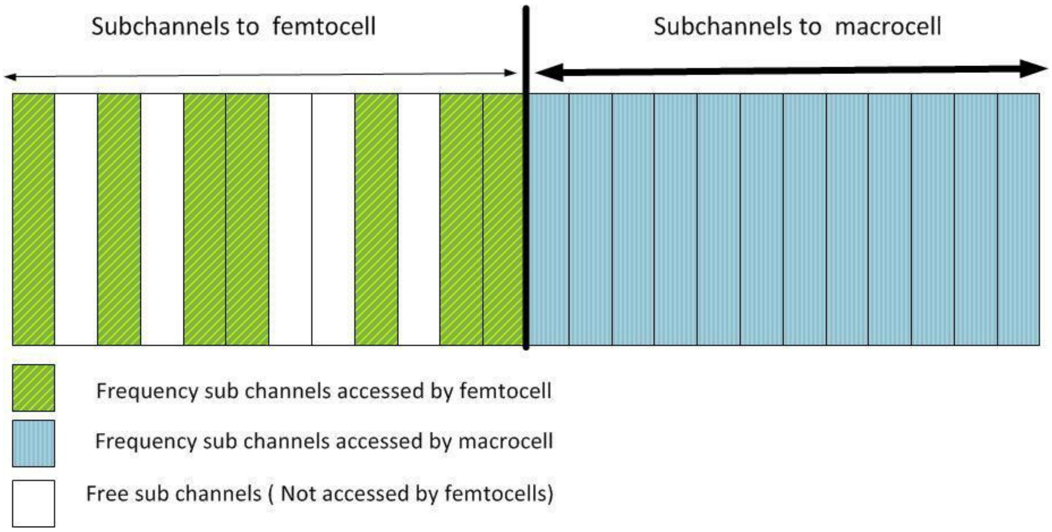


Figure 2.14: Spectrum sub-channels division

2.8.2 Providing QoS Awareness over an Internet Backhaul

Allocated and distributed nature of FBSs raises many technical challenges for the increasing requirements of multimedia applications, and this requires more management over the systems accessible resources.

To decide on an appropriate spectrum band, cognitive radio networks should support QoS-aware communication, considering dynamic and heterogeneous spectrum environment. Femtocell can interface with wireless communication system without any requirements for installing additional equipment's in wireless communication networks because of using a Radio Network Controller (RNC). Mobile Internet Protocol Television (IPTV) technology for mobile telecommunications has been developed which is a representative service of broadcasting and telecommunications convergence as shown in Figure 2.15. ´Mobile IPTV´ will be important service of International Mobile Telecommunications-Advanced (IMT-Advanced) system. Therefore, the work should be performed towards developing core technologies for cellular network based ´Mobile IPTV´ and personal IP wireless broadcasting systems. Internet Protocol (IP) backhaul needs QoS for delay-sensitive traffic and providing service parity with macrocells. Additionally, it should provide sufficient capacity to avoid creating a traffic bottleneck. While existing macrocell networks provide latency guarantees within 15ms, current backhaul networks are not equipped to provide delay resiliency [45].

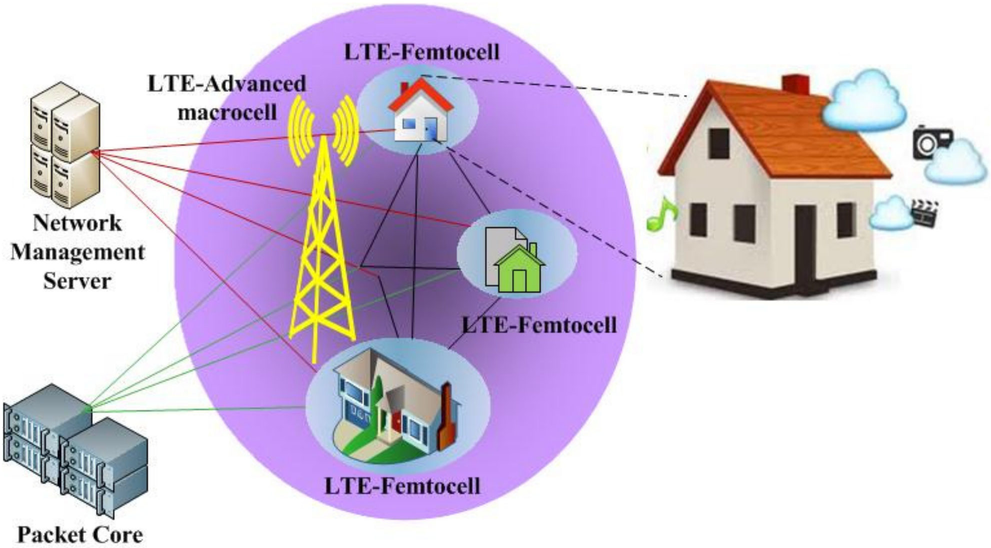


Figure 2.15: Mobile (IPTV) technologies for next-generation systems

Lack of network objectivity poses a serious concern, except in the scenarios where the wire backhaul provider is the same firm or in a tight strategic relationship with the cellular operator.

2.8.3 Resource Management and Network Planning

Resource management is one of the most important functions in the cognitive femtocell network because the system relies on it to guarantee a certain target QoS, maintain the planned coverage area, and at the same time offer high network capacity. The control procedures for radio resource management in networks with femtocells should manage radio resources despite the limited backbone capacity. To achieve an effective utilisation of backbone capacity, new scenarios will be needed for data routing among users served by the same FBSs [46]. These objectives often tend to be contradictory, for example QoS levels may be increased at the expense of coverage or capacity reductions and vice versa. The key challenge to improving spectrum utilisation, by handling cognitive femtocell users to enable access to the spectrum dynamically without disturbing PUs, is resource management which must have an efficient MAC mechanism that can efficiently and adaptively allocate transmission powers and spectrum bands among CR users based on surrounding environments. Besides routing, spectrum-efficient techniques for power control, scheduling and broadcast services transmission are needed. Additionally, novel user admission policies and FBSs identification techniques are necessary in the new system with escalating numbers of users.

Network planning and resource management need to cooperate with each other in order to meet the above requirements to efficiently use scarce radio resources. The network planning aiming to tune these elements statically at a high level, radio resource management within FBSs will need to provide efficient and effective adjustment mechanisms to dynamically balance these restrictions as the surrounding environment changes.

2.8.4 Interference Optimisation Problem

One of the most important challenges is the interference. In general, the interferences occur among network elements that belong to the different tiers of the network, i.e., interference between femtocells and macrocells. However, there are two kinds of interference in femtocell communication networks; the first one is called cross-layer interference that interference occur between femtocell and macrocell and the other one is called co-layer interference that occur between femtocell and others femtocells which is deployed in the coverage of the main macrocell [47].

For example, femtocell UEs and macrocell UEs act as a source of uplink cross-tier interference to the serving macrocell base station and the nearby femtocells, respectively. On the other hand, the serving macrocell base station and femtocells cause downlink cross-tier interference to the femtocell UEs and nearby macrocell UEs, respectively. Again, in OFDMA-based femtocell networks, cross-tier uplink or downlink interference occurs only when the same sub-channels are used by the aggressor and the victim [48].

However, this approach requires a higher spectral efficiency because both tiers access all resources. Nevertheless, in such configuration, cross-tier interference occurs, which could degrade the overall network performance unless interference is efficiently handled.

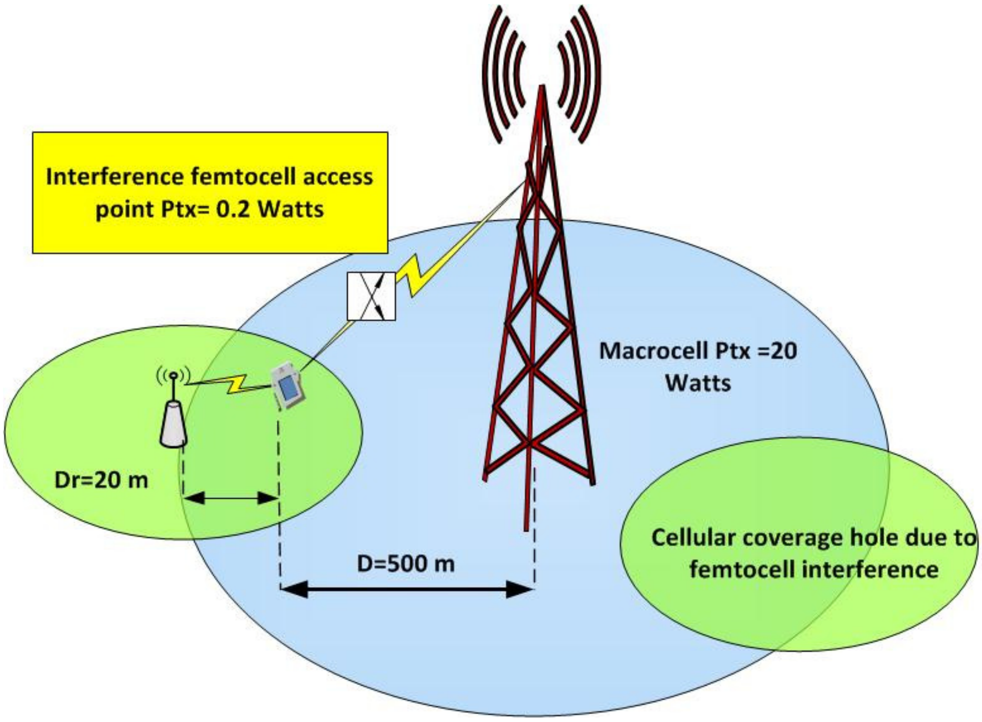


Figure 2.16: Macrocell downlink interference to the femtocell user

As shown in Figure 2.16, the Downlink Dedicated Physical Channel (DL-DPCH) interference from macrocell operating co-channel to femtocell can be modelled as the ratio of the received DL-DPCH power to interference from the femtocell loading and interference from the co-channel macrocell base station. The strong interference in the downlink (DL) from the macrocell should be well organised to satisfy the QoS requirements of both femtocell users and macrocell users. Interference problems could occur by macrocell base station DL connected to a far femtocell mobile user which may subsequently be jammed due to the presence of a closer DL femtocell user who is using the same frequency/time.

On the other hand, Up Link (UL) mobile user connected to a macrocell could be jammed due to the attendance of a close UL user connected to a femtocell using the same frequency/time, as shown in Figure 2.17. Therefore, the interference management techniques are essential to reduce the impact of femtocell on the macrocell [49].

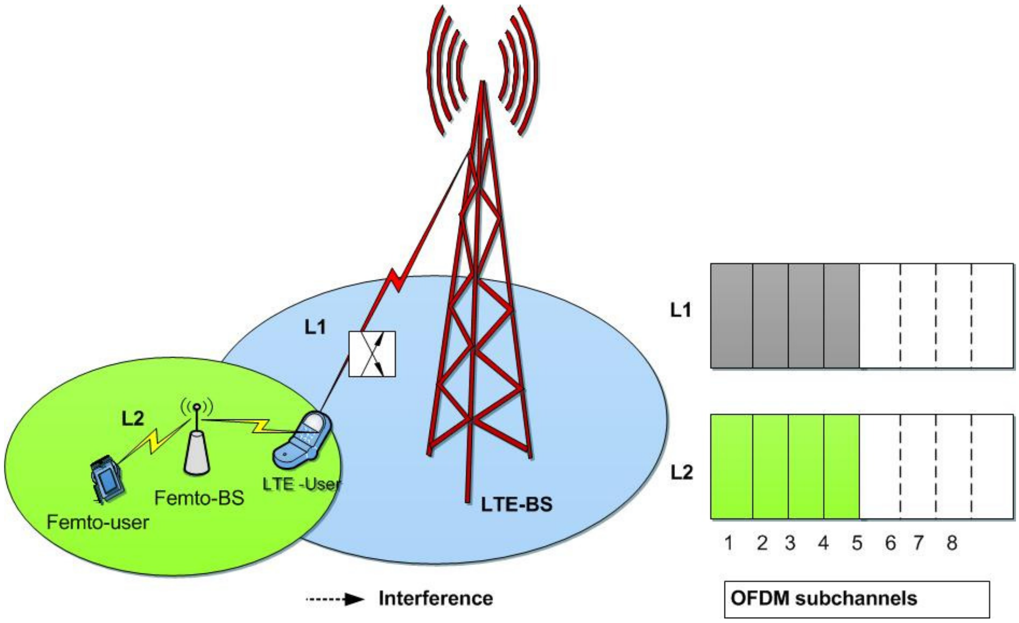


Figure 2.17: Downlink interference in LTE-femtocell OFDM co-channel

Example: Consider an OFDM reverse link with parameters:

- Distance of macrocell user to macrocell= 500meters
- Distance of macrocell user to femtocell= 30meters
- Femtocell radius= 40meters
- Processing gain=128dB
- Path-loss exponent= 4dB

- Desired receive power= 0dBm (1mW)

Interference power from user at femtocell:

$$= 10 * \log_{10}\left(\frac{500^4}{30^4}\right) = 4887 \text{ dB} \tag{2.4}$$

OFDM Interference suppression:

$$= 10 * \log_{10}(128) = 21.07 \text{ dB} \tag{2.5}$$

Signal-to-Interference Ratio at femtocell = -27.8 dB

In this scenario the macrocell user is connected to the macrocell base station at the cell edge. This user is located in the same FBS zone where no access is allowed. The macrocell user is thus interfered in the downlink by the fully loaded FBS. The best solution for this case is that the procedure of an adaptive power control is required to maintain capacity, which can benefit from an increase of up to 16%.

2.8.5 Mobility Problems

Handover from femtocell to macrocell is more complicated in the reverse case. Therefore, seamless handover between macrocell BSs and femtocell systems as well as between FBS should be supported, but at ordinary speeds. Cognitive femtocell users are a temporally visitors to the spectrum. Therefore, if the specific sector of the spectrum that is in use is required by a LTE user, the communication needs to be continued in another vacant portion of the spectrum. Furthermore, for the abovementioned system requirements, there is an expectation that the LTE air interface will provide further optimisation for femtocell operation. For example:

- Signal measurement report to support advanced interference management, radio resource management, and femtocells location.

- Optimisation of UEs scanning, selection, network entry, and handover to the desired BSs in multilayer networks consisting of macrocell BSs and large numbers of femtocell BSs. These features would further optimise femtocell operations and facilitate their usage [50]. Mobile users should be able to select a proper operating network so that corresponding access can be employed. Handover issues among the cognitive femtocell networks can also be considered in the scope of cell selection.

The mobility management may captures the best available channel, primary user activity on the selected spectrum may necessitate that the user changes its operating spectrum band(s), which is referred to as spectrum mobility. Each time a CR user changes its frequency, the network protocols may require modifications to the operation parameters. The purpose of the spectrum mobility management is to ensure smooth and fast transition leading to minimum performance degradation during a spectrum handover. An important requirement of mobility management protocols is information about the duration of a spectrum handover. This information can be provided by the sensing algorithm. After the latency information is available, the ongoing communications can be preserved with only minimum performance degradation [31].

2.8.6 Self-Organisation and Power Efficiency Challenges

Efforts to increase the energy efficiency of information and communication systems in mobile radio networks have recently gained a lot of attention. Besides reducing the carbon footprint of the industry, there is a strong economic incentive for network operators to reduce the energy consumption of their systems. Currently over 80% of the power in mobile telecommunications is consumed in the radio access network, more specifically the base stations [51]. Improvements can, in principle, be achieved in three ways: Firstly, reducing the power consumption of base station either by using more power efficient hardware or by using new advanced software to adjust power consumption to the traffic situation based on the mobile distance. Secondly, by optimisation of individual sites, through the use of more efficient and load adaptive hardware components as well as software modules. Thirdly, by using intelligent network deployment strategies, effectively lowering the number of sites requisite in the network to achieve certain performance metrics such as spectral efficiency coverage. To allow adaptation to changes in the network environment (i.e., configuration and properties of neighbouring macrocells/femtocells) an ongoing measurement and self-optimisation process is performed to adapt parameters such as scrambling code, pilot power and maximum data transmit power, sleep mode technique and power saving. This ensures minimal impact on the macro-cellular network and ensures that femtocell performance is maximised under the given constraints.

To avoid high operating costs and redundant power consumption, femtocell should support plug-and-play and implementable self-configuration and self-optimisation algorithms. In addition, the numbers of sites per square kilometer act with respect to inverse of the range. That may generate a lot of load on the energy consumption for a small coverage area [52].

2.9 Conclusion

The evolution of the cellular and wireless networks is leading to a multi-technology, multi-terminal, multi-application, and heterogeneous wireless environment that is representing the 4G wireless networks. The basic architecture of the main cellular and wireless technologies is described in detail. The chapter also introduced the technical background of femtocell techniques and deployment issues. There are numerous challenges that will require to be addressed by the service provider in order to make the femtocell able to impact on subscribers in terms of improving the spectrum efficiency performance. The main challenges were described to enable a clear view for the main requirements of the 4G wireless technology.

In order to achieve seamless connectivity within the heterogeneous wireless environment an efficient mobility management is needed. From a technical viewpoint, the main focus of this thesis is to design and implement network management algorithms for improving cognitive femtocell coexistence in two-tier networks.

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Chapter 3

Spectrum Management in Cognitive Radio Systems

The spectrum coordination of cognitive networks is a major challenge in large/small domains to achieve an efficient resource allocation and to meet the QoS requirements of different traffic downloading requests. In this regards, a novel spectrum management model is proposed for resource allocation, spectrum sensing, and spectrum decision making. Primary and cognitive networks are considered to coexist with each other under dynamic spectrum wireless access to validate the given solution. The cognitive network uses 802.11e technology that allows cognitive users to identify and access the available frequency spectrum without interfering primary users. Then, a novel solution for LTE-femtocell resource management is investigated with new algorithms that are able to capture the key parameters of spectrum access prioritisation as a function of the available free transmission channels. The spectrum management model is integrated into PHY and MAC layers of the cognitive radio system to enable the user to communicate reliably between LTE and femtocell networks.

3.1 Introduction

Cognitive Femtocell System (CFSs) is an emerging technology in the next generation networks to ensure active coverage and higher throughput for small range communications. However, it is necessary to manage the quality of service for the reason of limited network resources available to access. In addition, the assignment of resources among an increasing number of consumers requires scheduling services and time slot management for each spectrum channel available [1]. Thus, the solution relies on using cognitive femtocell radio as the femtocell technology to exploit the spectrum efficiency in coexistence with LTE macrocellular system in a realistic scenarios and networks.

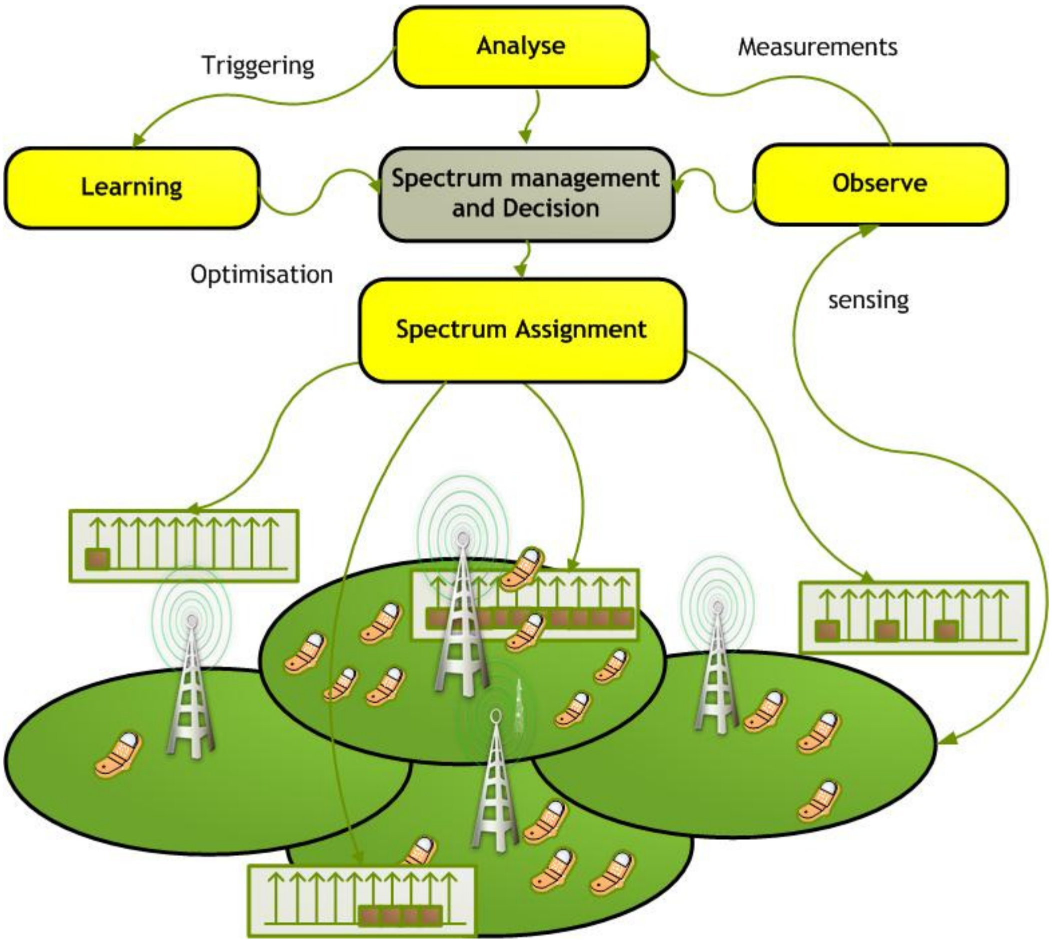


Figure 3.1: Spectrum management architecture for cognitive radio networks

In this spectrum management model the QoS requirements are adjusted according to the spectrum availability in order to create traffic queues that support different types of applications with similar QoS requirements.

Accordingly, transmission decisions are made to send the long traffic packets in advance of other applications whenever there is a channel space available for such actions. The proposed spectrum management architecture can be mainly classified into two parts: decision making and spectrum sensing as shown in Figure 3.1.

The obvious advantage to the cognitive radios and the closely related technologies is not just spectrum efficiency but also moving towards a policy-based adaptive radio. To apply this, it is necessary for these developed radios to be controlled in such a way that underutilised portions of the spectrum can be utilised more efficiently. This is called as opportunistic spectrum management and it is supported by transmission policies. The network control of these advanced radios includes control of the configuration of the radio and the RF operating parameters. Regulatory policies which govern the allowable behaviour, i.e., RF operating parameters, are part of this network control. The control policies may, for some scenarios, also include network operator and user policies [2].

In this chapter, a novel spectrum resource management system is proposed to allocate the available spectrum efficiently using new algorithms and modules. The main theme of this chapter is to combine the capacity of different resources to provide good broadband access to both stationary and mobile cognitive users. However, high throughput demands for mobile end users in the future may need more resources than what are currently available for the existing macrocell networks. The important contribution in the proposed systems with respect to existing literature is the analysis of spectrum occupancy over different sub-bands of the channel's environment. To our knowledge, there is no other model technique that takes account of all these parameters into one model.

3.2 Related work

The dynamic spectrum and resource management optimisation methodology aims to provide a communication network with higher capacity using many techniques. The dynamic spectrum sharing model in [3] is aiming to maximise the total throughput of both primary users and secondary users at the same time. The problem is formulated in two approaches for allocating channels to primary users with fixed allocation and random allocation. In the fixed allocation approach, the fixed channel is located for a number of primary users all the time, with different number of mobile users in different channels. In the random spectrum allocation approach, the primary user has a priority to access the spectrum at any time dynamically and randomly in each time [4].

The authors in [5] have addressed the downlink spectrum sharing challenges in cognitive radio femtocell as a mixed integer, nonlinear programming problem, and used decomposition methods to solve this problem. The new solution involved a cooperative channel allocation and an adaptive power control approach to improve spectrum access and cognitive service delivery. On other hand, an optimised spectrum resource management for a cognitive LTE network with femtocell is proposed in [6]. Here, the base station and users are equipped with CRs and can intelligently adjust power, frequency, and other features to allow the spectrum requests of the entire network system. The design is based on stochastic optimisation in order to take advantage of the cognitive radio technical flexibility and ability to utilise the spectrum.

The approach in [7] proposed a Cognitive Resource Management (CRM) for cognitive femtocells that can autonomously adapt the radio resource usage to avoid any interference with the macrocell station. The effective capacity of the CRM that specifies a QoS guarantee capability for the system was analytically derived. The CRM identifies an optimum sensing period to achieve radio resource utilisation for a certain QoS profile. Moreover, a cooperative radio resource management to investigate the multiple cognitive radio networks in interference environments was proposed by [8]. The aim of this research was to achieve shared radio resources fairly among multiple non cooperative cognitive radio networks in order to improve the overall network performance. The main goal of this research was to achieve information sharing and decision distribution between CR networks in a distributed approach.

Prior research has been focusing mainly on framework management function. Scheduling for wireless networks has brought a lot of research attention that mostly includes centralised and distributed architecture approaches [9, 10]. Centralised scheduling algorithms were proposed based on chart method by assuming that a central controller has full awareness about on the network. The technique finds the best set of non-overlapping links with increasing the total throughput in overall system. Investigators, meanwhile, have been considering a two-layer design for QoS in wired and wireless networks. The authors in [11, 12] have addressed extensively a QoS solution to avoid variations in available system resources based on the status of the packets in a queue and the system resource availability. Also the scheduling entity has ability to schedule the data transmission of different mobile users on the best available channels based on the information collected from the cognitive sensor was examined. The authors propose a cooperative cross layer design and sensing mechanism in order to get advantages over the aforementioned traditional approaches.

The proposed optimised design for cognitive radio networks is using a resource management opportunistic technique to solve the problem of spectrum sharing and maximise the network capacity. The management model in [13] suggested independent functions between the physical and the MAC layer, while the other research work in this field does not reflect the queuing system with multi-tasking services of the next generation system networks.

Finally, our early stage research in cognitive femtocell [14], proposed a spectrum utilisation framework to control the spectrum packet delivery between the macrocell and the cognitive femtocell using a Priority Queuing (PQ) strategy. The proposed framework deals with a resource management approach that is represented by spectrum allocation management optimisation where the CR in each femtocell node, upon allocation of channels to its applications, decides about the imposed channel restrictions. Additionally, a comparative fairness is achieved by a unique priority scheduling performed by the CR.

In contrast to the literature, this work analyses the parametric classification for each user’s traffic profile and then tackles the spectrum utilisation requirements for each cognitive user individually. The main idea is to investigate the location of spectrum required to exploit the different types of the traffic and the availability of white holes in the spectrum band. Then, decisions on data transmission are made based on the size of the available time slot. This leads to an efficient utilisation of the spectrum and resource management for the LTE-femtocell stations to provide a sufficient level of reliability to the end users. In this management approach, femtocell clients can be served locally by efficiently utilising the scarce network resources without communicating with the macrocell base station aiming to fully exploit the spectrum holes.

3.3 Problem Formulation

In the following sub-sections, the free channel probability aspect is studied in order to maximise the irregular spectrum access for a distributed system composed of a LTE macrocell and femtocell base stations.

3.3.1 Free Channel Occurrence

The deployment of cognitive femtocell is an infrastructural efficient way of utilising the LTE macrocell allocated spectrum. Although, the transmission range of cognitive femtocell is limited, supportive relays for self-coexistence of multiple femtocell base stations are required for effective cooperative spectrum allocation. For example, two nearby femtocells might detect different channel accessibility in a macrocell allocated spectrum. In order for these two femtocells to optimally exploit these available channels, they may need to run an interference aware resource allocation scheme in order to avoid interference with each other and with the macrocell [15]. Collaboration between the many femtocells within a certain macrocell is vital for interference avoidance and efficient spectrum sharing. Femtocells can similarly depend on cooperative transmissions to increase the spectrum utilisation with other femtocells outside their transmission range.

Developed cognitive femtocell base stations technologies can solve the problem of spectrum scarcity and maximise the throughput to the end-users. The given solutions in this chapter respond to high numbers of channel adaptations which is likely to occur in cognitive femtocell communications. The main idea is to switch between the transmitted applications according to the available channel free time that satisfies the requested QoS of certain application. Considering a very dynamic trade of white holes between neighboured femtocells, the proposed solution significantly increases the overall network capacity. This means that an application can be either transmitted or buffered according to the durations of the available accessed channels.

3.4 System Model

In this section, the incorporation of the new spectrum management model in the cognitive femtocell node is explained in details. The design objective is to maximise the available resources in the LTE macrocell system in order to be used in an efficient way. This is performed using an upgraded CR node features that exploits the best available spectrum bands.

The model assumes a system with multiple concurrent applications, each of which can operate at different levels of quality based on the system resources available to it. The goal of the model is to be able to allocate resources to the various applications such that the overall system utilisation is maximised under the constraint that each application can meet its minimum needs. The main challenge in the cognitive system design is the ability to manage the spectrum sharing and resources allocation between the femtocell and LTE system. This can be done by creating new unified spectrum resource management algorithms in the PHY and MAC layers that receives different applications with various QoS requirements and assign them to the free channels available. The spectrum status is exported from a sensor that is located in the physical layer. Then, the spectrum allocation can be managed for applications profiles before finally enabling the transmission action.

Spectrum and application resources should be delicately tuned and dynamically allocated to the cognitive user and cooperative transmissions [7], in order to fully utilise the spectrum and take advantage of channel reuse and diversity. This is a complete solution for two-tier networks that uses cognitive radio as the terminal radio access technology for real time services. Spectrum utilisation is achieved using efficient channel allocation or time slot access based scheduling within a transmission period.

The time slot is reflect the spectrum availability and is determined to transmit certain services without harming the primary users and the main macrocell base station. The motivation behind a spectrum management is to share the information across the layers and to solve inherent problems of temporarily wireless links. The radio spectrum management is responsible for accessing and releasing radio channels, including signalling and carrier channels. Several functional modules are included in order to improve the collaboration between several layers functionalities, as shown in Figure 3.2. The spectrum resource management unit is activated once a data frame is received from application for processing. The packet has usually the attributes of the requested QoS that is required to decide the following transmission actions.

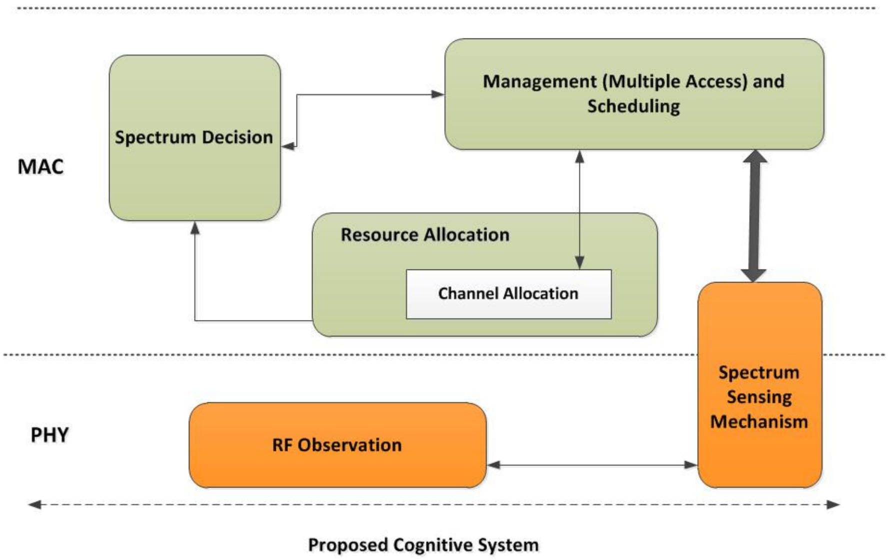


Figure 3.2: Functional design of spectrum management

The management function has the ability to interact between different modules provided by the wireless situation using acquired data from the cognitive sensor about possible "free" spectrum. Also, it can exploit spectrum band based on scheduling and dynamic channel allocation to maximise the total network capacity as well as achieving reasonable resource allocation over CR.

The cognitive sensor sends the detected free channels with their potential time slots to the management unit. Therefore, the resource management has the complete information about the free channels that can be used to deliver the requested applications. Once a decision has been made on an appropriate channel, the time slots in that channel need to be allocated to an application while determining the transmission power to avoid interference to the primary network. Then, the spectrum decision unit decides when the channel should be accessed to avoid overlapping with other SUs during spectrum access. The opportunities in the spectrum are identified by the RF observation and then forwarded to the management function. If there are not enough resources for the requested data packets, the packets will be buffered onto a queue for the next available and suitable white space. However, according to the IEEE standard 802.11 in 2007, the channel adaption delay is defined as 224µs [16]. Assume each cognitive radio system can complete receiving all buffered packets before it starts transmitting again.

In order to fully exploit the spectrum space opportunity, the channel allocation function is introduced with controllable parameters to be able to allocate channels such that the interference to the primary users is limited below an acceptable level. However, dynamic allocation of resources such as power, and bandwidth can result in better performance than fixed resource allocation strategies [17]. Finally, this integrated set of functions and modules works collaboratively to attain the most efficient spectrum access model.

3.4.1 Spectrum Sensing Model

An important function of the sensing process is the compulsory detection to determine the presence or absence of PUs on a channel. Detection features that are typical in the physical layer of cognitive radio system are: interference, SNR, and energy detection [18, 19]. The system cannot specify the proper channel slot time for each flow, therefore, management unit can use appropriate scheduling schemes to ensure the balance between the tasks and to meet the minimum QoS of all admitted flows. The CR incorporates the following various functionalities for spectrum sensing, these are depicted in Figure 3.3.

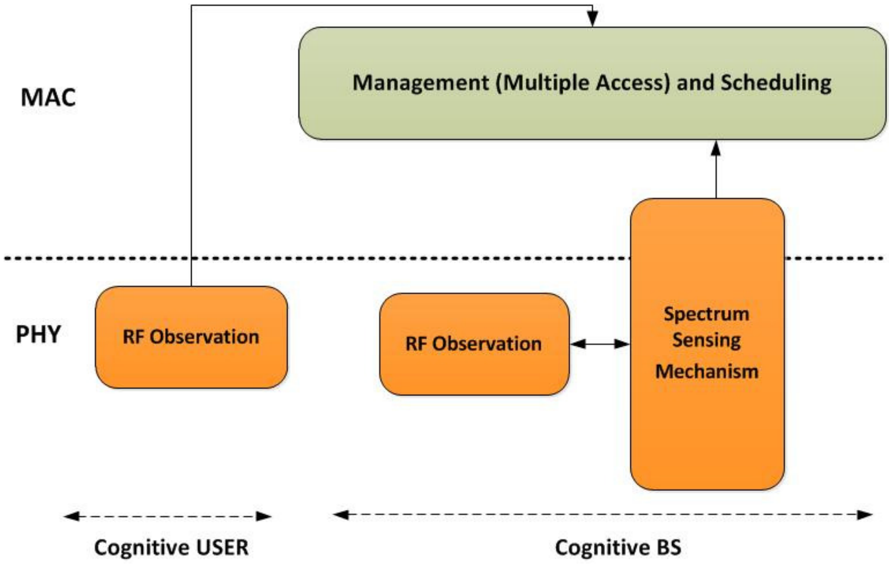


Figure 3.3: Function of spectrum sensing

The process performed by the cognitive radio to detect and analyse local spectrum holes starts by collecting the information about the wireless environment using radio observations that is controlled by the sensing mechanism unit. This allows an efficient and accurate identification of the present spectrum availability. The new sensor control mechanism is illustrated in Algorithm 3.1 that considers the signal strength received by cognitive user to select the appropriate free channel.

Algorithm 3.1 : Cognitive Sensor Control

```
1:  Procedure
2:  application request based on QoS service
3:  management function send set request to cognitive sensor
4:  cognitive sensor determine the noise power for the channel
5:  measure SNR and Interference
6:      if (SNR < threshold) then
7:  measure channel bandwidth availability
8:     else
9:  adapt to another channel
10: return to 4
11: end if
```

The process starts when a data application arrives at the management unit with a connection request. The management unit forwards the request to the cognitive sensor to check the “free spectrum” channels accessibility, and detects free channels/time slots using a probe to check interference power. The cognitive sensor uses the energy detection technique to determine the absence and presence of the primary user based on the SNR and interference measurements. Upon the response, the sensor sends the identities of the detected free channels with their particular specifications to the management unit. Then, the management unit creates a profile for each application and the assigned channel information. The management unit does not assign the same channel to multiple applications to prevent any confusion and interference in delivering the services to the end-users. Moreover, because of the channel limitation imposed by the channel availability for being a secondary user to the spectrum, variable transmission rates are allocated on the link.

3.4.2 Interference Avoidance Module

The SNR of the PUs signal detected by the secondary users may be very low. Therefore, the secondary users must make sure to avoid any interference even at the edge of the primary's coverage area, as shown in Figure 3.4.

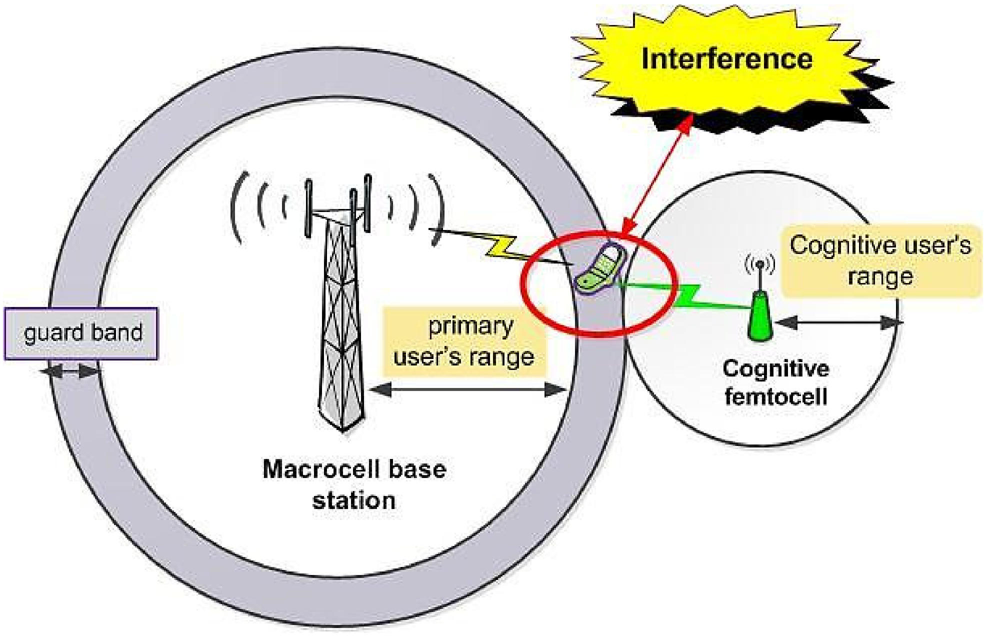


Figure 3.4: Avoiding interference at the edge of the primary's coverage

The location of secondary users is assumed to be within the primary's cell range or around it in the guard band, undertake a risk of potential interference with the primary's transmission. Therefore, a new Algorithm 3.2 is proposed to avoid the interference and collision with primary user. Interference in CR networks depends on the sensing accuracy, which is determined by the observation time. However, in periodic sensing, CR users cannot sense the spectrum bands during the transmission time, which leads to an increase in interference. Thus, for the interference avoidance, both the observation time and the transmission time need to be considered in the periodic spectrum sensing method [20]. Here the new features in a cognitive femtocell are all about the way to identify the interference. As a result, a radio resource management scheme that can effectively mitigate interference, achieve a fully radio resource utilisation and provide QoS guarantee had been identified as the major challenges and are urgently needed to realise the theory of the cognitive femtocell networks. To prevent the interference, one typical solution is to divide the whole available spectrum into several frequency bands and the femtocell use different frequency band other than those of the LTE networks.

Algorithm 3.2: Interference determination

```
PREV_PKT, CURT_PKT received
    if PREV_PKT ends when new one arrives then
collision doesn't occur
    end if
evaluate arriving packet is valid or noise
    if arriving packet is valid then
determine interference of PREV_PKT on ARRV_PKT
end if
```

3.4.3 Spectrum Decision Making

A spectrum decision function is proposed for cognitive radio networks in order to utilise the unused spectrum portions with consideration to the application requirements. Each spectrum band is characterised for the spectrum decision based on local observations of CR [21]. The desire to transmit an application over an unoccupied spectrum band implicates evaluation of the spectrum sensing information and characteristics of the radio environment. Therefore, the changing nature of the spectrum usage needs to be considered in any spectrum characterisations. Based on these factors, the spectrum decision function determines the best available spectrum band to satisfy the requested QoS requirements [22]. The spectrum decision must be organised carefully to consider other challenges such as the short term fluctuations in the spectrum availability, and the heterogeneous nature of the application requirements of the cognitive radio users. In this approach, spectrum resources are managed in the cognitive node by a reconfigurable collection of different data traffic functional modules, as shown in Figure 3.5.

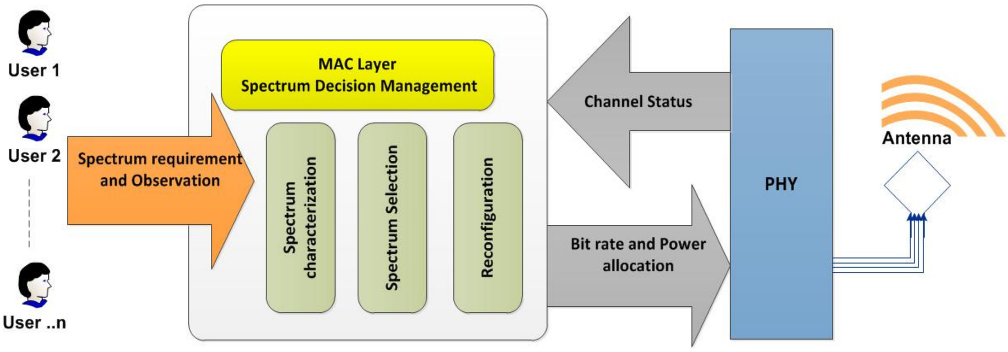


Figure 3.5: Spectrum decision function

Algorithm 3.3: Spectrum Access Decision

```
Procedure
data arrive
allocation to the  adjacent FBS
management  unit send request to cognitive sensor
spectrum availability
    if (No Free Channels Available) then
        buffering data of different applications (4 Buffers/Queues)
        reserve new resources by looking for free channels
    end if
        if (Free Channel Available) then
            cognitive sensor will check SNR and BER
            set specifications of transmission characteristic (power,
            modulation ,interference)
        end if
            if (CHANNEL TRANSMISSION TIME IS SUFFICIENT)
                then
                transmit to UE
            end if
else
buffer data according to application
get data from another application to transmit
check if  there is any data from other applications
return
```

The main functionalities required for spectrum decision are explained as bellow [21]:

***Spectrum Characterisation*:** Based on the observation, the CR determines the characteristics of each available spectrum band.

***Spectrum Selection*:** The CR determines the best transmission opportunities to satisfy user QoS requirements.

Reconfiguration: The CR reconfigures communication protocols as well as RF front-end technologies in response to the radio environment and transmission requirements.

The framework design of the spectrum management function has the ability to check the domain network for new available resources, and obtain comprehensive information about the radio channel resource availability. This novel spectrum access decision making is shown in Algorithm 3.3.

New approaches to efficiently solve the utilisation problems presented in the spectrum resource management strategy by exploiting the unique network characteristics. To imitate the model characteristics, the data rate requirement of each cognitive user in the resource allocation function should adapt according to the traffic status. The scheduler can decide on the number of required transmission data rates for each traffic queue in symbol duration according to the QoS requirement of the traffic, such as the maximum tolerable delay.

3.4.4 Scheduling Mechanism

In this section, a novel process using Round Robin scheduling is introduced to balance the interchange between cognitive femtocell and their clients and the effects of channel availability. Round robin scheduling allows an easy balance of resource utilisation between tasks that are ready to be executed [23].

The cognitive nodes need an efficient scheduling scheme to transmit data whenever an opportunity of transmission arises. Scheduling data transmission is important mechanism in resource management because spectrum holes may not always be available. To guarantee that data are transmitted only at the appropriate time, the femtocell node needs to adapt its data transmission scheduling. After identifying the receiver of the FBS as the next hop to the forward data, a FBS source node needs to decide the most suitable time to truly transmit the data onto the path to the cognitive femtocell receiver node directed by the data scheduling function. Data scheduling usually adapts to change in network resources management according to the data priority and bandwidth. In this manner, schedules of packets to be transmitted to different mobile nodes are created according to their bandwidth levels (which reflect the quality of a link on which a packet is transmitted) and this avoids a packet destined to a mobile node with a low quality channel to block other packets bound for a mobile node with a high-quality channel.

In the proposed scheduling policy, the terminals are assigned the shared resources in order (one after another) as illustrated in Figure 3.6. Bandwidth scheduler ($bandwidth\_ sdu$) is responsible for allocating numbers of slots to each connection based on its requested bandwidth and QoS. Moreover, it should also decide whether a packet was received or not in a femtocell base station network.

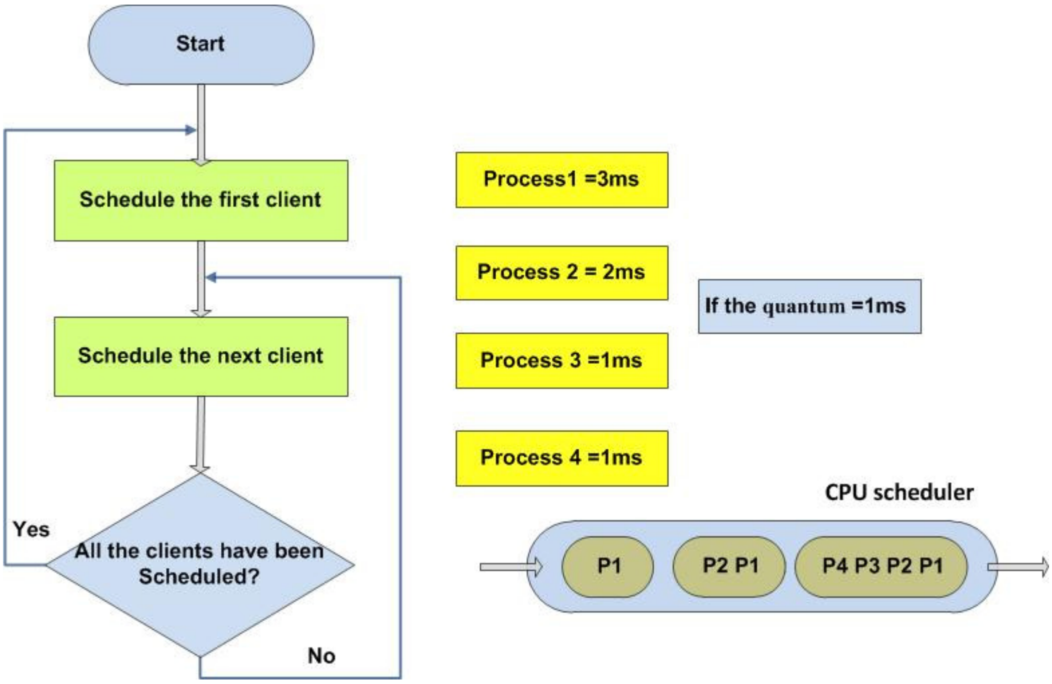


Figure 3.6: Round Robin scheduling approach

In this work, the bandwidth is distributed to various applications of VoIP, Video, Hypertext Transfer Protocol (HTTP), and Email. In order to support high QoS, the MAC layer defines four service classes including Unsolicited Grant Service (UGS), Real-Time Polling Serves (rtPS), Non-Real-Time Polling Services (nrtPS), and Best Effort (BE). Regarding Round Robin, the bandwidth is allocated to each connection according to the transmission parameters [24].

The scheduler is designated using algorithms to evaluate channel quality, like maximum SNR or system throughput. In Algorithm 3.4, the scheduler first allocates polling slots to rtPS and nrtPS flows if last polled time exceeds polling interval. Then it scans the list of all admitted flows and allocates the admitted number of slots for UGS flows.

Algorithm 3.4: Bandwidth Scheduling

```
/*check available channel with requested bandwidth*/
sch_ calss = sev_flow ← setting← sch_ calss
// If it is packet type VoIP data then
  if sch_ calss = UGS then
    sch_bandwidth = sev_flow, setting ← max traffic data rate;
    bandwidth=sch_bandwidth*(avg_sdu_size+mac_header_size) /ave_sdu _size);
    end if
// If it is packet type Video stream or HTTP flow
  if sch_ calss = rtPS stream or sch_ class = nrtPS then
      sch_bandwidth = ser_flow ← parameters ← max traffic data rate;
      bandwidth = sch_bandwidth *(avg_ sdu_ size + mac_ header_ size)/ave_ sdu_ size)
end if
    if is uplink data transfer=true then
// set polling bandwidth overhead :one admission BW request at each application
bandwidth_reserved =sev_flow ← setting ← max traffic data rate/(8 *sev_
```

```
    flow – avg_sdu_ size)
BW_Tr = bandwidth_reserved *mac_header_size*8
    end if
end if
// If it is packet type best effort flow
    if sch_ calss = BE then
        transmission permitted
    end if
        if BW_Tr ≤ available bandwidth then
            transmission permitted
        end if
else
// reject this transmission
transmission rejected
```

The idea behind the proposed algorithm is that for each scheduling interval, a Protocol Data Unit (PDU) is scheduled for transmission on a specific sub-channel. The priority is assigned based on the instantaneous channel condition of the PHY layer and the QoS constraint of the MAC layer subject.

The service flow class defines the QoS parameters that are exchanged on the connection. Moreover, each link has unique identifier to distinguish between different connections. In the proposed cognitive system a service flow is characterised by a set of QoS parameters such as end-to-end delay, latency, etc. Each service flow is assigned to the service classes and each service class is assigned with one of four scheduling types, as shown in Figure 3.7.

Cognitive MAC system can support four types of services, Unsolicited Grant Service (UGS), Real-time Polling Service (rtPS), non-Real-time Polling Service (nrtPS) and Best Effort. Schedulers have the goal of maximising the efficiency of resource utilisation while satisfying the QoS requirements. However, the algorithm is focused in the design of rtPS and nrtPS class schedulers as the scheduling of UGS connections is defined by the standard and BE connections don’t need any specific QoS requirements. rtPS delay traffic is very sensitive and has hard delay condition, whereas nrtPS traffic is able to tolerate longer delays with minimum throughput requirements.

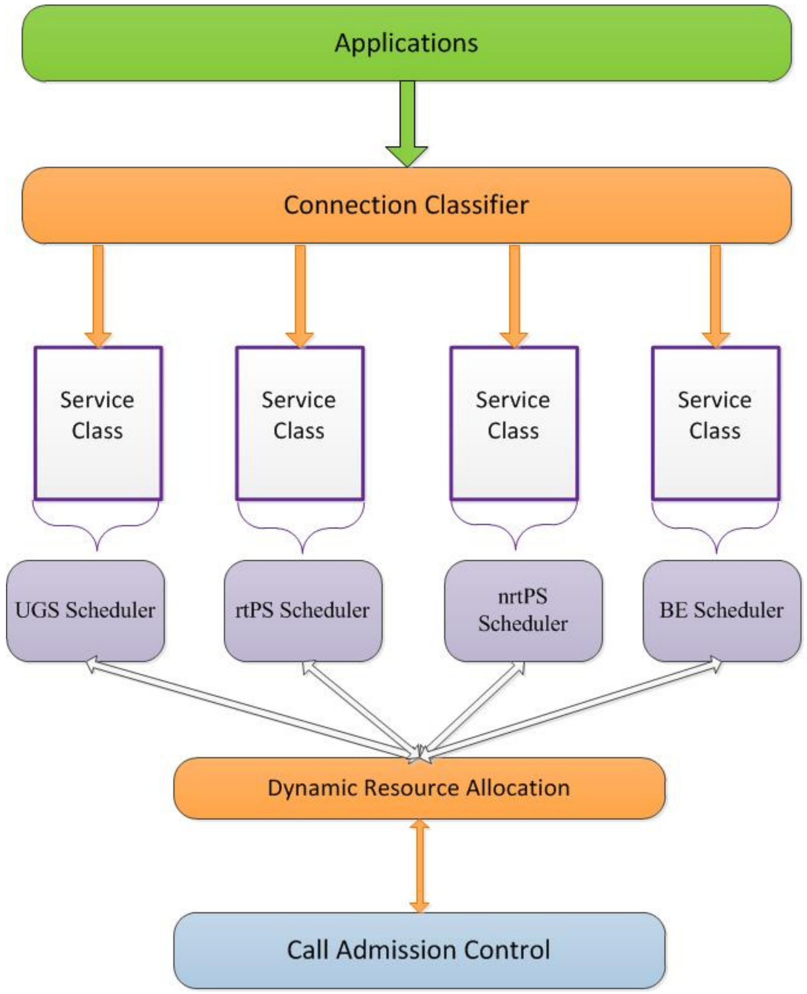


Figure 3.7: Class scheduler design

The scheduler class for each service type receives the allocated size of bandwidth from the management unit which includes the allocation of sub-channels, time slots, and transmission powers for each different cognitive application in the service queues.

The scheduler assigns the requested number of slots for nrtPS and rtPS streams if the numbers of slots in demand are less than the requested number of slots. Else, the number of slots will be allocated into more than one frame. The outstanding slots are assigned to BE data stream. After assigning BE data flows, the scheduler marks any remaining slots as free slots available for other data streams.

3.5 System Implementation

The proposed cognitive system is implemented using advance OPNET version 17.1 wireless network simulator that is based on developed C++ code functions of the program. The OPNET is an advanced research tool enables modeling various kinds of networks and currently provides models supporting WLAN, and LTE standards [25].

OPNET's network domain provides several types of link objects that are usually used to make connections between devices separated by some physical distance. These links transfer data in the form of user defined messages called packets. Generally, OPNET simulations generate a sequence of transition states for a system model. The model evolves through these states as a function of time, based on the specifications of the behavior of model components and of their interactions. To the extent of the developed model specifications, this evolution is representative of the way in which the new system functions perform over time. The project involve many nodes that coexist together to share the available resources based on distributed network architecture. In this way, the negotiations between cognitive nodes to exchange the information and coordination messages are performed using the IEEE 802.11 distributed coordination function (DCF) [26] and Common Spectrum Control Channel (CSCC) [27], as shown in Figure 3.8.

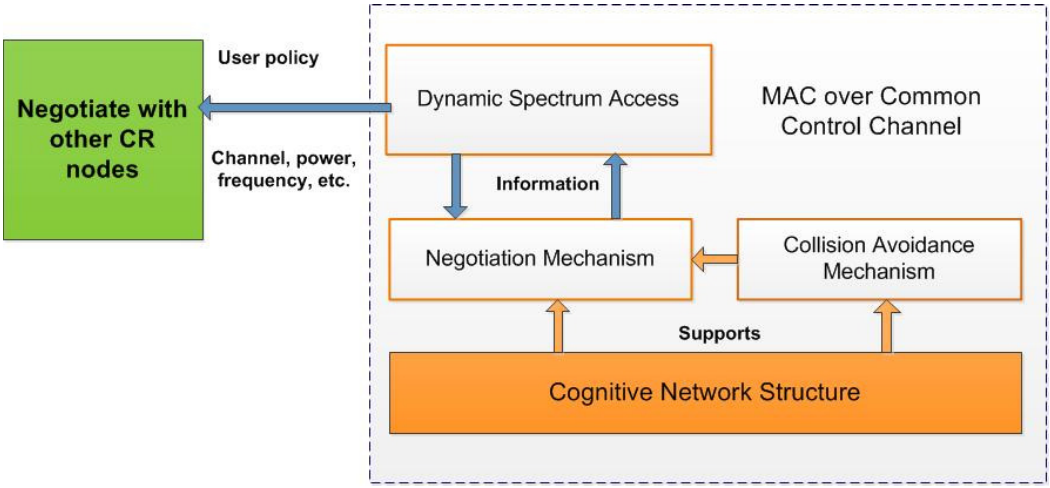


Figure 3.8: Structure of DSA negotiation policy

The negotiation phase to initiate the spectrum access process by a CR node involves the issuing of re-organisation query which then extend to neighbouring nodes. The negotiation and building process for the network topology solutions are explained in [28, 29]. Further details can be found in Appendix A.

In the case of this project, very specific advanced functionality is required and most of the developing is performed in the PHY and MAC layers. The challenging task is to integrate the spectrum management model in a new customised node that is able to increase the performance of the default node in accessing the spectrum holes. The proposed system, shown in Figure 3.9, is evaluated using advance OPNET17.1.

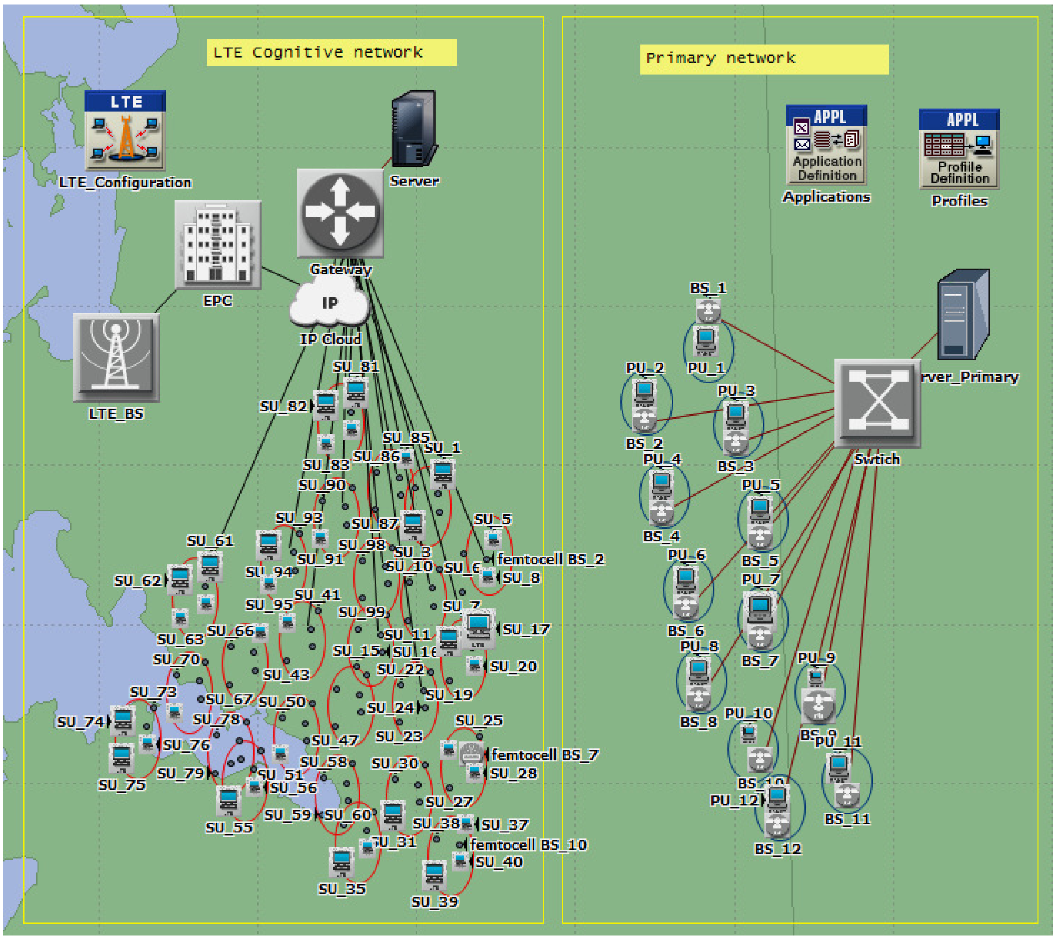


Figure 3.9: Cognitive LTE-femtocell systems testbed in OPNET

3.5.1 Integrating the New Cognitive System

This section discusses the integartion of spectrum management modules and processors to allow the definition of a new set of actions by developing a process model using the C++ functions in the process domain. The general approach to develop a process models is shown in Figure 3.10. This is performed by incorporating new process models with the standard OPNET nodes that require intimate knowledge of the standard, built-in OPNET connections. In new process models that implement new applications, a quite deep understanding for the internal functions of the standard process model is required. This knowledge is needed to determine how to invoke the new process model within the OPNET's code.

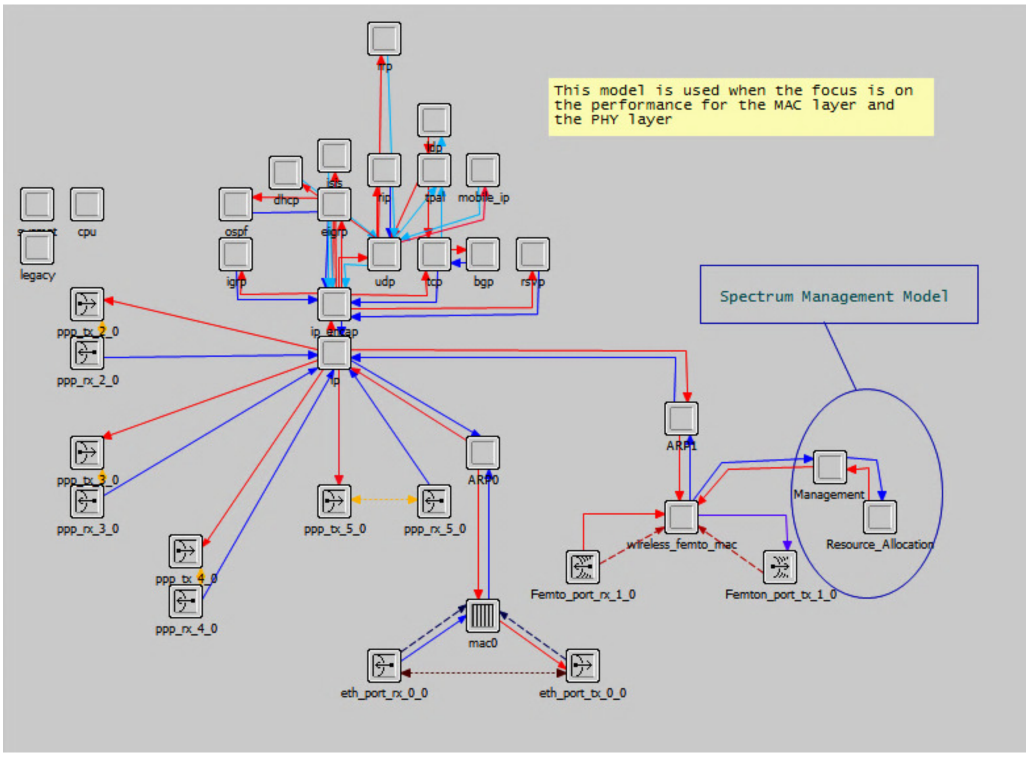


Figure 3.10: Modified node modules in OPNET

Node models are usually defined via one or more functional elements called modules and by the data flow between them. The behaviour of individual modules is specified either via a set of built-in parameters or through one or more process models. The following work involves the details of the new proposed modules of management and recourse allocation units. The details of the particular node and process models are presented in the following subsections.

The 802.11e standard is used with the enables Carrier Sense Multiple Access with Collision Avoidance (CSMA/CA) based MAC protocol, and has been considered as a cognitive network in this study [30]. CSMA/CA has the ability to listen before talk, to implicitly sense PU, and the advantage to effectively solve the cognitive radio self-coexistence issues in the overlapping CR BSSs scenario is shown in Figure 3.11.

The ‘init’ state obtain the MAC parameter values set by the CR and calculate the contention periods. Then, *‘idle’* state is the machine enters an idle state and waits for an incoming event. The event can be either an incoming packet from the source modules, a feedback interrupt from the MAC process to inform it of a successful transmission, or ready to send for the next packet to the MAC layer to contend with other stations for the radio channel. However, the *‘transmit’* state is able to update the contention window triggers the *SEND_PKT* event and the state machine enters the transmit state.

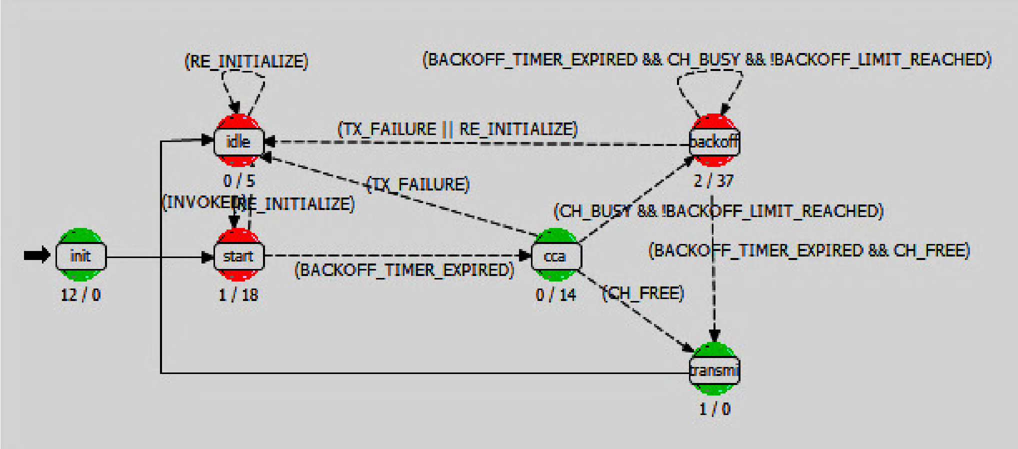


Figure 3.11: Channel access mechanism in MAC (Process Domain)

Algorithm 3.5: CSMA/CA Mechanism

```
// Check if the channel is available.
    if channel_ available = CR_CSMA_CHANNEL_
        AVAILABLE () then;
/* transmission attempt failed*/
Tx_failure = OPC_FALSE;
// If backoff is reached the limited and channel is busy.
    if (CH_BUSY && BACKOFF_LIMIT_REACHED)
end if
```

All the cognitive base stations are sharing a set of radio channels, and before any node transmits data, the investigated channel must be idle for a contention period. When detecting certain channel availability, the cognitive radio must be continuously sense it throughout this period in order to determine whether the channel is idle or not, this is shown in Algorithm 3.5. However, ACKnowledgement (ACK) packets enable a cognitive node to determine whether its transmission was successful or not since it cannot otherwise detect a collision. The transmitter is completely aware of the collision after it times out waiting for the corresponding ACK for the packet transmitted. If there is no ACK packet received or an ACK is received by mistake, the transmitter will try again to retransmit the data packet until reach the maximum number of retransmissions that has been allowed before adapting to another channel [31].

3.5.1.1 Generate Management Process Model

The management process model consists of six state conditions: *init*, *domain_setup*, *idle, hl_pk_arrival*, *schedule,* and *tx_complete*, as shown in Figure 3.12.

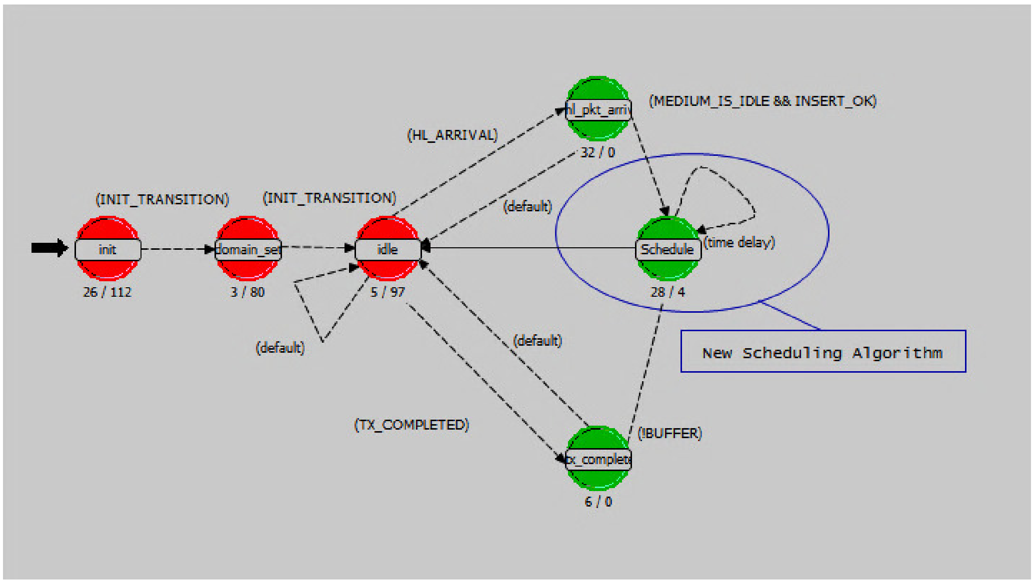


Figure 3.12: Management module (Process Domain)

The time interval between each new packet arrival can be modelled as a constant value or any other value of statistical distribution (normal, Poisson etc.). The management of the spectrum is activated once a packet arrives at the "init" state. This will initialise all other process model variables and data structures.

Then, the data transmission arrives at the unforced process state model *"domain_setup"*. This state is responsible for initialising the reachability set for this node and updating the position of this node with regards to other project nodes since the exit the initial state. Next, the *"Idle"* state checks whether the incoming packet is a *"tx_complete"* data packet, higher layer data packet, or a domain_setup data packet. The actions here as following: if the packet is coming from higher layer then it goes to *"hl_pk_arrival"* state, and if the data packet is coming from *"tx_complete"*, then it goes to *"tx_complete"* state. However, if the packet is coming from "schedule" state then the packet will be queued and then sent to *"hl_pk_arrival"* state.

Each incoming higher layer packet is mapped into one of the outgoing connections to the *"schedule"* state and the packet. The *"schedule"* then decides to transmitte or returne to the *"idle"* state again depending on the channel availability and the free buffer size. The state machine *"schedule"* generates an interrupt to delay outgoing packet while looking for a transmission opportunity that suites the transmission frame. This is performed while calculating the current time slot. If the current time slot is enough to meet the requirements, then, the transmitter is checked; if the transmitter is free the state machine "schedule" will deliver the packet to the buffer in *"tx_complete"* state. At this stage, if there is enough time to transmit the entire packet, then, the packet is sent down to the transmitter's *"physical layer" mac_phy_pkt_send ()* function that sets the physical characteristics of the transmission channel.

3.5.1.2 Generate Spectrum Resource Allocation

Each new data packet that enters the network specifies the minimum requested rate which is the minimum amount of bandwidth that the data packets needs to operate properly, and the maximum requested rate which is the maximum amount of bandwidth that the data packets can utilise. These values are called the Requested Bandwidth Range (RBR) and all spectrums' admitted accesses are guaranteed to receive the amount of bandwidth within its RBR. If there is a sufficient amount of bandwidth to support the new data packets request then all the other data packets that share resources with the newly admitted data packets are controlled to accommodate the new data packets arrival. As described above the goal of the resource model was to design a simple interface that, on the one hand enables the user to easily choose a best free channel available when running simulations and on the other hand to easily add another channel protocol in the future. To reach this goal the concept of spectrum decision processes is used in the OPNET simulation environment. The processes are known as child processes of the general MAC layer. The “Dec_Made” state is used as a control child process to process the control messages. If the incoming “control_packet” in MAC is bandwidth request then BS control child process is invoked. If there is no free channel available then the request transitions back again to the resource allocation process, as illustrated in Figure 3.13.

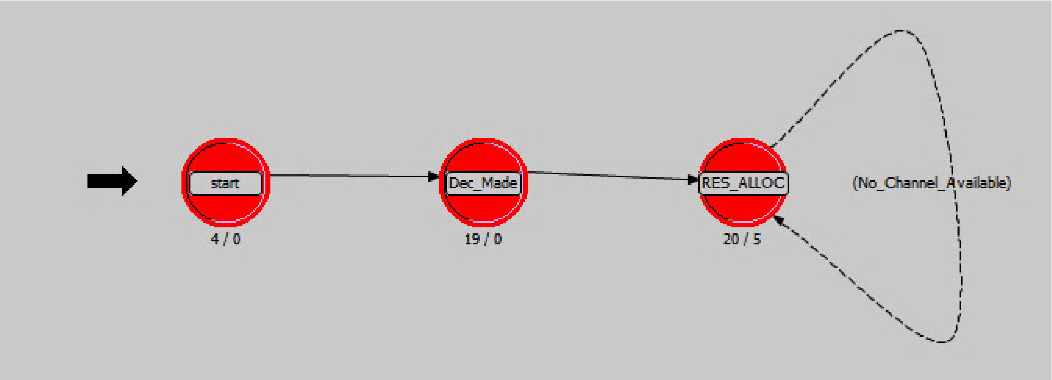


Figure 3.13: Resource allocation module (Process Domain)

The queue packet procedure is modified to examine the value returned by the “RES_ALLOC” process before placing the available spectrum in the queue. When a cognitive node is enabled in a simulation, the MAC layer process model will be called. The MAC model will check if the MAC interface is connected and make sure that the packets can be forwarded to the radio transmitter.

3.6 System Performance

The advanced LTE version is used with specifications of the 4G radio network for fixed nodes. The cognitive femtocell nodes were tested at different positions in the macrocell domain and it were working successfully. However, in the following project scenarios the cognitive femtocell nodes are deployed at the cell edge in order to solve the problem of low LTE coverage. This allows a realistic investigation of the system performance as the power of the macrocell declines at the far ends of the cell and femtocells are likely to be used to support communications at such places. The simulation field is a grid of 1km^2 with 100 UEs and 50 FBSs. The femtocells are randomly positioned at the edge of the cell with one LTE-BS was used to simulate the macrocell base station, Mobile Ad-Hoc Network (MANET) stations as the primary users of the spectrum and 802.11e standard as a cognitive network.

Coverage range is assumed to be 30m for femtocell. LTE base stations have random trajectories, fixed pedestrian speed of 5km/h and they can have different types of connections simultaneously active. The simulation considers four types of traffic connection (HTTP, Data, Video, and VoIP services time interval of 5ms. Results are collected as average values over simulations connection times of 15 minute each run. The Hata propagation model [32] is used for determining the level of interference of wireless channel model, and path loss urban medium city. LTE provides data rates up to 100 Mbits/s in the downlink direction, data rates up to 50 Mbps in the uplink direction and latencies in the radio access network of 10 milliseconds.

3.6.1 Results

The performance of the proposed system model of spectrum management is presented in this section. Four traffic applications (voice, video, data, and HTTP) are simulated with proposed spectrum management model versus the traditional cognitive femtocell model in [33]. The studied scenarios are set to use random spectrum access at variable transmission intervals. A specific numbers of femtocell nodes are set to coexist with the macrocell base station and other primary users in an open access model. Therefore, a link is established as long as the channel condition given by the RBR is acceptable within the transmission distance. The monitoring indicators were developed to show the new system solution performance of each type of traffic individually to allow better performance evaluation of the studied solution. Assuming all users are moving with pedestrian speed, then mobility has very small impact on the evaluations and results are subject to change only because of the spectrum allocation function. Table 3.1 presents the system parameters for the simulation. All users are assumed to be independent from each other, and the mobility of individual users is not considered in this scenario.

Table 3.1: New LTE-femtocell system characteristics

Name	Value
Macrocell radius	1000 m
Femtocell radius	30 m
Bandwidth	5 MHz
Femtocell power	20 dBm
LTE transmit power	40 dBm
Noise variance at receiver	-95.0
Path loss exponent	3
Packet size	1024 bits
Number of traffic per user	4

The results show that, as the connections time decreases due to the increase in the site femtocell users, the Bit Error Rates (BERs) of various applications increases slightly since fewer radio spectrum resources are available for the FUEs to transmit, as shown in Figure 3.14. The femtocell proposed system with an increasing numbers of end-users performs better than the traditional femtocell node case in each simulated traffic case. Although the BER values fluctuate for various traffic models, it can be noticed that the similar traffic profile runs reflects a significant difference in results. For example, the proposed spectrum management model has a very low BER with voice traffic compared to the very high values of BER for the same traffic but with the traditional scheme of scheduling and accessing the available transmission opportunities. This show the advantages gained from the new spectrum allocation scheme and the successful installation for assigning the requested bandwidth to the admitted users.

The impact of increasing the number of femtocell users on the SNR performance is considered, as shown in Figure 3.15. The proposed system selects a channel at each time slot for certain traffic type and moves to the next traffic in priority of sending and queue. The average transmission rate is a function for the time available at instance. Notice that deploying the proposed femtocell network due to the heavy penetration loss of the signal from macrocell BSs, the femtocell network is observed to boost up the SINR of the whole network with maximum 50dbm. However, significant reduction in the service time can be achieved in the low load region if randomise the selection of free channels available.

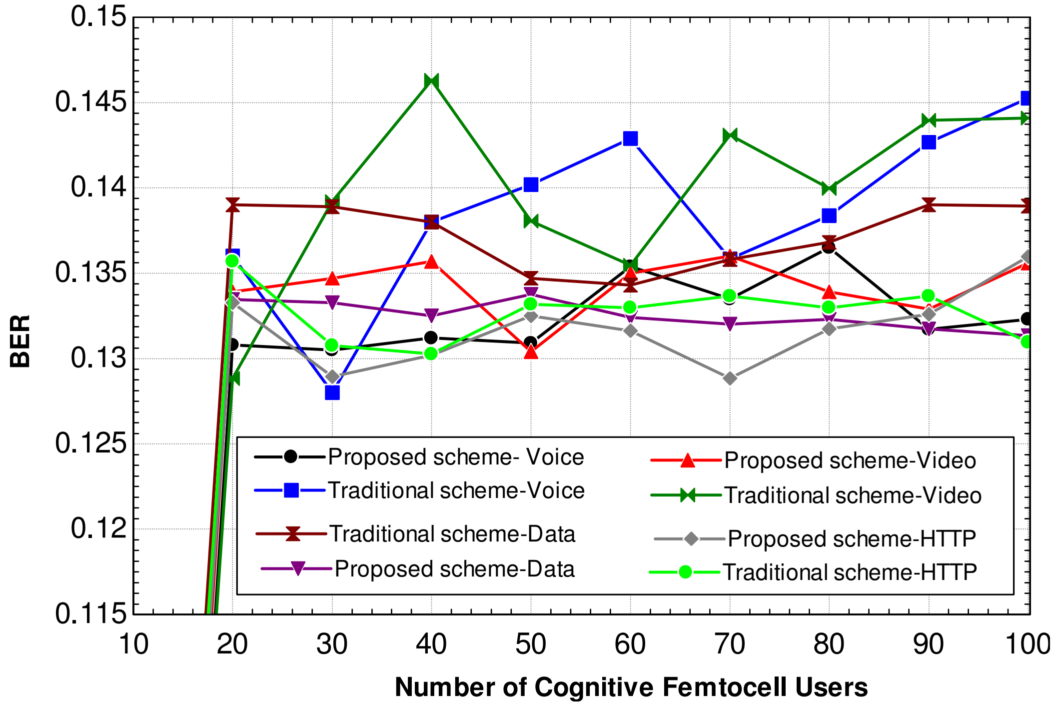


Figure 3.14: BER vs. number of site femtocell users

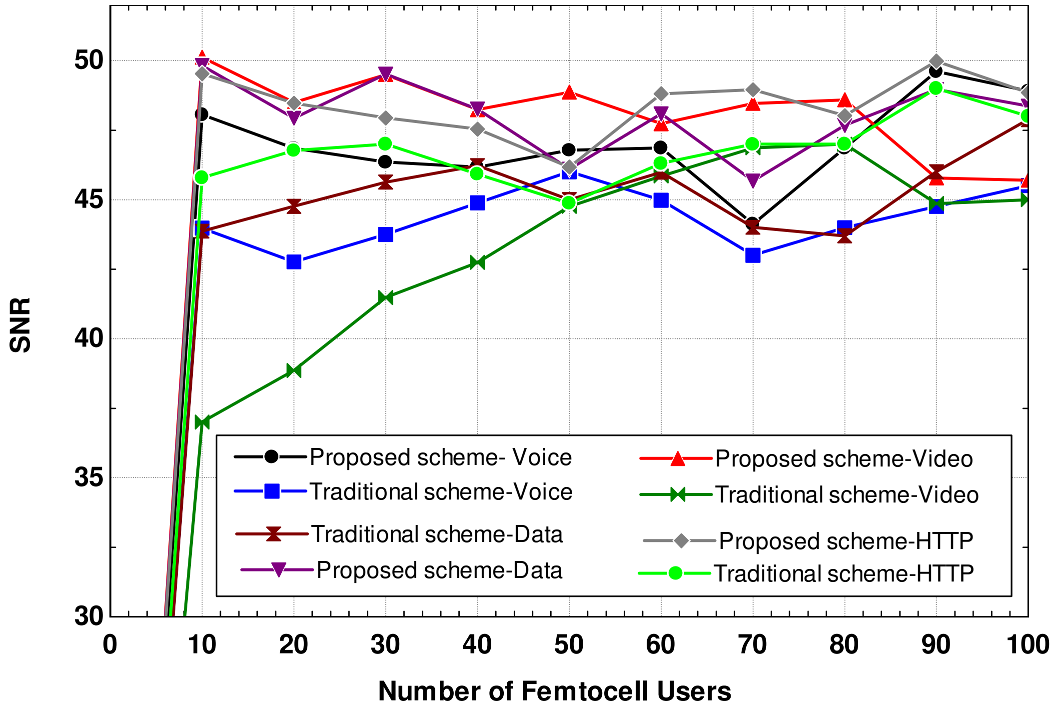


Figure 3.15: SNR vs number of site femtocell users

The results show that the proposed system increases the performance of femtocells system in accessing the available spectrum band. This is shown through reducing the total transmitted power during link establishment and connection compared to the traditional scheme as a function for the number of femtocell users, as shown in Figure 3.16.

The high transmitted power is a result of inefficient allocation that leads to huge number of links terminations and links re-establishments while connecting to end-users. This has been solved in the proposed spectrum allocation scheme that helps to maintain links for longer times and enables to reduce the numbers of links terminations and hence the power required for multi-transmissions. The proposed cognitive system is capable of reduced the transmitted power from 5W to 4W when the number of end users is 10. This means the new system is able to reduce the transmitted power by 20% as a way to achieve spectrum utilisation.

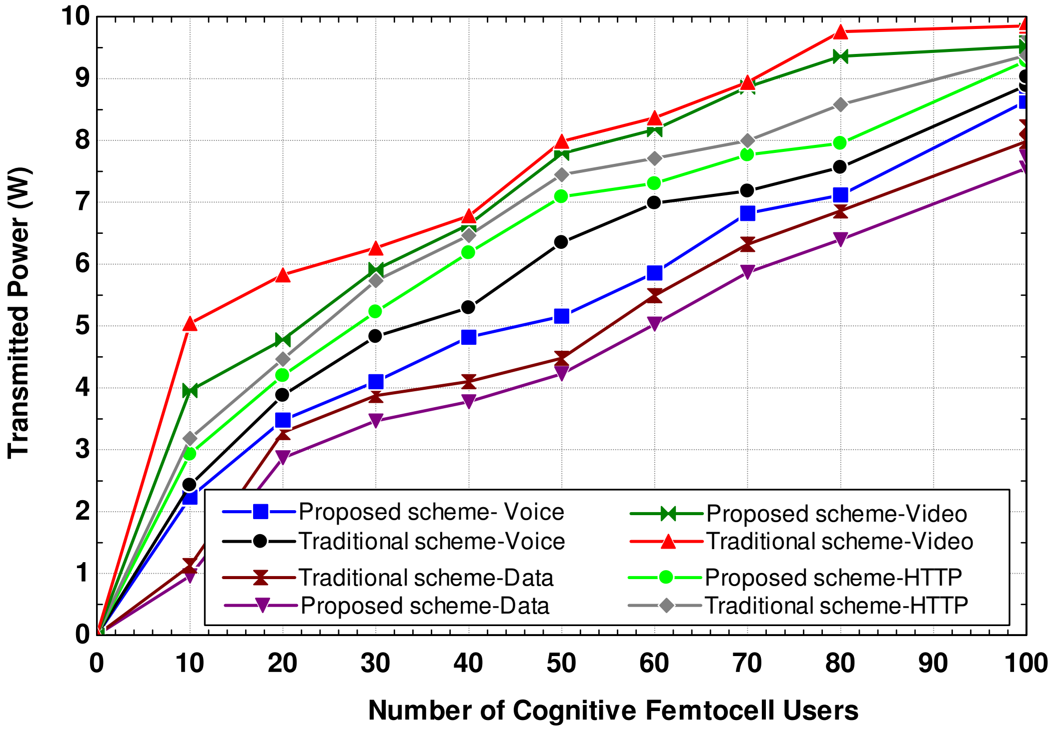


Figure 3.16: Power vs number of site femtocell users

The increase in throughput is more gradual and noticeable with the increase in numbers of femtocell users, as shown in Figure 3.17, since the proposed system is able to nearly utilise all the available bandwidth. The given results are a function of a particular traffic pattern that is used in the simulation settings. For example, in the voice case, the network throughput steadily increases with an increase in the number of users. However, the total throughput in this case is greater with the proposed system compared with the than normal channel allocation model. There is degradation among all patterns as there is always a chunk of bandwidth that the femtocell is unable to use and access. In the case of a cognitive network, the total system throughput can be improved further by assigning certain femtocells to secure channels and predefined services. This enables the scheduling of non-consecutive nodes in the chain to use non-overlapping parts of the spectrum.

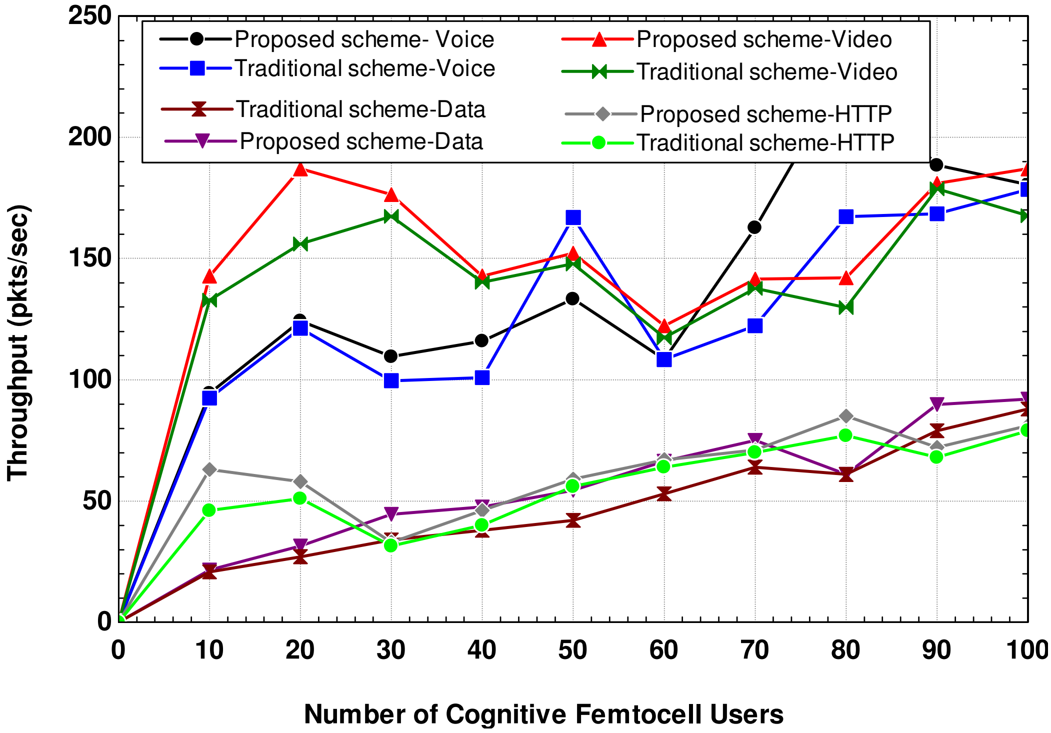


Figure 3.17 Throughput vs number of site femtocell users

Figure 3.18 shows the end-to-end time delays for different types of traffic. The time delay increases as the numbers of end-users increases. However, the improvement of adding the proposed model is quite clear in all different traffic profiles. Furthermore, the system delay for all traffics types is mostly the same when the numbers of users dropped to below 10. When each flow generates traffic in connection with the increase in number of users', the proposed system adaptively allocates more bandwidth to each traffic flow, and hence traffic patterns with larger white space achieve higher throughput and lower time delay compared to non- the proposed models. In the proposed scheme, more UEs achieve search procedure of available channels, and it accesses the free spectrum very quickly.

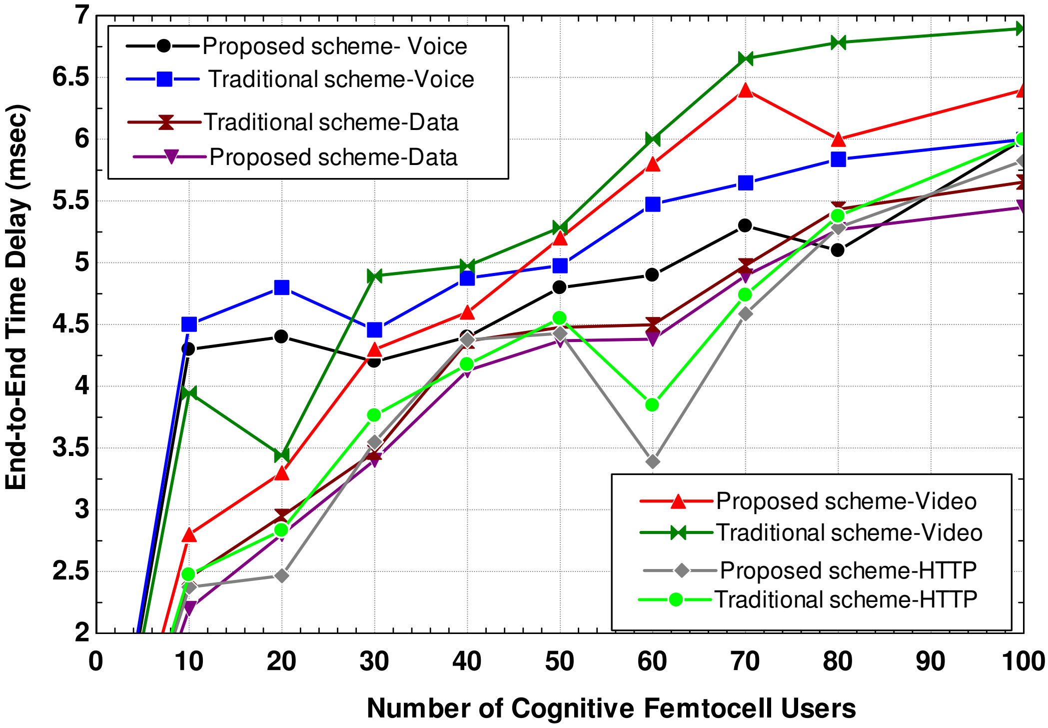
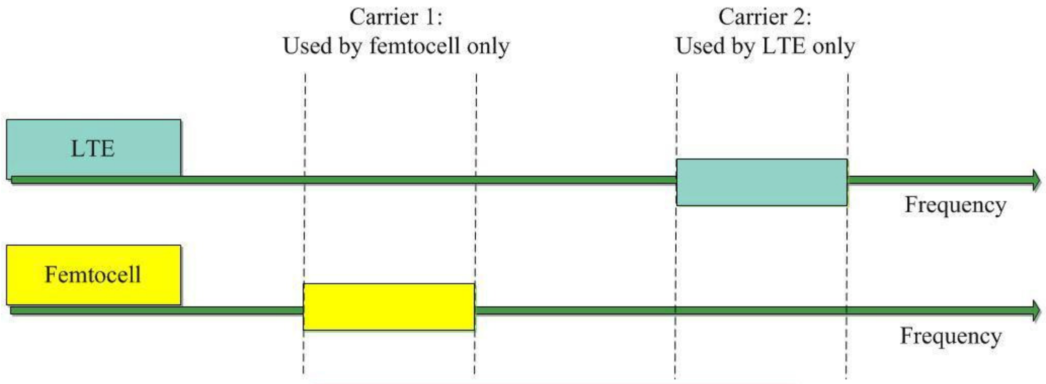


Figure 3.18: End-to-end time delay vs number of site femtocell users

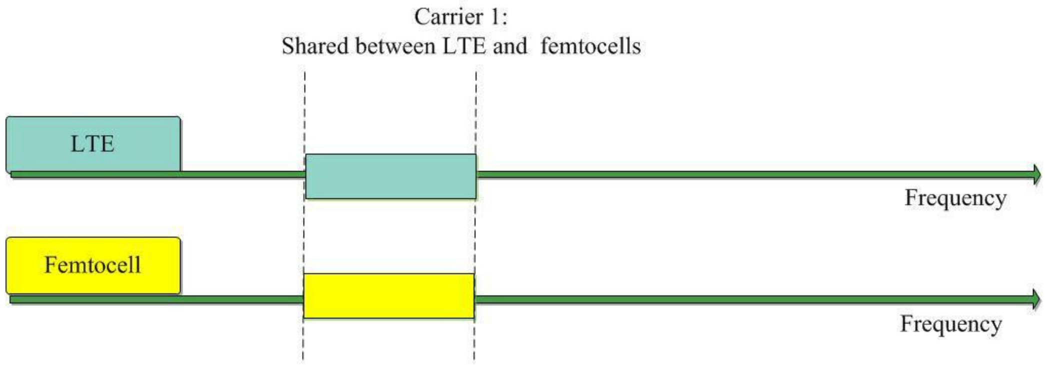
3.7 Spectrum Utilisation based Bandwidth Allocation

3.7.1 Channel Allocation in LTE and Femtocell

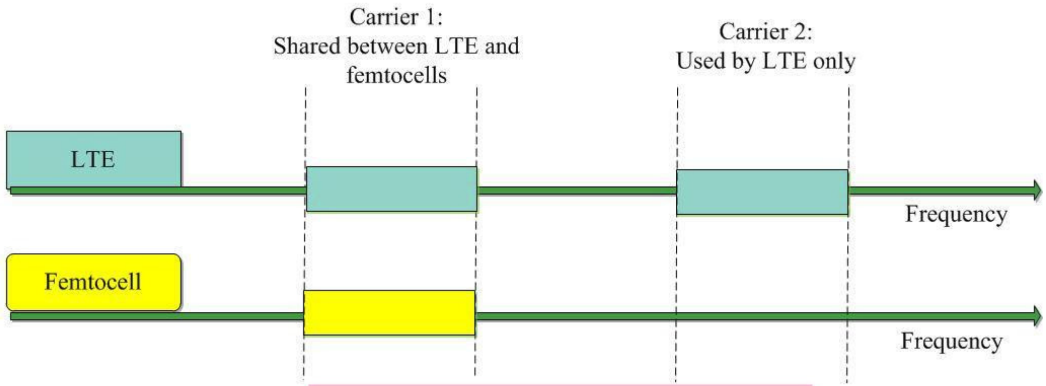
Different channel allocation approaches can be considered for LTE-femtocell deployments to ensure flexibility and optimisation in terms of spectrum access options. The key decision depends on several factors such as how many carriers are available for cognitive users, efficient spectrum utilisation, and whether public access is granted or a private access model is preferred. In this section, a range of practical spectrum allocation schemes and the criteria is investigated in order to choose between them, as shown schematically in Figure 3.19.



(a) Separate carriers



(b) Shared carriers



(c) Partially shared carriers

Figure 3.19: Various channel allocations

Using separate channel has the advantage of causing no interference between macrocell and femtocells assuming sufficient frequency guard spacing. On the other hand, co-channel deployment of femtocells and macrocells have the advantage that there is no separate carrier must be reserved for femtocells. As a result, this scheme does not limit the available channels for femtocells coverage and can be used in coexistence with macrocells. In the case of partially shared channels, some carriers with long times of availability can be shared between macrocell and femtocell base stations. While the co-channel operation mode can occur in combination with shared channel allocation at later times. The LTE base stations has the priority of accessing all the available channels whilst femtocells can only use sections of the available channels when they are not used by the macrocell. When a macrocell user comes close to an FBS that has no access to the spectrum, it keeps its connection with the macrocell LTE band without interfering with the femtocell transmission domain users [34].

3.7.2 Queuing Mechanism

Each router must implement some queuing discipline that governs how packets are buffered while waiting to be transmitted. Various queuing disciplines can be used to control which packets get transmitted (bandwidth allocation) and which packets get dropped (buffer space). The queuing discipline also affects the latency experienced by a packet, by determining how long a packet may wait to be transmitted. Examples of the common queuing disciplines are First-In First-Out (FIFO) queuing and Priority Queuing (PQ). The PQ is a simple variation of the basic FIFO queuing. The idea is to mark each packet with a priority; the mark could be set, for example, in the IP Type of Service (ToS) field [35].

In PQ, packets that arrive at the output link are classified into more than one queue based on their priorities. The packets with highest priority are then served first, next the second higher priority and so on. In order to assign priority the packet header (for example, the value of the ToS bits in an IPv6 packet, its source or destination IP address, its destination port number, or other criteria should be used. Each priority class typically has its own queue for choosing a packet to transmit. The priority queuing discipline will start by transmitting the packets of highest priority class from the nonempty queue (that has packets awaiting transmission). The choice among packets in the same priority class is typically achieved in a FIFO manner. The problem with PQ is that lower-priority packets may get little attention [36]. A queue scheduling discipline manages the allocation of network resources among different traffic flows by selecting the next packet for processing.

3.8 System Model based Priority Spectrum Allocation

The LTE macrocell and cognitive femtocell base station are considered using several queuing applications. Assuming that FUEs produce A_{pp} applications represented of an order 1, 2, · · ·, M, and the users are moving in the same transmission domain of the base station. Then, each request received at the base station is assigned a priority value according to the system delay requirements of different users. Simultaneously, the cognitive base station explores the transmission blocks in $\mathcal{N}$ sub-bands of an available spectrum. Each sub-band is represented by i_{sb} = 1, 2, · · ·, $\mathcal{N}$. An OFDM symbol consists of A narrow band sub carriers divided over a fixed bandwidth $B\mathcal{W}$.

Based on the size of the detected block in a sub-band, the base station computes the number of active sub-carriers (A$-$ $\mathcal{K}$) in sub-band N_{sb}, where $\mathcal{K}$ represents the number of occupied or inactive sub-carriers in an OFDM symbol of total A subcarriers. This process is repeated over all sub-bands 1, 2, · · ·, $\mathcal{N}$ in the targeted spectrum of operation, as shown in Figure 3.20 [37].

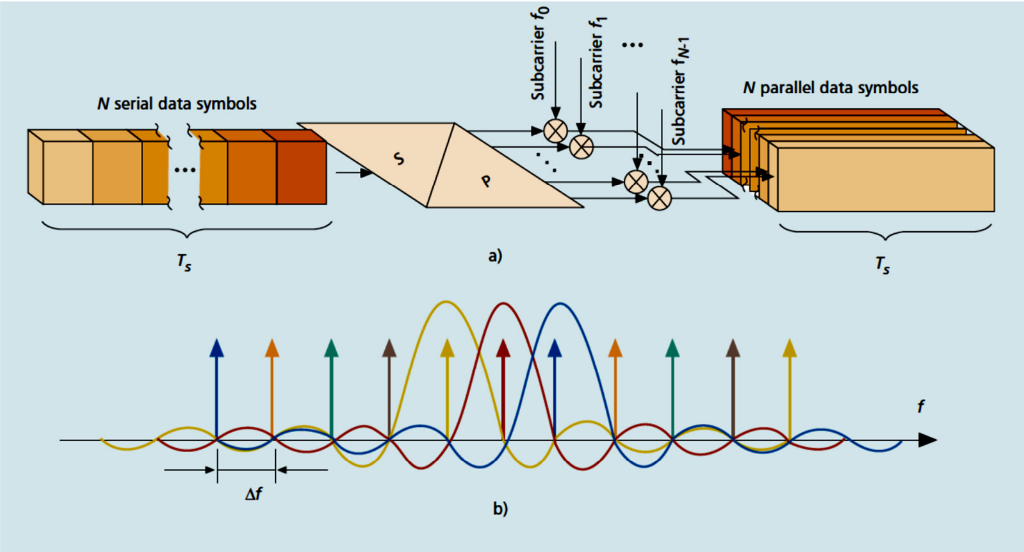


Figure 3.20: OFDM, a) Multicarrier transmission, b) orthogonally [37]

The proposed priority allocation scheme is specifically designed for OFDM based wireless systems that can support dynamic spectrum access. This bandwidth can span across a definite number of sub-bands in the spectrum considered. Hence, it is essential to have knowledge of the following:

- LTE user occupancy in the sub-bands to compute idle periods.
- Bandwidth occupied by each LTE user in these sub-bands to compute the numbers of inactive OFDM sub-carriers left to femtocells usage.

Once this information is available, the cognitive base station can decide on the number of sub-carriers to be made inactive.

Higher spectral efficiency can be achieved by increasing parallel transmissions in less number of time slots per frame. This can be defined also as scheduling the maximum number of parallel transmissions with the minimum number of time slots. Suppose that an i^{th}-cognitive users occupies a bandwidth of BW_i in sub-band $i_{sb} = 0, 1, \cdots, \mathcal{N}$. The number of OFDM sub-carriers in sub-band i_{sb} is $\frac{BW_{\mathrm{i}}}{BW/_{\mathcal{A}}}$ [38]. Thus, the number of inactive sub-carriers $\mathcal{N}_k$ can be expressed as:

$$\mathcal{N}_k = \sum_{i=1}^{\mathcal{N}} BW_{\mathrm{i}} \left(\frac{\mathcal{A}}{BW}\right) \tag{3.1}$$

If we assume that all the LTEs occupy the same bandwidth BW_{equal} in their respective sub-bands, then Equation .3.1 can be re-written as:

$$\mathcal{N}_k = (\mathcal{N}\mathcal{A}) \left(\frac{BW_{equal}}{BW}\right) \tag{3.2}$$

As a result, the femtocell cognitive node can compute the effective capacity C_{eff} as:

$$C_{eff} = \left(1 - \mathcal{N}\frac{BW_{equal}}{BW}\right) C \tag{3.3}$$

where C denotes the individual sub-band capacity.

3.8.1 Spectrum Allocation Technique

In this scheme, the cognitive base station constructs a priority queue for real time applications and it allocates the most important application to the available sub-band that satisfies the joint requirements of delay and BER. This strategy follows the spectrum pooling technique illustrated in [37].

This technique is dealing with spectrum as one pool, so the CR will be able to access the spectrum at any time, and any channel whenever is available. In this technique, all applications share the common relation of delay and BER demands. The scheme follows the same strategy for the subsequent sub-bands. This type of spectrum allocation compares BER requirements of all applications in the queue before allocating a sub-band to certain application. All real time applications such as VoIP and video conference need better BER performance of a minimum transmission delay ($< 224\mu$). On the other hand, all non-real time applications can be served on sub-bands with lower BER performance. In this figure, the cognitive base station allocates the best available sub-band that satisfies the specified requirements of a UE. This selective allocation is based on the prioritised bandwidth demand, BER and delay requirements and as well as the throughput [39].

It is very important that the algorithm supports different types of services. Priority is determined based on the data rate requested by an application, with minimum BER threshold of (10^{-3}). The unique feature that added to our priority queuing strategy is the allocation of a certain channel for each application. This is done to achieve fairness among requested applications, as shown in Figure 3.21. On receiving M application requests from the UEs, the cognitive base station prioritises a i^{th} request, for $\mathrm{i} = 1,2, \ldots .\mathrm{M}$ into a queue based on the BER and delay requirements. The scheme also computes the BER support of the j^{th} sub-band, $\mathrm{BER_{sb}(j)}$, and its number of inactive sub-carriers $\mathcal{N}_k$ of OFDM symbol, $\mathcal{N}_{k_{sb}}(j)$, computed using Equation 3.2.

To be more acceptable, two vectors, $alloc\_chj$ and $alloc\_appi$ are defined to keep track of the channel numbers assigned and the indices of FUEs which have been allocated sub-bands for their requests, respectively. Now for every user$i$, a search is performed for a suitable sub-band out of the N sub-bands.

The decision block ensures that an allocated j^{th} sub-band is never allocated again to a requesting FUE ($alloc_{chj} == 0$) as well as that a i^{th} FUE is never allocated two or more sub-bands at the same time instant ($alloc\_appi$ ==0). After this decision, a sub-band is allocated only after checking that the $\mathrm{BER_{sb}(j)}$ is better or equal to the i^{th} user's requested $\mathrm{BER_i}$. All the sub-bands with BER support $\mathrm{BER_{sb}(j)}$ equal to or one order better than the requested $\mathrm{BER_i}$ of the i^{th} users are stored.

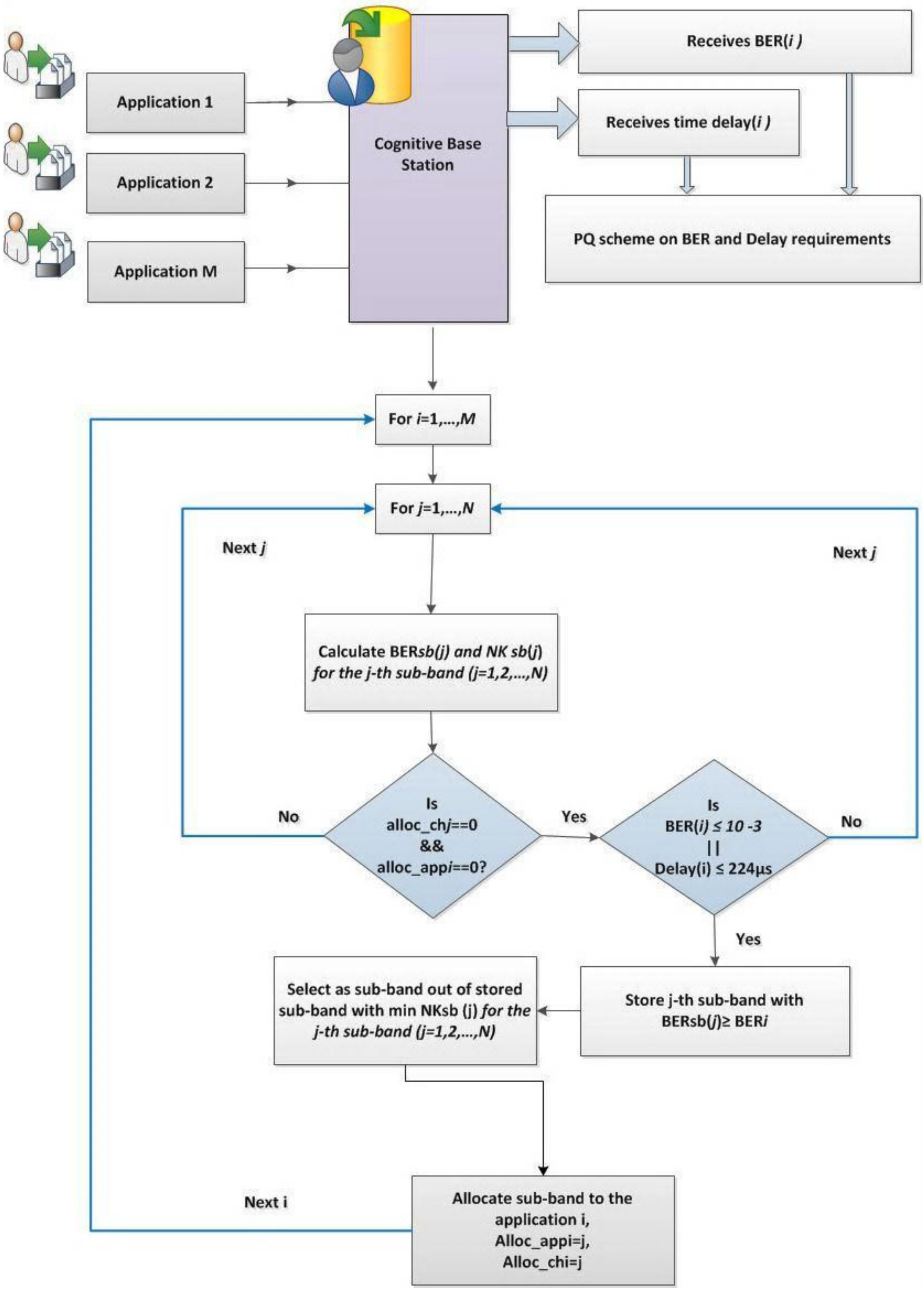


Figure 3.21: Scheme for allocating UEs to the OFDM sub-bands

In the final stage, once a channel is allocated, the status of j^{th} sub-band and i^{th} user request are set appropriately to prevent duplicate allocation of sub-bands and user requests $(\mathrm{alloc}_{\mathrm{chj}} == 1)$ and $(\mathrm{alloc}_{\mathrm{appi}} == 1)$. This process is iterated over all the M requests.

3.8.2 System Assessment

The cognitive system is simulated using six channels. The main target is to show the system improvement the results from using PQ policy. However, the proposed priority spectrum allocation performance is examined using the following steps [14]:

- Different time transmission intervals are set for different packet sizes of VoIP, and video applications. This helps to explore the advantages of adapting the packet format according to the transmission opportunities by evaluating the requested types of services compared with the time slot available for cognitive communications. This is performed by the resources management unit, which controls data flow in the system. However, the physical layer identifies the opportunities in the spectrum. Then, the MAC layer evaluates an optimisation function and a class of priority is given to each traffic type.
- The time allocated for cognitive transmissions is decided according the sensors' data that detects the spectrum availability and primary existence. This is adjusted throughout simulations using the CSMA/CA MAC protocol mechanism. As a result, packets will only proceed when there is a time for transmission and they are in the right queue of priority for delivery as given by their traffic type. In the studied model, back off intervals are chosen randomly for the secondary user. Finally, in the last part, acknowledgment is received and checked for successful packet delivery.

In this setup, six test scenarios examine the proposed spectrum allocation. In each scenario, cognitive base station accesses the available channels for cognitive communications. These channels are shared between the cognitive users and the primary networks that use 15%, 30%, 45%, 60%, 75%, and 90% respectively of the overall channels' time.

In the first scenario, the cognitive femtocells BS send their packets of Video and VoIP data for 85% of the time of the 1st channel while the primary users use the other 15% of the time of this channel and all the rest of channels, as shown in Figure 3.22.

In the second scenario, cognitive femtocells are using channel one for 85% of its time and channel two for 70% of its time, while primary users use all the rest of the time and channels for primary broadcasting. The same sequence is applicable for the rest of the channels (up to six channels) that are assumed to be allocated for cognitive systems. To compare the performance of the proposed system with and without PQ, the above evaluations are performed in which the traditional PQ applied at the femtocell node.

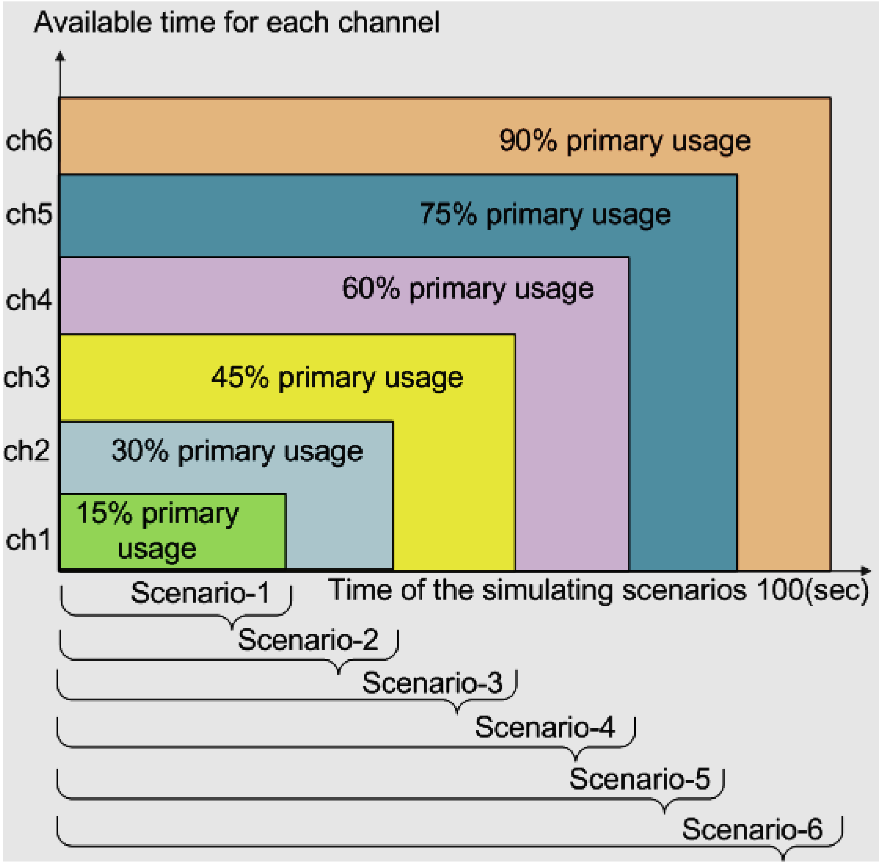


Figure 3.22: Channels free time as a percentage

3.9 System performance

3.9.1 System Specification

The proposed cognitive networks are simulated for the LTE-femtocell nodes using the spectrum utilisation based priority queuing strategies. The simulation environment, considers 6 different scenarios. Each scenario has three cognitive femtocell nodes. Each FBS have two users transmitting VoIP and Video applications. Moreover, the main macrocell base station is created using the LTE standards. The Ad hoc On-Demand Distance Vector (AODV) routing protocol intended for use by mobile nodes. It offers quick adaptation to dynamic link conditions while the main base station is linked to the femtocell nodes via optical fibre connections. In this configuration, a profile for each client was set that uses two applications as mentioned above.

For setting the free time profile, different time intervals within LTE are considered as multiples of a basic time unit $T_u = 1/30720000$. The system frame has a length of $10ms$ for 20 slots, $T_{frame} = 307200 * T_u$. Each frame is divided into ten equally sized sub-frames of $T_{sub\_frame} = 1ms$ in length ($T_{sub\_frame} = 30720 * T_u$). Scheduling is done on a subframe basis for both the downlink and uplink. Each sub-frame consists of two equally sized slots of 0.5 ms in length $T_{slot} = (15360 * T_u)$.

The time of the simulation run was set to 600 sec. The same network is used in each of the studied scenarios with the same profile of free channel time and strategies of each of the two different cases. The main goals of the application to achieve spectrum utilisation based priority queuing in the cognitive network in order to overcome the congestion and time delays during packet delivery for cognitive applications. The network features were set as specified in Table 3.2.

Table 3.2: Spectrum allocation system parameters

Parameter	Value
Type of traffic	heavy traffic load
Video coding	MPEG4
Type of video service	streaming multimedia
VoIP	PCM quality speech
Type of voice service	Interactive voice
Packet size	1500 bytes
Frame Duration	5ms
Slot time	10µs
Buffer size	500kbps
packet length	1024 byte
LTE Power	40dBm
Noise figure	9 dB
Antenna gain	15dBi
PHY technique	OFDM
Femtocell Power	20dBm
Bandwidth	5MHz
Noise figure	9 dB
Antenna gain	5dBi

3.9.2 Results and Analysis

The performance of the cognitive system is examined using two approaches: Firstly, with new proposed priority spectrum allocation policy. Secondly, using the traditional LTE-femtocell architecture and without the priority queuing PQ policy installation.

Figure 3.23 shows the throughput comparison for the two cases of PQ scheme and traditional scheme with video and VoIP traffic applications. By using priority spectrum allocation, throughput is improved by approximately 10%. The results suggest an increase in the overall network throughput. In other words, when voice data becomes part of a network, the priority has to be given to real time applications, while the video packets are buffered. The increase in the number of channels available for the cognitive communication leads to a considerable increase in the throughput. The analysis of this work was defined for a certain profile of channel's free time and availability. This means that the throughput can be increased or decreased as a function of the increase or decrease in the availability of resources. This is highly affected by the activities of the PU and the number of packets to be delivered by the cognitive network.

Figure 3.24 shows the end-to-end time delay for the two different cases. The simulation results will also show the effect of the slot size on queuing delay and the end to end MAC delay. The VoIP shows the lowest average delay, in contrast, to Video, which has the highest medium access delay. In both cases, the installation of the PQ shows a significant improvement in the system performance compared to the traditional spectrum allocation scheme. These results show that scheduling spectrum access as a function for the client's priority can improve the overall cognitive network performance.

Figure 3.25 shows the medium access delays for the simulated scenarios. Considering this graph, it is obvious that all QoS requirements of the priority policy are met using the proposed scheme. This medium access delay is calculated as the duration from the time when it is inserted into the transmission queue, (which is the arrival time of the higher layer data packet and the creation time for all other frames types), until the time when the frame is sent to the physical layer for the first time.

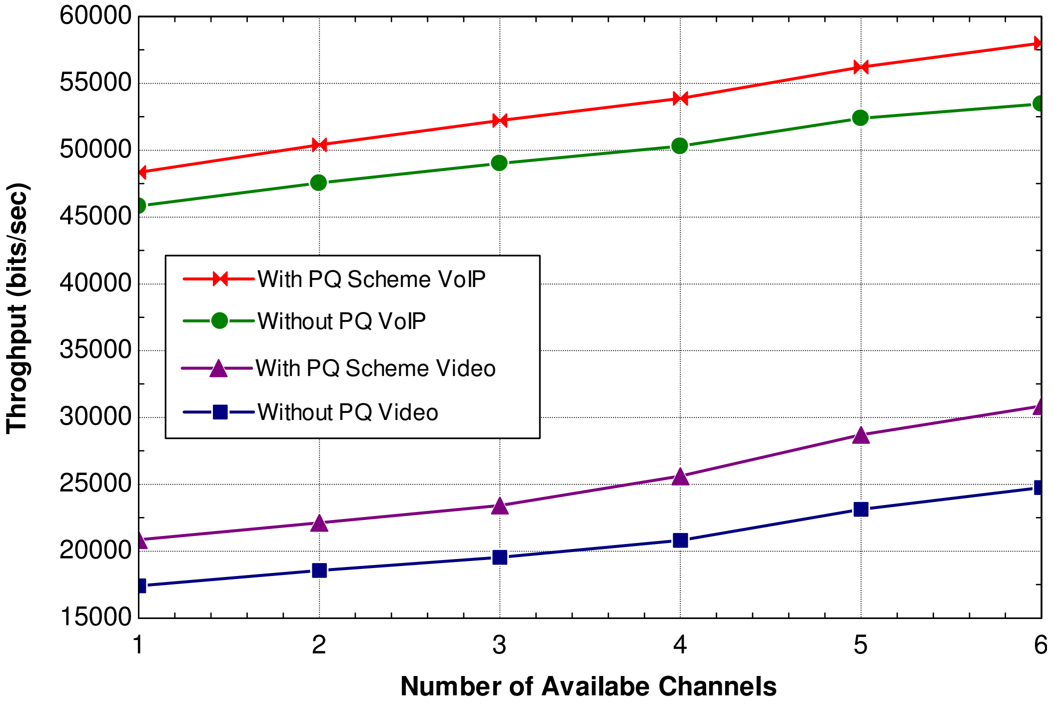


Figure 3.23: Throughputs of the two applications Video and VoIP

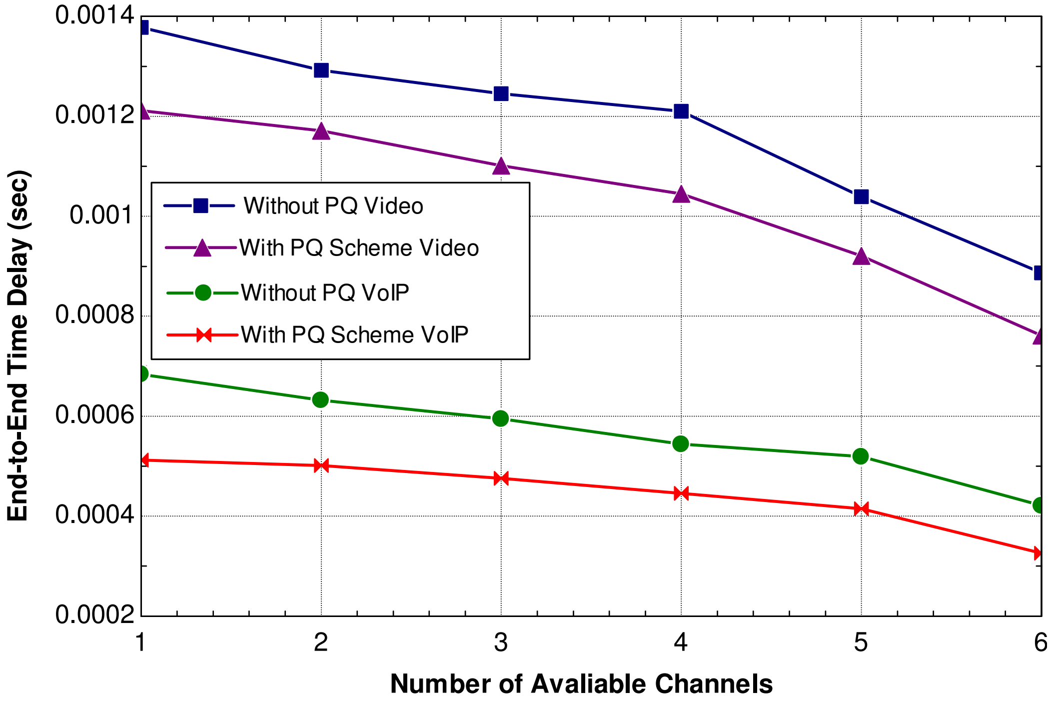


Figure 3.24: Comparison of End-to-End time delay

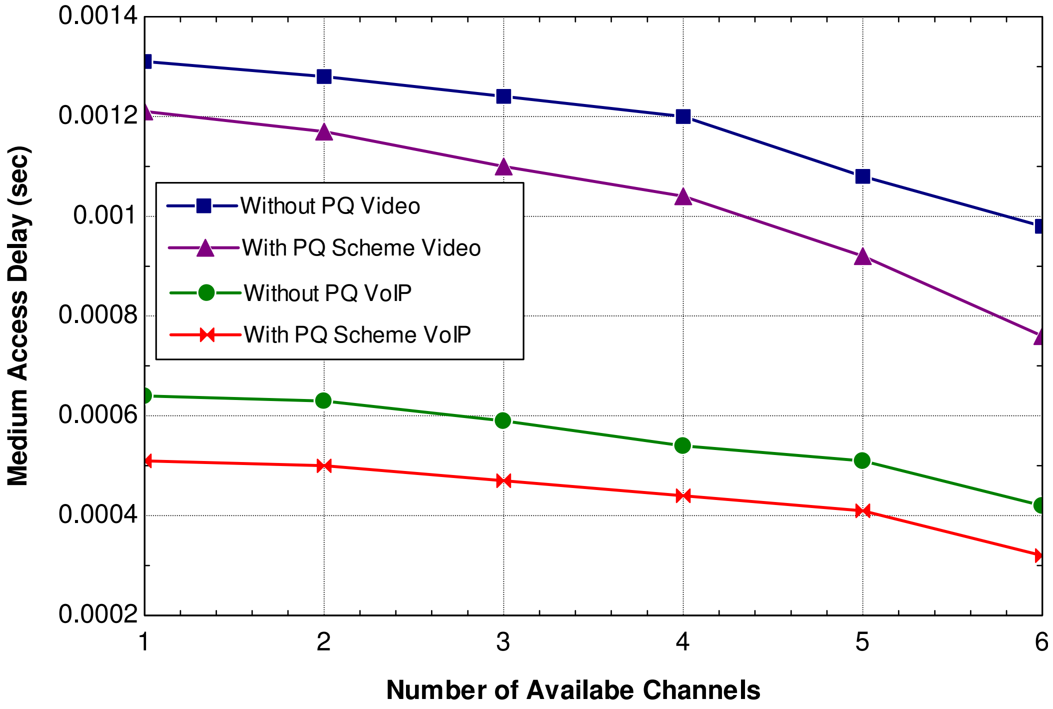


Figure 3.25: Medium access delay for the two applications Video and VoIP

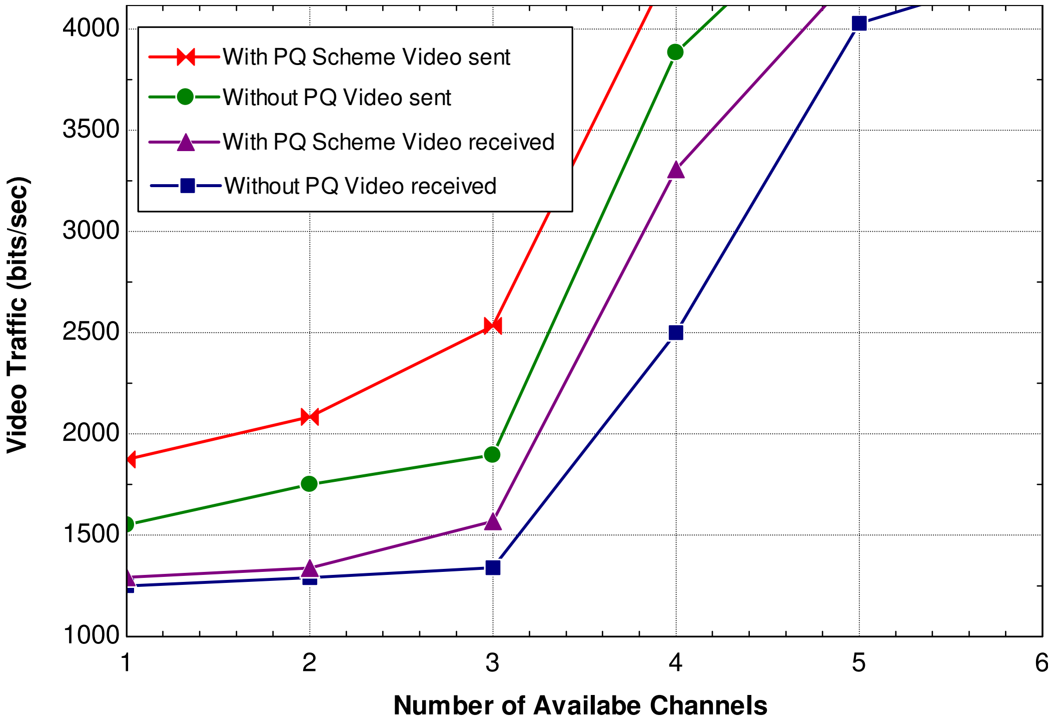


Figure 3.26: Traffic sent and received for Video

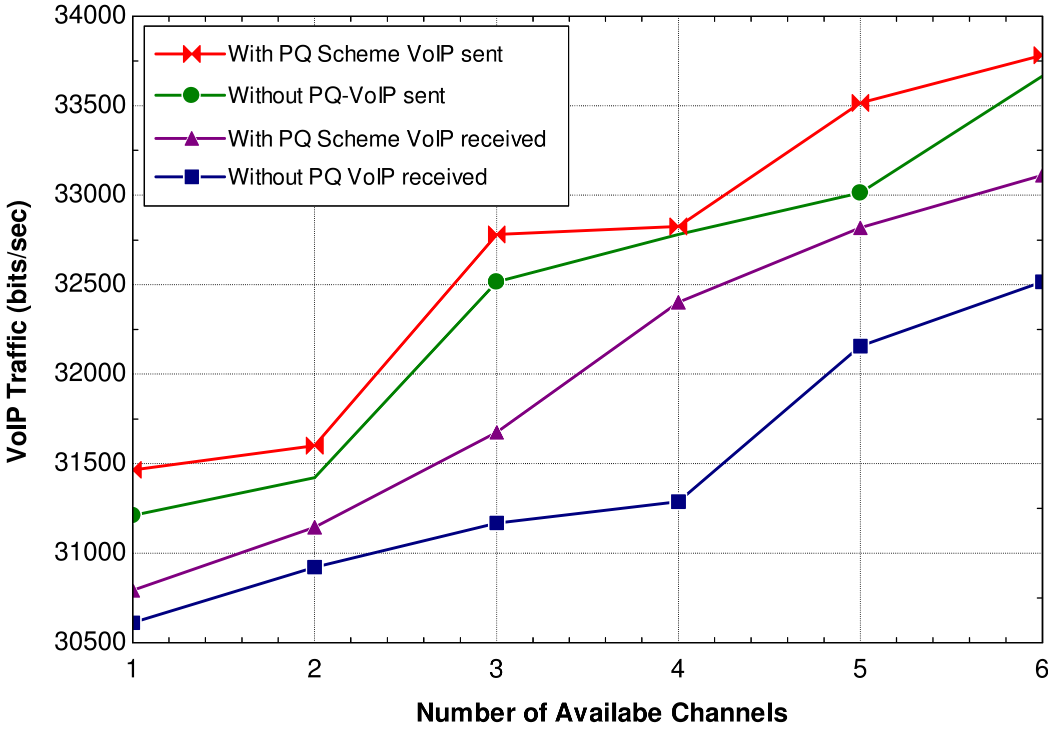


Figure 3.27: Traffic sent and received for VoIP

The traffic sent and received is plotted in Figures 3.26 and 3.27. It can be seen that the amount of traffic sent is much higher than traffic received for the same cases. Also, PQ policy installation shows a better performance compared to without PQ cases for the same numbers of channel availability and opportunities of accessing the spectrum. Clearly, the proposed cognitive system is successful for an outdoor environment and more reliable for future applications. To sum up, results show that the developed femtocell network architecture was able to handle the spectrum allocation in the cognitive femtocell in coexistence with the LTE macrocell and to support the end users with the requested quality of service. Priority queuing strategies are essential for determining the performance of the network in terms of various QoS points, for instance, (throughput, delay, medium access etc.). Simulation results have shown that a cognitive femtocell with more spectrum opportunities can achieve much higher capacity than normal femtocells depending on the number of available of channels. As a result, the performance of existing macrocell networks can be improved by combining them with cognitive femtocells.

3.10 Conclusion

This chapter presented two spectrum allocation approaches. Firstly, novel resource management model is proposed to improve the bandwidth allocation in dynamic spectrum access models. This is performed by processing transmission requests in terms of traffic frames, then scheduling the traffic according to the available bandwidth in order to increase the capacity of delivered services. The proposed spectrum management framework incorporates PHY and MAC layers in order to assign suitable services to the available transmission opportunities. The proposed spectrum management system with the provided algorithms allows increasing the utilisation of the available resources for the LTE-femtocell system and improves the overall spectrum efficiency.

Secondly, a new spectrum allocation technique is proposed to perform a priority queuing for real time applications and allocates the most important application to the available sub-band to satisfy the joint requirements of delay and BER. This approach is introduced to identify the QoS requirements and white space available for transmissions. Real time applications are assigned to different data queues and transmission decision choice between them is made whenever the investigated channel matches the QoS requested and can maintain high throughput linking to end-users in order to achieve spectrum utilisation.

The proposed system models achieved higher degrees of spectrum efficiency in terms of lower end-to-end time delays, lower medium occupancy, high spectral efficiency, and considerably higher throughput. New research topics that re-design systems from cognitive users' viewpoints are raised to the industrial and research communities.

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Chapter 4

Radio Power Management and LTE Coverage Planning

Power management is an important factor for mobile networks that employ multi-tier levels and a diverse set of transmission operations. Since a new system of cognitive LTE-femtocell is implemented in the previous chapter, a new power control management system is introduced and developed to increase the power efficiency for the proposed network model. This chapter provides two contributions: First, a novel algorithm of adaptive power control in the MAC layer transmission pipeline that adjust the transmitted power according to the signal measurements from near mobile stations. Secondly, a coverage planning study is performed for cognitive femtocells to obtain the optimum Inter Side Distance (ISD) that deals with the ability of the network to provide services to the end users. In addition, a developed power consumption model is considered in order to estimate the effect of the daily energy consummation on cognitive networks.

4.1 Introduction

The concept of LTE networks is quickly emerging as the future technology of choice for heterogeneous networks, as shown in Figure 4.1. This is because next generation wireless networks need to combine the communication technologies with the delivered services. In this regard, femtocells are getting an increasing amount of attention for efficient cellular coverage that provides higher quality indoor/outdoor access at a low cost. This represents an opportunity for operators to obviate the need to deploy costly infrastructure by reusing existing small broadband interface base stations [1].

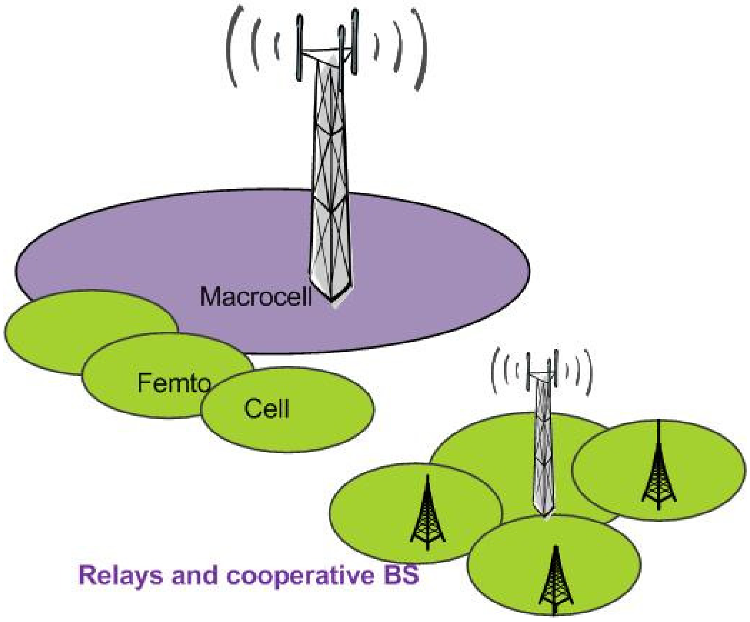


Figure 4.1: Cooperative in heterogeneous networks

Transmission rate is an important factor in determining the efficiency of a communication system. Transmissions at low rates cause higher occupancy (inefficient use of the shared spectrum), higher energy consumption, lower throughput and higher delay while on the other hand, transmissions at a higher rate are leading to communication failures. Therefore, an efficient rate adaptation technique which can determine the channel quality information and select an appropriate transmission rate can enhance the efficiency of any communication system. Femtocells have an extensive auto configuration and self-optimisation capability to enable a simple deployment, and are designed to automatically integrate themselves into existing LTE networks [2]. In this way, a self-configuration function can adjust transmit power based on the measurement of interference from neighboring base-stations in a manner that achieves roughly constant cell coverage [3].

This approach involves adapting the transmit power in a collaborative manner. Once the neighbour responsible for interference is identified, the suffering femtocell UE could negotiate on the transmit power to be used with this neighbors. If both parties drop transmits power then this may solve the problem although compromising the range. This may not be a desirable solution. Rather it may be an inconvenience, as the UE may have to move closer to the FBS to get sufficient service. Nonetheless, in the worst-case scenario where there is a high level of contention for the scarce spectrum, such a solution can at least ensure service availability/continuity by sacrificing the range. This solution has to be realised in a collaborative manner to have any significant effect [4].

The transmitted power of a femtocell consists of pilot power and traffic power (including signalling power and data power). Pilot power determines the coverage of the cell: high pilot power leads to the large cell coverage and low pilot power may lead to insufficient coverage. Moreover, the larger the allocated pilot power, the less the power is left for traffic, which causes throughput reduction in the femtocell. On the other hand, large pilot power may introduce high outage probability to neighbouring unregistered mobile users due to interference. Therefore, pilot power management involves a trade-off between pilot pollution and coverage [5]. Cognitive operators shrink the organisational demands to reduce the amount of traffic, the pilot power should be minimised to leave as much power as possible for traffic channels in order to increase cell capacity. This leads to an efficient power management which is an important component of radio resource optimisation [6].

Motivated by what is mentioned above, this chapter focuses on the power management in order to realise a pilot power configuration technique for the cognitive access networks. This improves the flexibility of the new cognitive system in reducing the power of transmission and increase the system resources competence. In addition, the study considers energy efficiency based on the daily traffic analysis and the femtocells deployment across the cell sites. The algorithms and mathematical models given in this chapter help to achieve higher levels of network re-configurability.

4.2 Related Work

The structural design of cognitive femtocell is based on infrastructure-based overlay LTE network and autonomous sensing of the radio spectrum unused by the macrocell base stations. A system composed of LTE and femtocells can improve the network performance by: reducing macrocell traffic, providing services in locations without signal or with weak coverage, and handling the local resource management.

Many studies in the literature deal with different methods for pilot power control management [7]. The goal is to ensure a constant femtocell radius in the downlink and a low pre-definable uplink impact to the macrocells.

Most of previous work on adaptive pilot power mainly concentrates on the cognitive radio users with only one type of service requirement, without considering the scenario with heterogeneous services. While in [8] the authors was proposed a power allocation scheme to improve the overall system throughput, defined as the total number of subscribers that can be simultaneously served and supporting heterogeneous services in cognitive radio environments.

First, the work was classifying the SUs by service requirement with minimum QoS guarantee. Then was formulated the problem of dynamic channel and power allocation of CR users as a mixed integer programming problem by design optimum algorithm.

A similar work can be found in [9], where the femtocell coverage can be optimised using the information collected during the mobility events of mobile users to improve the coverage area of femtocell BS and to reduce the unnecessary mobility signalling. Moreover, a new power control technique is address as the first step to minimise the interference when the femtocell sharing the spectrum and using the same frequency band with the macrocell. The authors in [10] undertook a comprehensive self-organisation model to control the femtocell power in the co-channel deployment in coexistence with macrocell in a hierarchical cell structure.

The issues of self-optimised coverage coordination in the femtocell networks were examined in [11], where a femtocell base station adjusts the transmit power according to the statistics of the signal strength that is measured at a femtocell downlink. In [12], cognitive radio UEs can adjust their transmit powers to limit any interference with PU and by considering the individual rate requirements of each CR. In this way, new adaptive algorithm of a distributed value based Signal-to-Interference-Noise-Ratio (SINR) at femtocells is employed in order to improve cross-tier interference at the macrocell due to co-channel impacts. The scheme involves adapting link budget analysis which enables simple and accurate performance insights in a two-tier network in a collaborative manner. However, in [13] CR UEs can update their transmit powers regularly to reduce interference to PUs, but there is no variations in transmission parameters of individual CRs were considered.

In [14], the researchers considered layouts featuring varying numbers of femtocell base stations per cell in addition to conventional macro sites and the power consumption. This was used as a system performance metric to evaluate potential improvements of this metric through the use of femtocell base stations. New research in [15] addresses a joint power and admission control scheme for cognitive radio network in order to maximise the energy efficiency of the secondary users and guarantee the QoS of both the PU and the CR. However, the research was providing both centralised and distributed solutions where the insight on how a CR user's interference is influenced by a PU's is not considered.

In contrast to these power management approaches, our target is to perform power control analysis of sub-band occupancy. Authors in [16] investigate the energy saving potential by exploiting a spatial two-tier network and two original power metrics for analysing the cellular network. The paper has been analysed the downlink energy consumption and provide a new energy efficient spectrum allocation policy in macrocell and femtocell cellular systems to reduce the downlink energy consumption. The energy consumption and network performance of the new emerged network are used to quantify the potential of this feature. Similar investigations with respect to base station densification and traffic are conducted in [17], where the researcher has tackled the issue of energy-aware management of cellular access networks. They tried to characterise the amount of energy that can be saved by reducing the number of active cells in the access networks during the periods when they are not necessary because the network traffic is low.

4.3 Power Management System

The management approach for power efficiency of 4G radio communications LTE system using cognitive femtocell is developed as shown in Figure 4.2 to be a self-organising system, by integrating optimisation and auto-configuration procedures as explained in this section.

Traditionally, the pilot power of the femtocell base station is setup to fixed values which means that all mobile users within the coverage area are receiving the same power irrespective of their relative positions to the base station. While, adaptive power control proposals suggest that a base station must listen to the radio environment to the make regular measurements of existing noise and power levels. Based on these evaluations, the femtocell will adjust the pilot power to a level that causes only an acceptable amount of interference. In the considered scenarios, a macro and femtocell base stations are employed to create an adaptive transmission domains. Provided by intelligent control modules, femtocells can adapt their coverage size according to the mobile users' position.

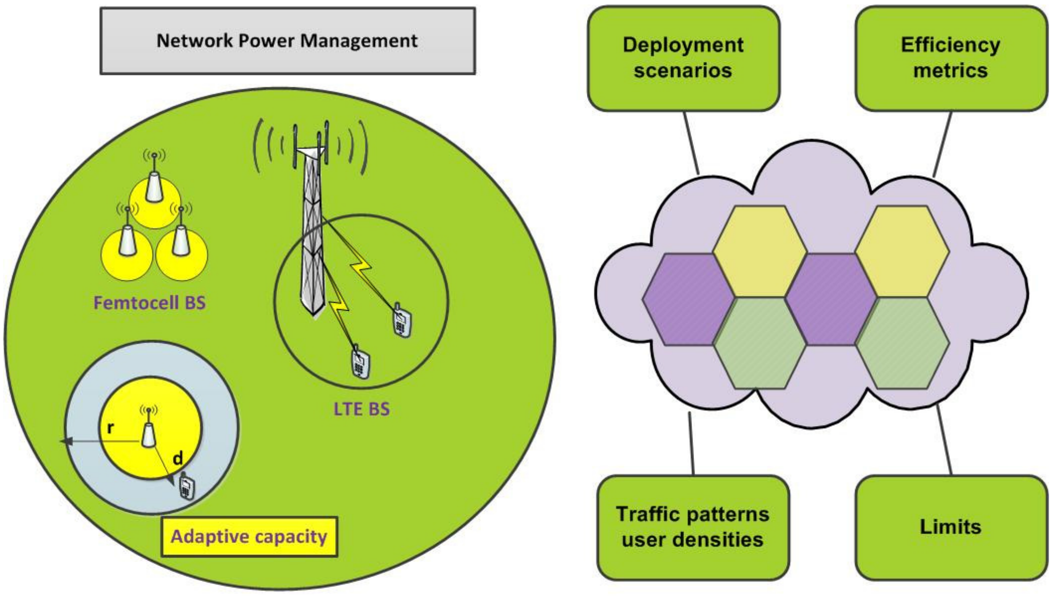


Figure 4.2: Management approach for power efficiency of 4G radio communications LTE system

The proposed method for adaptive coverage adjustment for femtocell management is able to steer the coverage power as shown in Figure 4.3, while the outer limits of the femtocell coverage area remain fixed. In this method, the transmitted power is a function of the client distance from the femtocell base station and the angle of transmission. Transmission adaptations occur whenever a mobile leaves the main macrocell area and gets into the femtocell zone. Then, the femtocell needs to identify the instantaneous position of the mobile to adjust the power of transmission.

At the first instance, the femtocell power is set to the maximum level denoted as distance d3 with power transmissions as P3. When active users are close to the femtocell, it operates self-optimisation and changes the power and coverage to alleviate power to the levels of P1 at distance d1. Hence, the transmission pattern is dynamically adapted to attain the most cost effective power savings by reducing the transmitted power whenever the mobile moves closer to the FBSs.

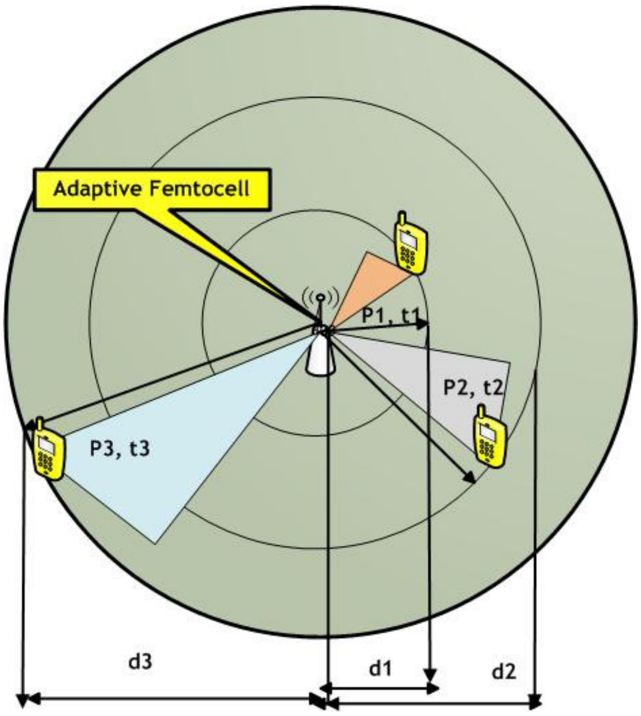


Figure 4.3: Adaptive coverage adjustment for femtocell management

4.3.1 System Formulation

For each femtocell with one subcarrier, the transmitted power is set to a certain value that is on average equal to the power received from the management system at the target cell radius of $r = 30\text{m}$, depending on the maximum power of the femtocell $P_{\text{max}} = 20\ \text{dBm}$.

In the downlink, both the pilot power and the maximum transmitted power must be configured. The same approach is also applied for the auto-configuration of the pilot power to achieve the target range [9, 16]. Here, the transmitted power from each cognitive femtocell is set to a value that is on average equal to the power received from the closest macrocell at the target cell radius of r, subject to a maximum power of $\mathrm{P_{max}}$, the femtocells transmitted power can be calculated in decibels as:

$$\mathrm{P_{femto}} = \min\left(\mathrm{P_m} + \mathrm{G(\theta)} - \mathrm{L_m(d)} + \mathrm{L_f(r)}\right) \qquad (4.1\,)$$

where $\mathrm{P_m}$ is the transmit power of the sector in which the femtocell is located, and $\mathrm{G(\theta)}$ is the antenna gain in direction of the femtocell where θ is the angle to the femtocell with respect to the sector angle, $\mathrm{L_m}$ is the path loss between the macrocell BS and the femtocell BS, and d is the distance between them. $\mathrm{L_f(r)}$ is the line of sight path loss at the target cell radius r (excluding any wall losses).
The initial self-configuration values only present the initial cell coverage boundaries of a femtocell, which is subject to change due to the installation of adaptive power control unit. In the uplink, the mobile user's power is limited to a value limiting the aggregate interference of all femtocell mobile users to the closest macrocell, thereby ensuring the uplink of the macrocell is not degraded significantly.

4.3.2 Proposed Scheme: Adaptive Pilot Power Control

In this section, novel algorithms are implemented in the femtocell base station to control cell coverage. The goal is to design algorithms that periodically update the pilot power configuration based on each femtocell's user signal strength and global traffic delivery in the network as shown in Figure 4.4.

Each femtocell is assumed to have a power value that guarantees a given received signal strength to its active attached users. This scheme is assisted by standard measurement reports, which are performed by the users and feedback to the cells for channel quality estimation purposes. The objective behind this is to find the optimal pilot power vector P^{new} which determines the cell radius $r_{i,f}$ for each femtocellf_i, such that:

$$\text{Max} \quad r \tag{4.2}$$

$$d_i \le r \qquad i = 1,2, \dots \dots \dots \dots \dots .., N$$

$$0 \le p_i \le p_{maxi,} \qquad i = 1,2, \dots \dots \dots \dots \dots .., N$$

where r is a radius of femtocell BS coverage. The above optimisation is equivalent to a Max-Min problem: max-min d_i, $i = 1,2, \dots \dots \dots, N$, which maximises the minimum femtocell radius in the network. P_{maxi} defines the maximum pilot power in each cell i which constrains the cell radii solved from Equation 4.2. The power is adjusted at a vector of P_i corresponding to each cell radius of d_i.

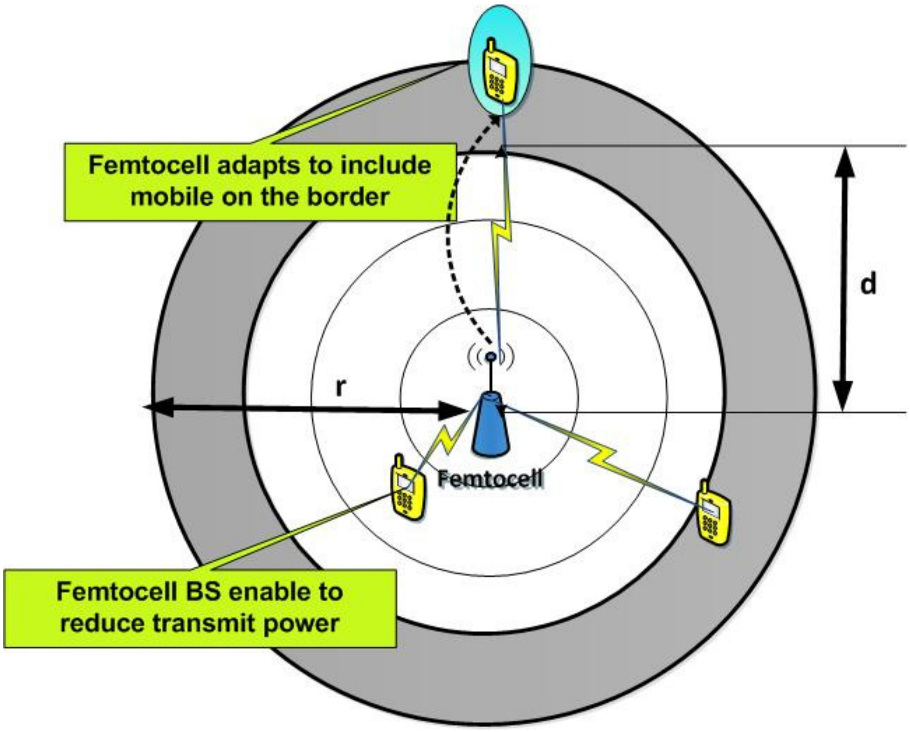


Figure 4.4: Femtocell coverage as a function of mobile distance

The other challenge of power optimisation is to save more power than other traditional femtocells in the area which they have fixed transmitted power. According to equation 4.2, all users' deployed access points cooperate to smooth out the potential big variance of cell sizes in an arbitrary infrastructure topology. This dissimilarity is much more adaptive than setting up a constant cell radius of (10) meters for all femtocells as studied in previous work [7]. Now, the function

$P_{i,f}$ is introduced to replace the radius expression $\mathrm{d_i}$ in equation 4.2 and the original problem becomes:

$$\text{Max} \quad \mathrm{r} \tag{4.3}$$

$$P_{i,f} \le \mathrm{r}, \qquad \mathrm{i} = 1,2,\dots\dots\dots\dots\dots.., \mathrm{N}$$

$$0 \le \mathrm{p_i} \le \mathrm{p_{max}}, \qquad \mathrm{i} = 1,2,\dots\dots\dots\dots\dots.., \mathrm{N}$$

The function of $P_{i,f}$ maps the adjustable power vector P^{new} to each of the cell radii $\mathrm{r_i}$. This replacement can be used because a particular pilot power allocation pattern P^{new} uniquely determines each femtocell size in the network.

In more detail, user f_{UE} sends a measurement report to its serving femtocell base station F_{BS} regularly at $T_{\text{measurement}}$ time intervals. The femtocell user report indicates the received signal strength $RSS_{avg,UE}^{pilot}$, measured by a user f_{UE} in the pilot of femtocell F_{BS}.

After receiving reports from all its connected mobile subscribers, the femtocell then identifies which one is the strongest signal. It should be noted that since femtocells are likely to uniformly distribute their power among all subcarriers in order to avoid large average to peak power ratios [18]. The femtocell BS adjusts its transmitted power $\mathrm{P_{adj}^{new}}$ for each subcarrier according to the following equation:

$$\mathrm{P_{adj}^{new}} = \left\{ \begin{array}{c} P_{fem}^{max} = \dfrac{\mathrm{P_{fem}^{t}}}{\mathrm{N_{UE}}} \\ P_{fem}^{old} + (\mathrm{RSS_{avg,UE}^{far}} - \mathrm{RSS_{avg,UE}^{pilot}}) \end{array} \right\} \tag{4.4}$$

where P_{fem}^{max} is the maximum power of the femtocell BS, $\mathrm{P_{fem}^{t}}$ is denote to the total power radiated from femtocell BS to all subscriber in its domain and, N_{UE} represents the total number of existing subcarriers.

P_{fem}^{old} denotes the current power radiated to each subcarrier; $RSS_{avg,UE}^{pilot}$ is the average received signal strength estimated for the active user (derived using measurement reports); RSS $_{\mathrm{avg,UE}}^{\mathrm{far}}$ is the targeted received signal strength by the cell for the farthest user.

Algorithm 4.1: Pilot power control proposed scheme

```
1:   /* Calculate the avg. power of signal linked with transmitted PKT*/
2:   femtocell not active
3:   surrounding awareness
4:   any active user
5:   wake up triggered pipeline
6:   Received Signal Strength(RSS) from mobile
7:   check the channel statue
8:      if Channel is already occupied then
9:          adapt to another channel
10:     end if
11:  pilot power $P_f^{max}$
12:         if user in coverage
13:            self-power optimisation ($P_{adj}^{new}$)
14:            $\mathrm{P}_{\mathrm{adj}}^{\mathrm{new}} = \begin{Bmatrix} P_{fem}^{max} = \frac{\mathrm{P}_{\mathrm{fem}}^{\mathrm{t}}}{\mathrm{N}_{\mathrm{UE}}} \\ P_{fem}^{old} + (\mathrm{RSS}_{\mathrm{avg,UE}}^{\mathrm{far}} - \mathrm{RSS}_{\mathrm{avg,UE}}^{\mathrm{pilot}}) \end{Bmatrix}$
15:         end if
16:             if (d>r)
17:                 go to (2)
18   else
19       if (d≤ r)
20           network coverage
21       end if
22   end if
```

This power control runs on a regular basis on a frequency of femtocell BS in order to adapt the femtocell coverage to any kind of environment and to cope with the mobility of users within the offices. The proposed scheme for adaptive power control adjustments is given in Algorithm 4.1. Mobile users have the ability to wake up the femtocell by transmitting data signals. This allows the femtocells to determine the SNR for the received request based on values obtained from mobile user communications as shown in Algorithm 4.2.

Algorithm 4.2: Signal to Noise Ratio

```
/*Compute the SNR for the given packet*/
get the packet power level
get the interference noise
Calculate SNR= (RECEIVED POWER / NOISE)
```

Normally, the wake-up signal could be received by more than one femtocell as they detect the same mobile signal strength. Then, the Radio Network Control (RNC) will be responsible to decide the femtocell that should be waked to start operation. However, when the femtocell is chosen to serve, its pilot power should be at the maximum value P_{fem}^{max} to ensure that the mobile user is covered. After that, and based on mobile position, the femtocell can adaptively update pilot power to reach the optimum value in order to save power. The power adjustment process keeps on until utilising the best coverage or the mobile leaves the maximum coverage area.

4.3.3 Radio Transceiver Pipeline Models

This section describes the functionality and implementation of the power control model in the radio transmitter pipeline. The model is developed using a modified MAC layer and PHY pipeline stages to configure the femtocell transmitted power. Advance OPNET version 17.1 simulations with a developed C++ system code were used to implement the network performance with the femtocell self-optimisation coverage model. OPNET [19] provides a comprehensive improved environment that supports the modeling of wireless communication networks and distributed systems.

The Simulation Kernel in OPNET has Transmission Data Attributes (TDA) to supply transmission feature with access to a minimum standard set of values in order to support negotiation between channel stages. The calculation of the power received occurs independently for each packet that is able to reach and affect the radio receiver channel. In this model, the busy or idle state information of the radio receiver channel is obtained when signal lock field is used to prevent the simultaneous correct reception of multiple packets. However, calculating the signal strength parameters as shown in Algorithm 4.3 identifies the mobile position.

Algorithm 4.3: Calculate the distance and transmission delay

```
/* Get the distance between Tx & Rx from kernel procedure */
/* Get the start distance between Tx & Rx */
start_prop_distance=op_td_get_dbl(pkptr, OPC_TDA_RA_START_DIST);
/* Get the end distance between Tx & Rx */
end_prop_distance=op_td_get_dbl(pkptr,OPC_TDA_RA_END_DIST;
/* Compute propagation delay to start and end the reception*/
prop delay ← prop distance /prop velocity
/* Check whether the propagation distance is higher than the max */
Else
/* enter both propagation delays in packet transmission attributes */
OPC TDA RA START PROPDEL ← start prop delay;
OPC TDA RA START PROPDEL ← end prop delay;
End
```

Channel match is employed to compute the compatibility between transmitter and receiver channels in terms of available or occupied channel. One of three possible functions must be allocated to the packet, as defined below:

- ***Effective***: This function is activated once packets in this group are considered suited with the receiver channel. Packet may possibly be accepted and forwarded to other modules in the receiving node, provided that there is no extreme number of errors.

- ***Noise:*** This function is employed to categorise the packets whose data content cannot be received, but that have an impact on the receiver channel's performance by causing interference.

- ***Disconnect***: If a transmission is determined to have no effect on a receiver channel's status. The Simulation Kernel will then crack the link between the transmitter and receiver channels for this particular transmission.

The channel match states are determined as shown in Algorithm 4.4.

Algorithm 4.4: Channel match statues

```
/* Check the PKT status */
    if (TX FREQ >= RX FREQ + RX BW) || (TX FREQ + TX BW <=
        RX FREQ) then
        set channel match statue to  disconnect
    else
        if (TX FREQ ! = RX FREQ) || (TX BW! = RX BW)
            Set match status to noise
        else
Set match status to effective
end if
```

Algorithm 4.5 gives the power calculation of the mobile signals arrived packets.

Algorithm 4.5: Power level of signal arriving at receiver

```
/* Compute the average received power in Watts */
/* signal associated with a transmitted packet */
if (op_td_is_set (PKPTR, OPC_TDA_RA_RCVD_POWER)) then
    path_loss = op_td_get_dbl (PKPTR, OPC_TDA_RA_RCVD_POWER);
```

In general, the calculation of received power is based on factors such as the power of the transmitter, the distance separating the transmitter and the receiver, the transmission frequency, and transmitter and receiver antenna gains. If transmitter and receiver are the same then calculations are unnecessary and the antenna gain is set to zero. Else, the gain is obtained from the kernel procedure *[P_TBL_PAT_GAIN (PAT_TBL_PTR, POLAR, AZIMUTH)]* which provides particular antenna direction to gain value corresponding to that direction.

System level simulations will help to examine performance of the new femtocell algorithms in different scenarios. On the other hand, it will assist to understand the performance of different strategies, e.g. power efficiency and packets delivery times.

4.4 Simulation

The simulation project was created to evaluate the performance of the proposed algorithms for power control. The model is tested with a number of femtocells, where each femtocell serves a maximum of four subscriber stations. Figure 4.5 shows the scenario setup. An open access network is used where mobile users are linked with the nearest femtocell base station; the signal is very weak from macrocell base station.

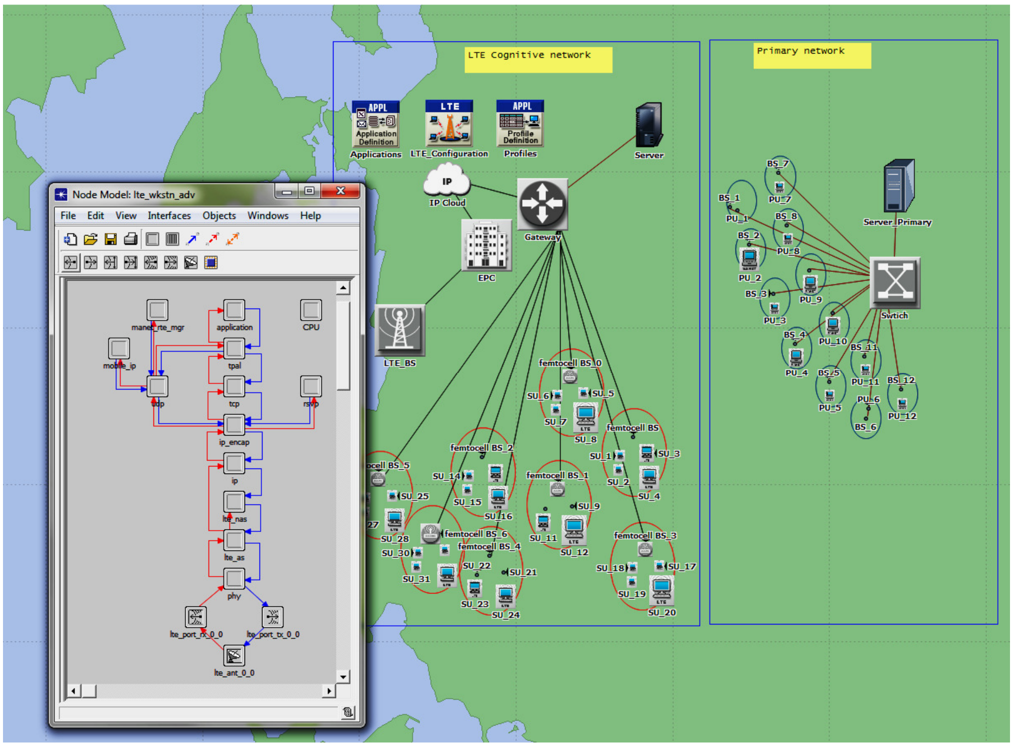


Figure 4.5: Sample of power management project in OPNET17.1

The performance of the proposed power control algorithm is calculated for 25 mobile end-users. Then the system was tested for 20, 40, 60, and 80% femtocells with activated power transmissions. These subscribers were deployed randomly at the macrocell-femtocell network domain. To validate the performance of the proposed adaptive pilot power configuration of 20dBm, the simulation is compared with fixed value of femtocell transmitted power, as in [7, 9]. The proposed algorithm dynamically determines the pilot power allocation according to the nature of cognitive network that can dynamically change the infrastructure topology in order to optimise the spectrum management. The network parameters were set as shown in Table 4.1.

Table 4.1: System parameters for LTE-femtocell network

Parameters	**Value**
Simulation time	5 mint
Transmit power LTE	40dBm
Transmit power femto	20dBm
Bandwidth	5MHz
Antenna gain macro/femto/mobile	(14/5/0) dB
Thermal noise density	-174 dBm/Hz
Noise figure in mobile	9 dB
Femto /mobile antenna pattern	Omni
Macro/femto shadow fading	4dB, 8dB
Noise density	-80dBm/Hz
Wall loss	15dB
Path loss outdoor	70dB

The simulation was conducted to examine the new power control approach that is connected to an IP cloud that represents the backbone Internet.

Figure 4.6 shows that the power consumption for the aggregate traffic loads of high and low profiles of variable numbers of cognitive femtocells. The installation of the new proposed scheme results in major improvement in system performance by reducing the values of system power consumption. This is due to the fact that the optimised power allocation scheme creates effective coverage areas that identify the exact UE location without any need to transmit power beyond the actual mobile location. The figure shows that high traffic profile consumes more power than lower traffic profile even with no change in the coverage area for the same mobile locations. This is because more packets consume more power during transmission and link establishment rather compared with low traffic. The overall consumed power increase gradually as the numbers of deployed femtocells increases, this is a direct outcome of the increase in the traffic transmitted with higher numbers of nodes and transmissions opportunities.

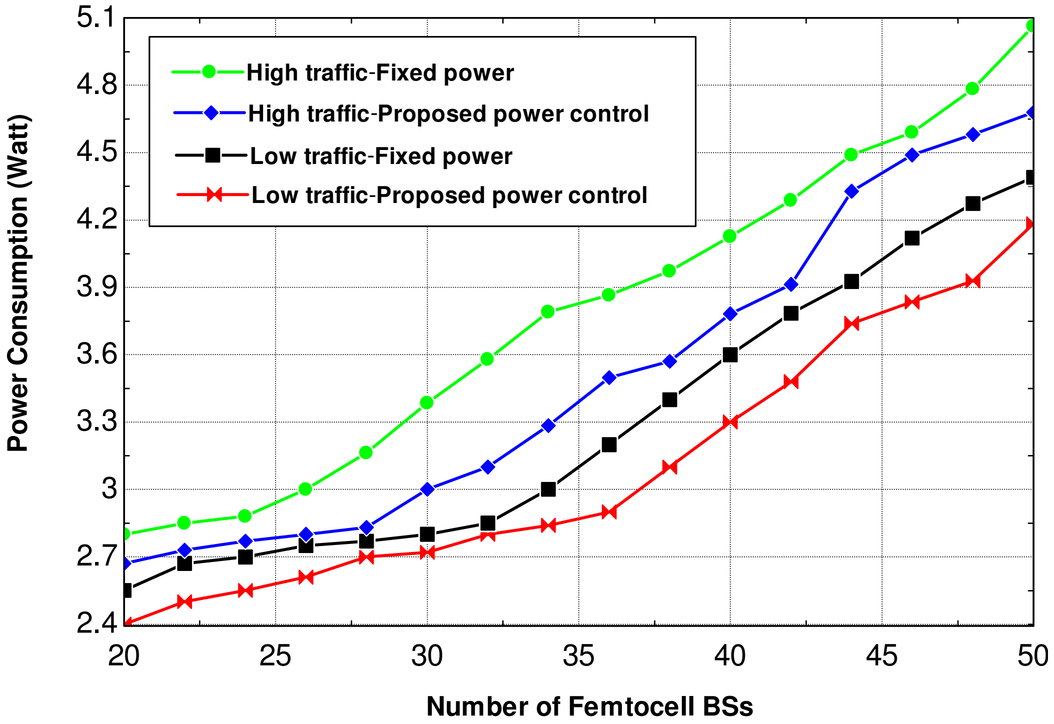


Figure 4.6: Power consumption as a function of traffic

Figure 4.7 shows mobile power received in Watts as a function of connection time in seconds at which femtocells users are deployed randomly in macrocell area. It is clear that the pilot power is improved with the deployment of the proposed adaptive power method in FBSs. A major savings is obtained in the received power using new adaptive pilot power scheme compared to the fixed pilot power model. These savings are necessary in deploying the future cognitive networks to optimise the cheapest network cost of operation and reduce the probability of interference occurrence between various tiers nodes.

The amount of power savings gained with the new power model is changing according to the mobile users' locations and transmission opportunities. However in some femtocells, there is more than 12 dB reduction in the transmitted pilot power using the proposed scheme.

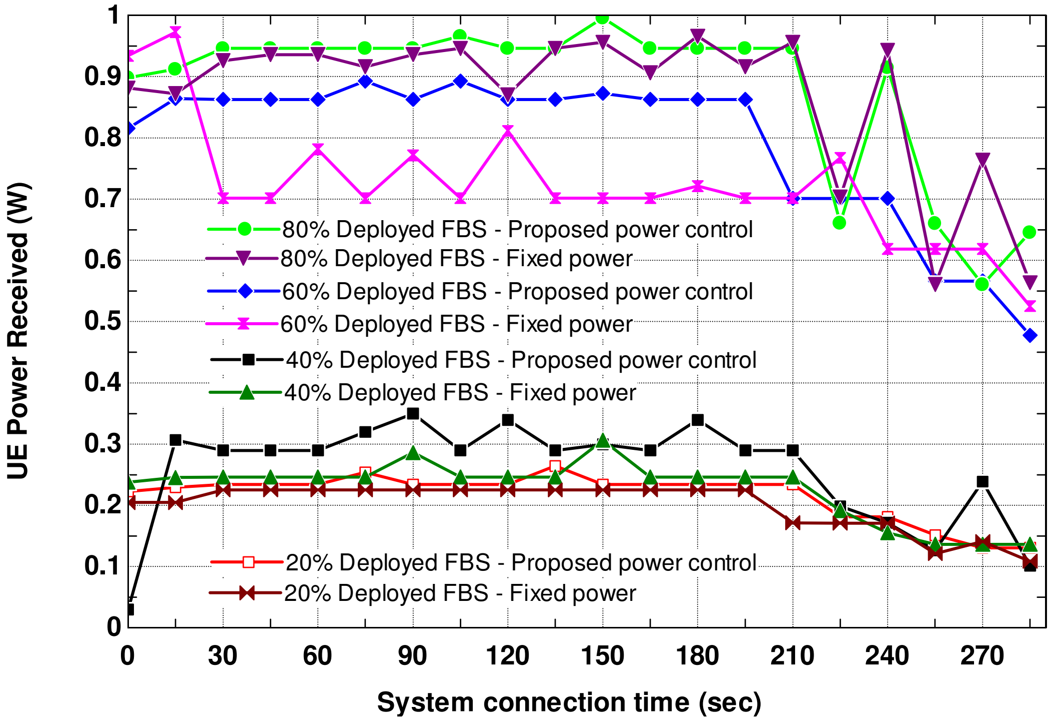


Figure 4.7: Mobile power received as a function of connection time

The average time delay for end-to-end transmissions is represented in Figure 4.8. The given curves show the system performance before and after using the power adaptation algorithm. The analysis combines the fixed pilot power and the proposed adaptive pilot power methods to show the overall improvement in time delay while adjusting the power of the system. The overall time delay is reduced by approximately 30% at each individual case by using the new adaptive power. This is due to the fact that there will be more opportunities for spectrum access, link formulation, and lower interference while more femtocells are set to use optimised transmission sites. This scenario analysis considers only the time of packets delivery between femtocells and their end-users. This means that the proposed model offers an improved coexistence between femtocell network wireless environments that share the same resources and bandwidth channel frequencies. On the other hand, it is understood that the proposed algorithm greatly outperforms the fixed pilot power scheme in terms of much lower outage probability of public UEs.

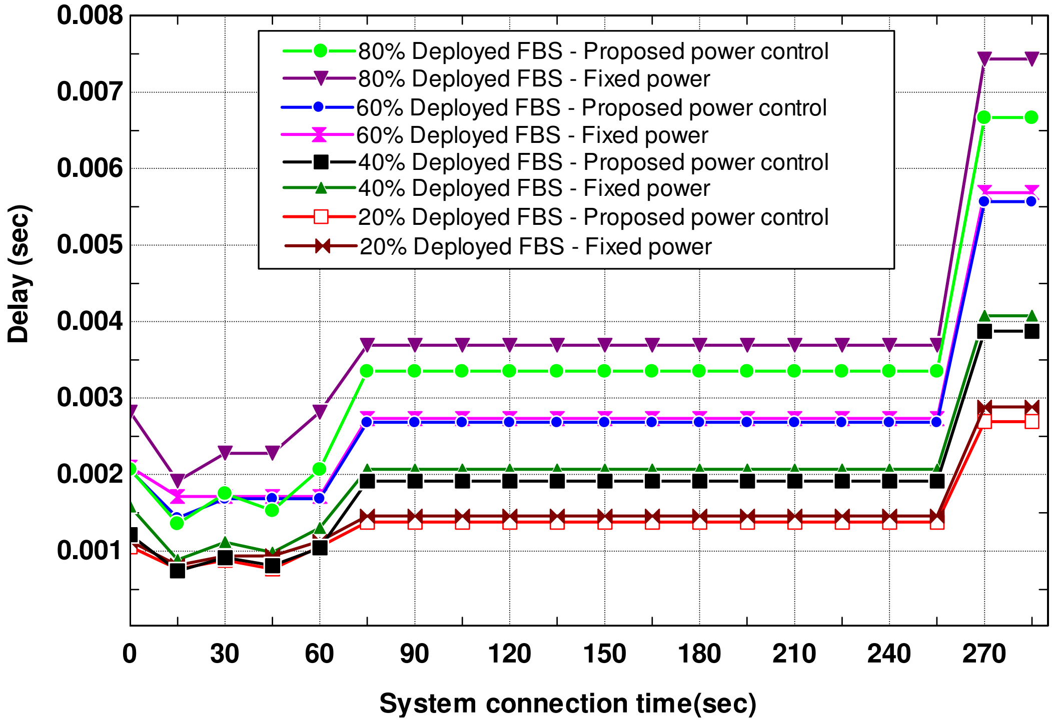


Figure 4.8: Time delay improvements due to the LTE femtocell design

Figure 4.9 shows the downlink channel SNR of femtocells versus the system connection time. This is a combined performance evaluation that considers the proposed pilot power for the femtocells provided by applying new algorithm of power adjusted. The graph shows the improved performance of using the adaptive power scheme compared to the fixed power. The flipped performance of various investigated cases, results from the fact that the adaptive power scheme needs some time to adjust the power of transmission while identifying the mobile locations. This happens again at the end of the simulation due to the fact that some mobile phones will be out of the coverage area of femtocells. This means that the same process of finding the mobile positions and adjusting power at femtocells need to happen again before the performance returns to be steady as shown for the interval from 70-240 seconds. Overall, our results confirmed the applicability of the proposed power-adjusting scheme for the cognitive system networks.

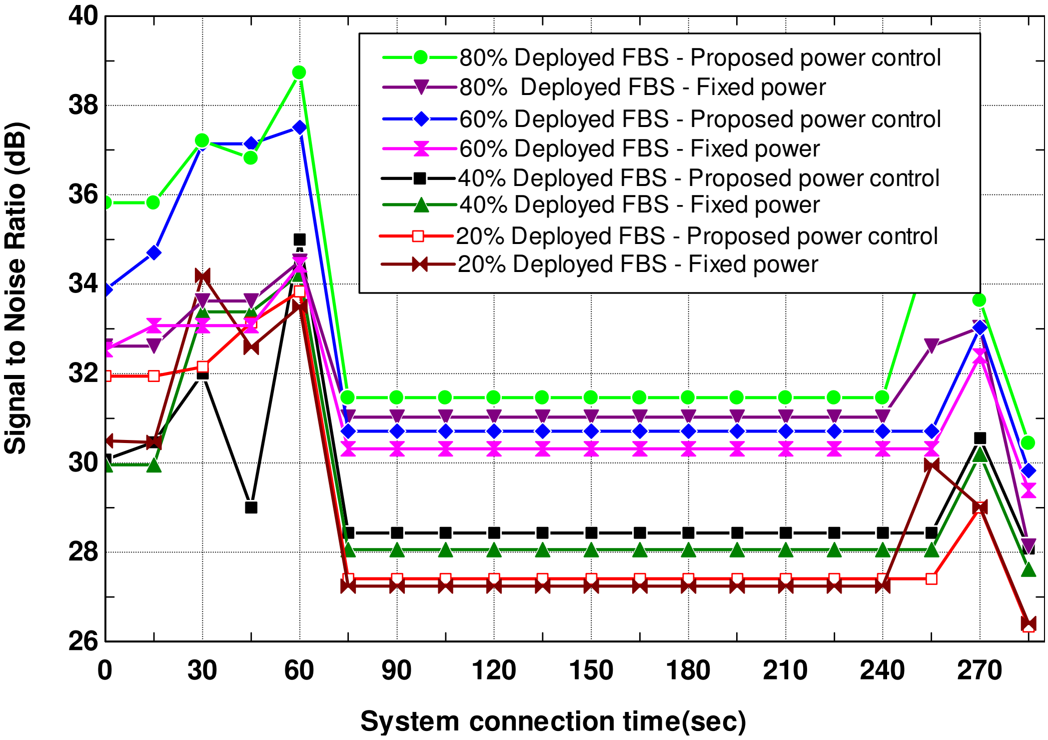


Figure 4.9: SNR improvements due to the LTE femtocell design

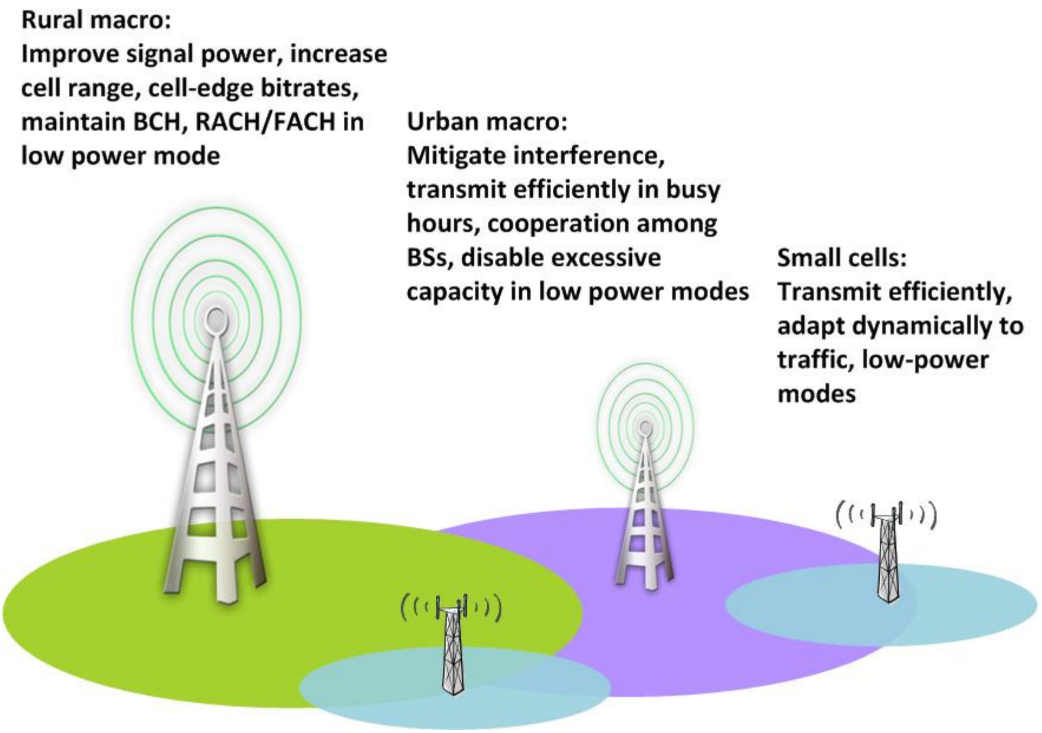
4.5 Power Consumption Estimation

In this section, the coverage parameters that affect the energy efficiency and cell coverage area are investigated for future cognitive networks that employ femtocell stations. This is supported by traditional concept of cell edge, cell area type information, and propagation models. In addition, the network's power consumption is characterised (in watts per unit area) for given coverage in order to optimise the BS cell radius with respect to mentioned factors.

4.5.1 Cell Coverage Area

The coverage nodes provide the sufficient field strength for the guaranteed service at cell edges in case of low traffic. If the traffic load increases and the assured service level cannot be provided, then femtocell nodes should be activated and power adapted back to the full-coverage mode.

Typically, umbrella macrocells are responsible for providing coverage for difference-sized areas like rural and urban as shown in Figure 4.10. In the some countries that have vast population areas can be covered by large macro cells operating in a low frequency band if available [20]. The cell coverage area is assumed to be hexagonal depends on the site configuration.



Figures 4.10: Networks node coverage for different size areas

The site coverage area of LTE can be calculated as following [21]:

$$\mathcal{A}_{\text{site}} = \frac{(\pi d^2)}{\text{No. of Sectors}} \tag{4.5}$$

The macrocell BS is considered as a regular grid of sites represented by the diameter d.

Figure 4.11 shows a three hexagonal cell models: Omni-directional site, Bi-sector site and Tri-sector site. Therefore, the number of sites to be deployed can be easily calculated from the cell area $\mathcal{A}_{\text{cell}}$ and using the deployment area site A_{site} :

$$N_{\text{site,coverage}} = \frac{\mathcal{A}_{\text{site}}}{\mathcal{A}_{\text{cell}}} \tag{4.6}$$

Where is $N_{\text{site,coverage}}$ is number of coverage sites. The macrocell base station network is modeled as a regular grid of sites symbolised by the site distance D, generating equally sized hexagonal cell structures of side length $R = \frac{D}{\sqrt{3}}$.

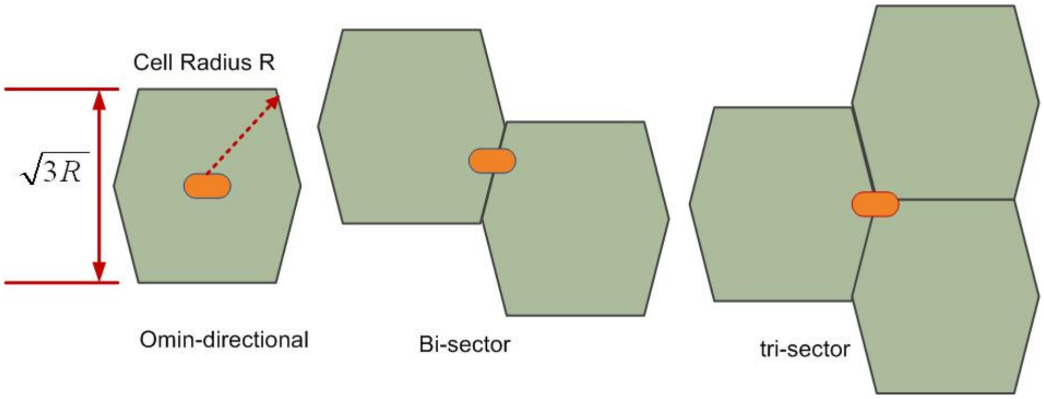


Figure 4.11: Hexagonal cell site types

These approaches are suitable for LTE macrocell/femtocell overlaid cell structure, where femtocell coverage must be controlled so it does not interfere with the outdoor macrocell. In order to achieve this goal, a coverage coordination scheme that is based on the numerical analysis of the signal strength and interference power measured at a femtocell downlink. This scheme comprises both the self-configuration and self-optimisation of femtocell pilot transmits power. With a self-configuration function, a femtocell BS initiates it's transmit power based on the measurement of interference from neighboring BSs in a manner that achieves a roughly constant cell coverage [22].

In the following calculations, the term cell is used to refer to the hexagonal region of one site. Each cell might be further divided into several sectors accordingly served by many co-located macro base stations as shown in Figure 4.12. For given inter site distance, the cell size area $\boldsymbol{\mathcal{A}}_{\mathbf{cell}}$ calculates as following [23]:

$$\mathcal{A}_{cell} = \frac{\sqrt{3}}{2}\,(\mathrm{D}/1000)^2\ \mathrm{Km}^2 \qquad (4.7)$$

The optimal cell size can be achieved once the QoS requirements of throughput and time delay are satisfied. This study considers a two-tier cellular network composed of overlaid macrocells and femtocells base stations in which both cells use the same frequency channel.

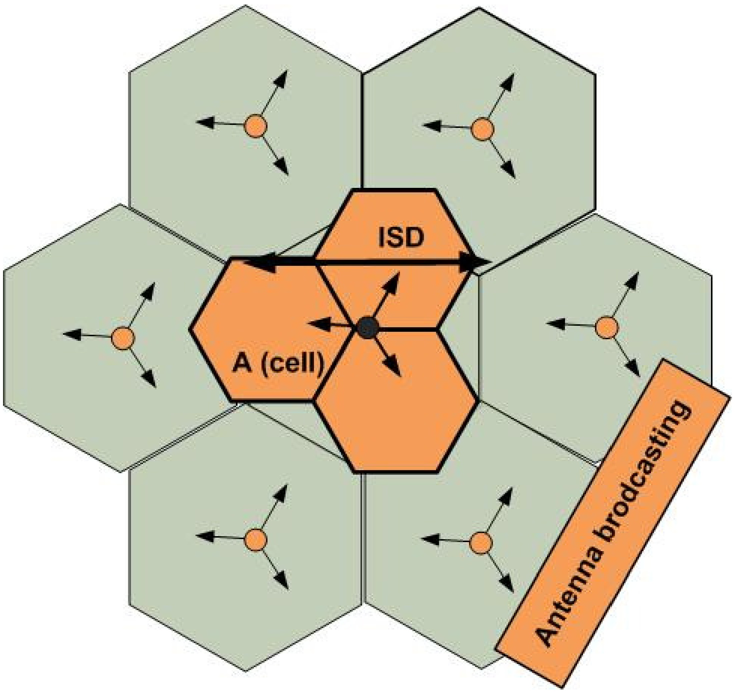


Figure 4.12: Regular grid of base stations and corresponding cell geometry with inter site distance ISD and cell area $\mathcal{A}_{\text{cell}}$

A femtocell BS is located at the edge of a LTE macrocell with radius (r). Both BSs users are equipped with an omni-directional antenna. The femtocell BS creates cell coverage which is adaptively adjusted by the proposed transmits power control in order to correspond to the coverage area. The transmitting power control is composed of two steps; where the femtocell BS initially self-configures its power and self-optimises cell coverage by using transmit power control based on the measurements of radio environments.

4.5.2 Area Spectral Efficiency

Spectral efficiency is a key performance parameter in cellular mobile radio networks that is the optimum spectrum used to provide a large amount of data at a specific bandwidth. It is defined for each location, as the ratio of throughput to the bandwidth of a user under the assumption of one single subscriber in a cell. According to the Shannon equation the maximum spectral efficiency is given by [24]:

$$Spectral\ efficiency = Log_2\left(1+\frac{S}{N}\right) \tag{4.8}$$

where $\frac{S}{N}$ is the signal to noise ratio.

In this study, area spectral efficiency is defined as the average of the spectral efficiency with respect to uniformly distributed location of users in the network per unit area. As the objective of the study is to quantify the energy saved due to the femtocell deployment, a traffic energy model is used based on the typical standards of various base transceiver station models. The throughput model is represented by the following equation:

$$\mathrm{TP} = \mathrm{ASE} * \mathrm{BW} * \mathcal{A}_{cell} \tag{4.9}$$

Where TP is referred to as the throughput, ASE is the area spectral efficiency BW is cell bandwidth, and $\mathcal{A}_{\mathrm{cell}}$ denotes the area cell size. One measure of area spectral efficiency of shared macrocell and femtocell is in terms of bit/sec/Hz/macrocell area. It should be noted that area spectral efficiency is expressed in bits/sec/Hz/km^2. Since Hertz (Hz) is the inverse of time, it is also correct to express it in bits/km^2. Thus ASE is the mean of all the users in the system divided by the cellular area and it would be different from individual data rates [24].

4.6 Power Consumption Modeling

In this section, a power consumption modeling is proposed to evaluate the power management in a LTE cellular network with femtocell BSs deployment. The power consumption is assumed from base stations aspect that has linear relationship to the utilisation of radio resource. Moreover, power use of typical base station is as follows: Power supply, cooling fans, central equipment, cabling, transceiver idling, combining/duplexing, power amplifier, transmit power, and transceiver power conversion.

A developed mathematical model is proposed to assess the power performance of femtocell framework design. A system model approach is essential since it is useful to make decisions based on logical assessment and it also supports performing the desired analysis that was previously applied in [17] to describe the macrocell base station power sharing. The goal of the proposed power consumption model is to make input parameters available for the simulation of total power consumption in 4G cognitive communication networks. The cell power is formulated by [25]:

$$P_{cell(watt)} = \mathcal{P}_{operator} + (\eta * P_{TX,LTE}) \qquad (4.10)$$

where $\mathcal{P}_{operator}$ represents the power operator, η denotes the cell load/capacity that may vary between 0.1 and 0.9 depending on the user's capacity and radio interface configuration, and term P_{tx} is the power that is needed to create required transmission power in the antenna output. The term capacity contains all capacity independent power that is needed to operate the BS. The relation between the average radiated power $P_{Tx,LTE}$ and a site's power consumption is linearly modeled for macro sites by [25], where it is linearly modeled for both LTE and femtocell sites by:

$$P_{LTE} = N_{sec}.\,N_{ant}\left(\forall_{LTE}.\,P_{Tx,LTE} + B_{LTE}\right) \qquad (4.11)$$

$$P_{fem} = \forall_{fem}\,.\,P_{Tx,fem} + B_{fem} \qquad (4.12)$$

where N_{sec} denotes the number of sectors per macrocell, N_{ant} the number of antennas per sector. The coefficients $\forall_{LTE}$ and $\forall_{fem}$ account for the power consumption that scale with the average radiated power. The transmit power and independent power offsets B_{LTE} and B_{fem} are both mainly impacted by the power spent for signal processing [26].

It should be noticed that in the case of LTE sites it is also impacted by site cooling due to hardware components contributing to thermal radiation regardless of the transmit power. The studied power modeling does not include the energy consumption used by other elements at the base station for that site such as: backhaul, antenna feeder cables, cooling, and backup power systems.

In order to measure the power consumption of a cognitive network relative to its area Area Power Consumption (APC) is used. This is defined as the average power consumption per cell divided by the cell area and is measured in watts per square kilometer [27]. The area power consumption of a network APC can be expressed mathematically as:

$$\mathrm{P_{consumption}} = \frac{1}{\mathcal{A}_{\mathrm{cell}}} \sum_{i \in I_A} P_i \tag{4.13}$$

Where the power consumption portion $\mathrm{P_i}$ of the site serving sector $\mathcal{A}_{\mathrm{i}}$ is determined by the following equation:

$$\mathrm{P_i} = \begin{cases} {}^{1}/_{\mathrm{N_{sec}}} \cdot \mathrm{P_{LTE}} & \text{if } \mathcal{A}_{\mathrm{i}} \text{ is a macrocell sector,} \\ \mathrm{P_{fem}} & \text{if } \mathcal{A}_{\mathrm{i}} \text{ is a femtocell sector.} \end{cases} \tag{4.14}$$

Note that in (4.14) only the power consumption figures P_i of sites are considered as long as they serve sectors belonging to the reference cell. In the same way the area $\mathcal{A}_{\mathrm{cell}}$ corresponds to this reference cell and then expanded to the whole investigated site area.

4.7 System Power Consumption Evaluated

4.7.1 Numerical Results

In this section, the numerical analysis of system networks is presented in order to obtain the optimum ISD value. Analyses are performed rather than simulations due to the fact that statistics allow better evaluations for the exact coverage areas than overlapped transmission domains in simulations. The model scenario consists of one macrocell base station with variable grid of sites symbolised by the site distance D, which ranges between 500-2000 meters, to generate equally sized hexagonal cell structures of side length R. Cell area needs to be covered by 95% for each considered site distance and base station domains of macro and femtocells. Mobiles are placed randomly at the edge of a macrocell area in a uniform distribution. Femtocell sites are assumed to support a circular area of radius 30m and are positioned at the cell edges where the signal levels of the macro LTE units can be expected to be very low. The numerical analysis is based on the users located outdoors only. The spectral efficiency (ASE) is assumed to be 6bit/s/Hz according to equation 4.10. The power model parameters are selected as the values resulting in equation 4.15, assuming that the coefficients of power consumption are $\forall_{\mathrm{LTE}}$=3.8, $\mathrm{B_{LTE}}$=68.8W, $\forall_{\mathrm{fem}}$=6.3, $\mathrm{B_{fem}}$=0.5W. The power consumption is calculated according to the equation 4.14.

The area power consumption analysis is given as a function of the inter site distance for various femtocell deployment densities and is depicted in Figure 4.13. Obviously, results show that area power consumption decreases as the femto density increases compared to the case when only LTE macrocell unit is in place. Also, all the performance graphs decrease with the inter site distance.

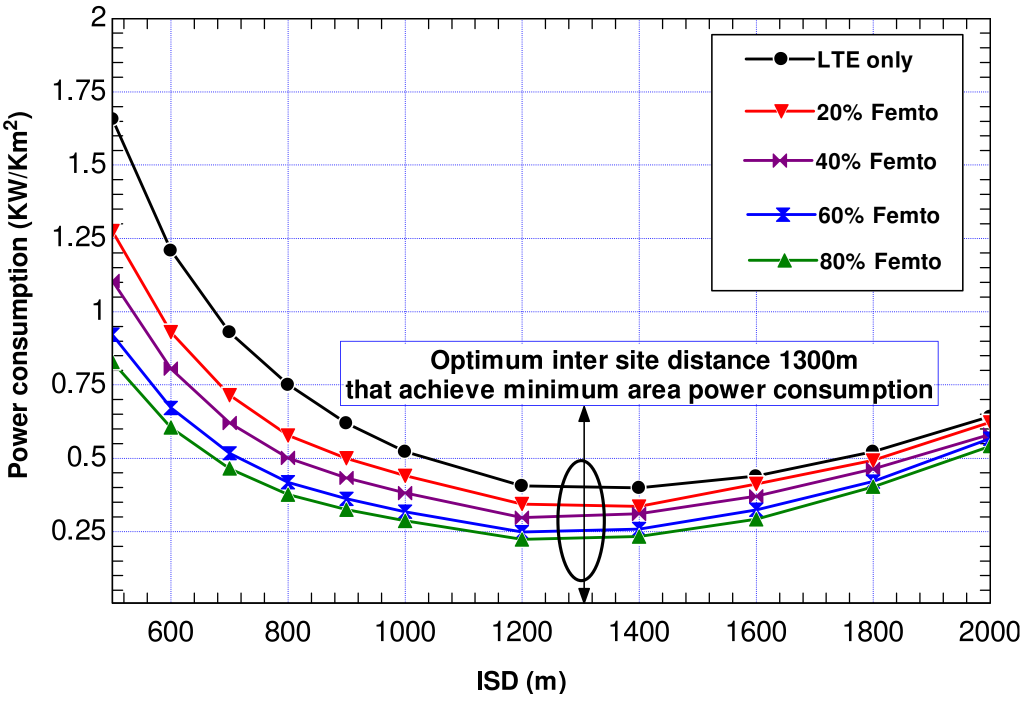


Figure 4.13: Area power consumption vs ISD

This confirms the fact that the femtocells deployment decreases the energy consumed in the system due to the small transmission domains and short formulated links. By ignoring the impact of shadowing, it is easier to identify the optimum cell radius as well as optimums inter site distances that achieve minimum area power consumptions for each analysed case. These are determined for LTE BS with f=2GHz, and minimum receiver sensitivity of $P_{min} = -70\text{dBm}$. Results show that the optimum corresponding inter site distance is ISD= 1300m that achieve minimum area power consumption of 400W/km^2. When femto nodes are deployed, they offload the premium users from the macro base station and free macro resources to utilise more basic users. It can be observed, that all deployment strategies have the same optimal inter site distance but with different values of minimum power consumptions. For cognitive LTE-femtocell deployment scenarios the power consumptions range between 800-1270W/Km^2, which is considerably less than the power consumed in the traditional services delivered by the macro LTE base station. Thus, the femtocell deployment reduces the power consumed in the system. However, femtocell base stations are not able to increase the optimum inter site distance for the site under coverage.

The results are compared with the research that has been done in [26], it is clear that the new model is improving the area power consumption with a logical and applicable approach by using developed power model. The power consumption for higher densities of deployed femtocell is decreasing for the same ISD value. The lowest power for ISD occurs at 1300m for the LTE, and then (20%, 40%, 60%, and 80%) of deployed femtocells respectively, where 90% coverage is maintained in all cases. This raises a new discussion of deploying femtocells quickly into the cognitive networks.

4.7.2 Simulation Results

Many traces are generated with a variety of number of femtocells in LTE macrocell area in order to measure packet delivery fluctuations in radio links. The path loss calculation could be by using COST231 Hata model [28] as shown in Figure 4.14. This model is normally used for carrier frequencies between 1500 and 2000 MHz. The propagation model describes the average signal propagation in that environment, and it converts the maximum allowed propagation loss in dB to the maximum cell range in kilometers.

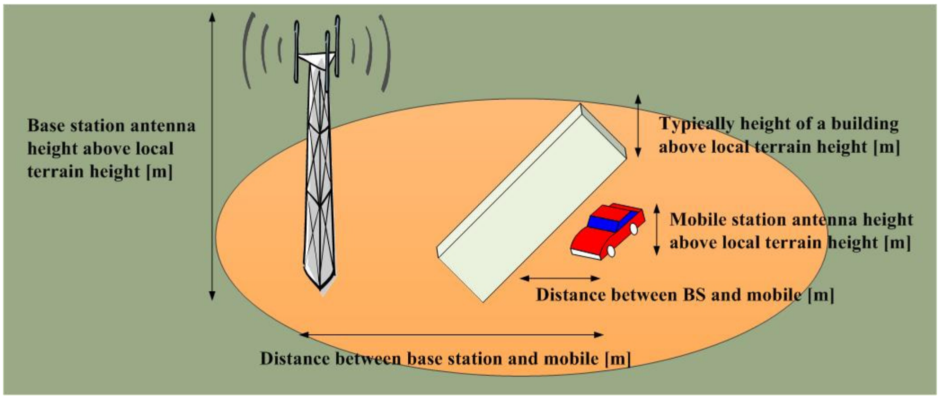


Figure 4.14: Okumura–Hata model

The total downlink throughput delivered from LTE layer to the higher layers in bits/sec for cognitive system performance is illustrated in Figure 4.15. The throughput is collected by all the UEs in the network systems. Here, we can clearly observe that LTE network at a certain size does not necessarily provide higher system throughput capabilities. In this model there is an increase in throughput figures by increasing the femtocell numbers and the peak throughput decreases noticeably after 275 sec. The farthest mobile to the base stations, the higher the probability of loss of line of sight communications. Also, the same holds for line of sight between mobile and interfering base stations. Hence, the SNR at a mobile is getting better the smaller base stations' size due to an increasing number of base stations generating significantly low load and high throughput. Obviously, there is a max peak throughput realising inter site distance, which corresponds to about 1300m in our example.

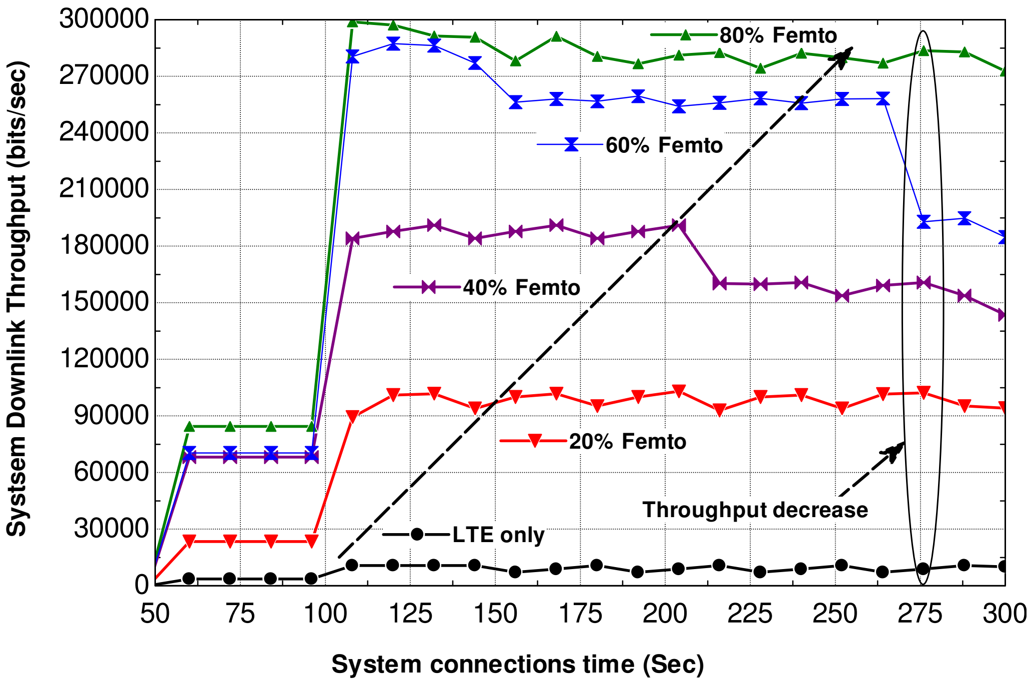


Figure 4.15: Downlink throughput delivered from LTE layer

From this figure it is shown that cognitive users in the transmission domain do not show any drop after the peak value of throughput. This is because that macrocell network is not fully loaded by cognitive users and the increase in traffic does not reach the threshold yet, which basically does not show their offloading nature. In the LTE only when there are no femtocell nodes, it is shown that great degradation in the throughput occurs when cognitive users are in the range, which gives a clear indication of advantage of femtocell deployment.

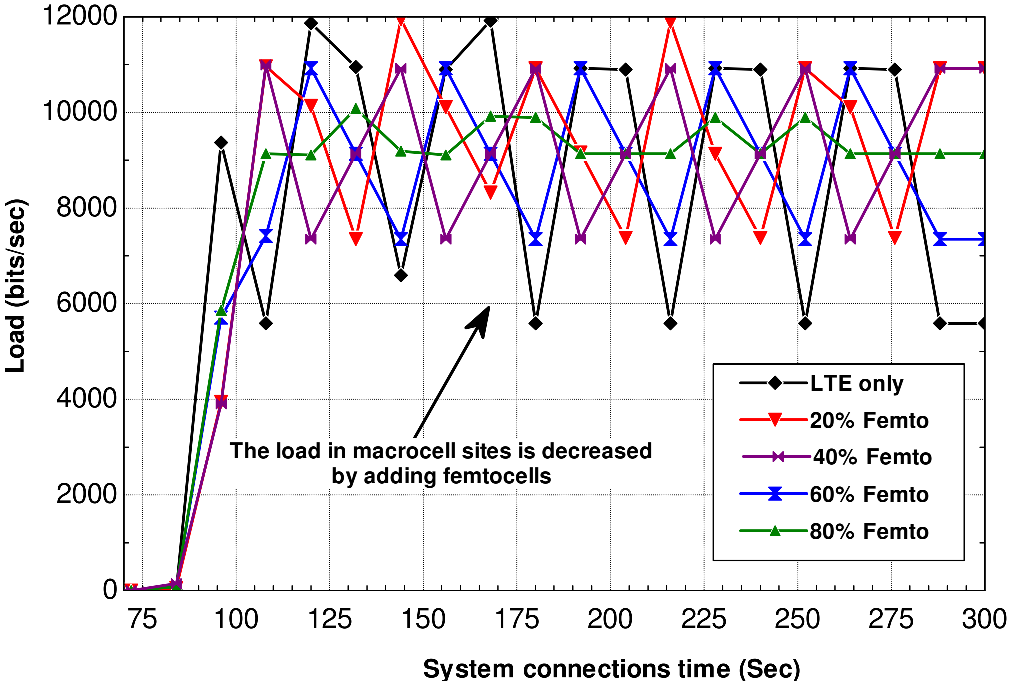


Figure 4.16: Impact of system load

Figure 4.16 shows that a smooth load transfer has been achieved using the new adaptive scheme where femtocells transmit at the maximum power at all times and both macrocell and femtocells BSs are using the same frequency band. On the other hand, load convey is measured from the time the traffic arrives to the LTE layers of the BS until it is delivered to the higher layer of the corresponding UEs with/without FBS. It is observed that the load performance is highly sensitive to the traffic increase in cells when the number of femtocell is increased. Therefore, more network stability and throughput advantages can be achieved with femtocell deployment.

The performance of average end-to-end packet transmission delay is shown in Figure 4.17. Clearly, there is an increase in connection time results in an increase the average packet time delay. However, an average of 20% throughput gain is achieved by the increased the number of femtocell BSs with in macrocell area within the bounded delay of 224µs. This is because the fact that the packet retransmissions caused by the MAC layer packet collision is successfully reduced by using the new proposed algorithm.

The simulation result of the pilot power algorithm supports the observation result in the previous section. The proposed pilot power based requirement decision is not helpful to avoid packet drops. On the other hand, the result resents that enormously large amount of transmission power is needed for the data rate requirement.

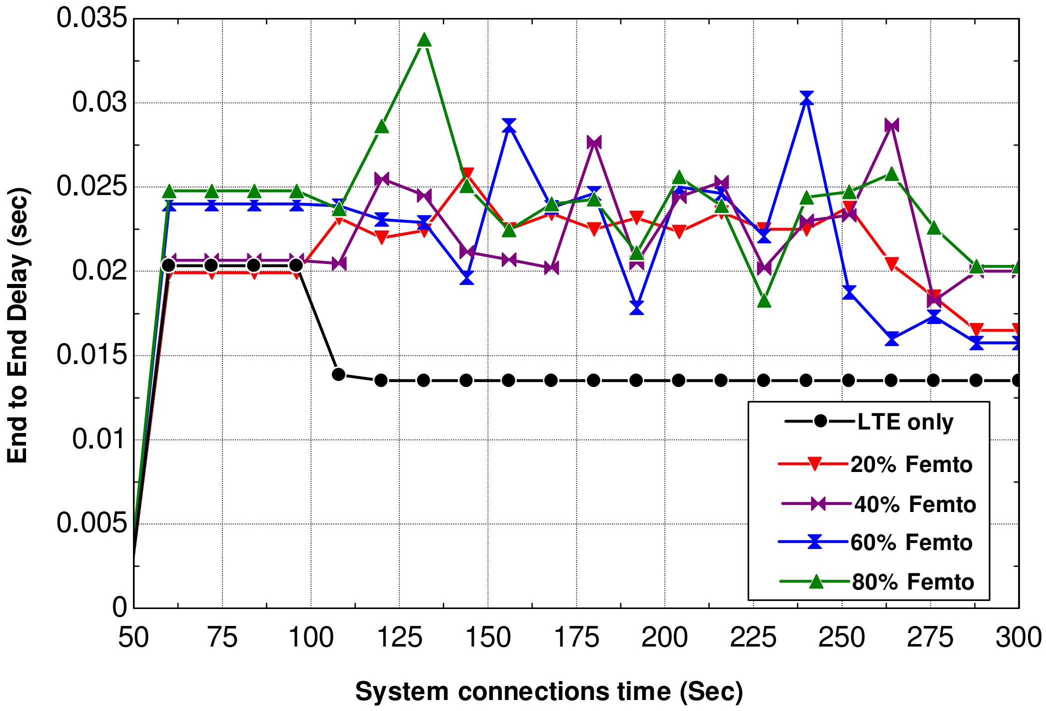


Figure 4.17: Average system end to end packet delays

4.8 Site Energy Consumption Modeling

The objective of this power model is to examine cognitive system based on the calculated power consumptions and to define an appropriate energy modeling that is saving energy. Therefore, a site power modeling is introduced based on typical values that consider integrated base station system for all users at a site. The model of the power consumption for a site system can be represented by the following equation [29]:

$$P_{\text{site}} = N_{\text{cell}}.\,[P_{\text{operator}} + (\eta * P_{\text{tx}})] \qquad (4.15)$$

Where N_{cell} refers to the number of cells in the site. η is represent the cell load, and P_{tx} is refer to the power transmit of the macrocell BS. The site energy consumption estimations for a system with a real time application can be computed at a certain time period T as:

$$E_{site} = N_{cell}.\left[P_{operator} + (\eta * P_{tx})\right]T \tag{4.16}$$

Impact of temporal capacity variations is investigated in [30]. The energy usage over time T (seconds) in LTE macrocellular network is given by:

$$E_{Net,LTE} = N_{site}.\ E_{site}.+N_{sub}.E_{sub} + E_{other} \tag{4.17}$$

This is a precise definition for the energy consumed in all macrocell and sub-macrocell BSs. Where N_{site} and E_{site} refer to number of BS sites and energy consumed by single BS site respectively, N_{sub} refers to number of subscribers and E_{sub} refer to the energy consumed by single user and the last term contains energy consumed by other mobile network elements such as the core network elements and radio network controllers in OFDM. When cognitive femtocell systems are deployed in such a network, the energy utilised by the network is given by [31]:

$$E_{Net,femto} = N_{site}.\ N_{cell}.(E_{cell} + N_f.P_f\ .T) \tag{4.18}$$

Where N_f the number of femtocell in each macrocell network and P_f is the power usage of the femtocell BS over time T.

4.9 Efficient Energy Scenario

In this cognitive system model, the estimation of the change in the network load and configuration is studied to see how that may affect the energy consumption level. The ISD is assumed to be fixed and the total number of cells is 3 so that interferences from other cells are considered up to two-tiers. The performance of a LTE is evaluated only for the cell centre, while cognitive femtocells are distributed throughout the edge of the cell. Macrocell ISD is the optimum value 1.3Km that has been gained from previous numerical calculations, and femtocell radius is assumed as 30 meters. Handover between a macrocell and a femtocell is not considered, so the performances of macrocell UEs and femtocell UEs are evaluated independently. As a performance measure we will use the daily energy consumption per square kilometer ($\mathrm{kWh/Km^2}$) is used in the network, expressed as follows [30, 31]:

$$\begin{aligned} {}^{\mathrm{E}}/_{\mathrm{A}} = \left(\mathrm{N}_{\mathrm{site}}^{\mathrm{new}} \cdot \mathrm{N}_{\mathrm{cell}} \cdot (\,\mathrm{P}_{\mathrm{operator}} + \eta^{\mathrm{new}}.\,\mathrm{P}_{\mathrm{tx}})/\mathrm{N}_{\mathrm{site}} \cdot \mathcal{A}_{\mathrm{site}}\right) * 24\mathrm{h} \\ + (\,\mathrm{N}_{\mathrm{cell}} \cdot \mathrm{N}_{\mathrm{f}}.\,\mathrm{P}_{\mathrm{f}}/\mathcal{A}_{\mathrm{site}}) * 24\mathrm{h} \end{aligned} \tag{4.19}$$

In the above equation, number of cells is $\mathrm{N}_{\mathrm{cell}}$, number of sites in new deployment $\mathrm{N}_{\mathrm{site}}^{\mathrm{new}}$ and corresponding load η^{new}refer to the new parametric values of the modified network with respect to the old parametric values of the reference network. Also, it should be noticed that the number of femto BSs is given per macrocell in the reference deployment. Either of these changes is expected to take place in one of the two compared networks depending upon the scenario. Daily energy consumption [32, 33] is formulated per square kilometre in the network as follows:

$$ {}^{E}/_{A} = \left(N_{cell} \cdot (\,P_{operator} + \eta^{new}.\,P_{tx} + N_f.\,P_f)/\,\mathcal{A}_{site}\right) * \;24h \tag{4.20}$$

Where $N_f$the number of femtocell in each macrocell, P_f is the femto power usage over time T, the parameter P_{load} refers to the power that is needed to operate the base station. Thus, the addition of a femtocell is only visible in the macrocell load factor.

4.10 Numerical Energy Consumption Analysis

The energy consumption is assumed to vary a lot depending on manufacturers. However, there exists a regulation on the energy consumption of a femtocell BS. EUs code of conduct on energy consumption of broadband equipment regulates the energy consumption of a femtocell BS under 9W [28].

Different deployments can be considered, with a variable number of femtocells and different possible positions in the cell. Cognitive femtocell systems are deployed to compare four different networks scenarios and assess how the change in network configurations will affect the energy consumption in the network system. The calculations start by dimensioning the network without femtocells. As long as cell range R is known, the cell area can be calculated using equation (4.7), and for daily energy consumption per square kilometer from the formula:

$$E/_{A} = \left(N_{cell} \, . \, (\, P_{operator} + \eta^{new} . \, . \, P_{tx})/ \, \mathcal{A}_{site}\right) * \; 24h \qquad (4.21)$$

The focus is on the downlink of an OFDMA system where in each sector the same resources are allocated. The load factor can be approximated by its average value across the cell to calculate the network load factor [33], where we used the following formula:

$$\eta = \eta_o + \; N_{users} \, . \frac{\left(\frac{E_b}{N_o}\right) . R_j \;\; v_j .}{BW} . (1 - \tilde{\alpha} + \tilde{\imath}) \qquad (4.22)$$

Where, η_o denotes to the minimum load due to control signalling, $\left(\frac{E_b}{N_o}\right)$ is the energy per user bit divided by the noise spectral density, N_{users} is the number of users in the cell, v_j is the activity factor of user j, R_j is the user bit rate, BW is the system chip rate, $\tilde{\alpha}$ is the spreading code orthogonally factor and $\tilde{\imath}$ is the other to own cell interference factor.

The values that are used in the numerical analysis are based on the Table 4.2. The mean load is considered that is depending on the expected $\tilde{\alpha}$, and $\tilde{\imath}$ over the whole cell.

Table 4.2: System theoretical characteristics

Parameter	**Value**
System chip rate	3.81Mcps
Shadow fading margin	6dB
Mean α (Average orthogonality factor in the Cell)	0.45
Mean ĩ interference ratio	0.60
Activity factor v_i	1.00
Minimum load	0.075
System load	1 to 100% (Used as an input to the system)

Figure 4.18 shows the relation between energy consumption in KWh per kilometer square and load (η) from (0.1 to 1).

It is observed that when the femtocells are deployed with total power (6W, 3W, and 2W) in LTE domain, around 25%, 17%, and 11% of energy would be saved and it keeps on increasing as the number of femtocells increases. The deployment of femtocells results in reducing the load and power delivered through the LTE.

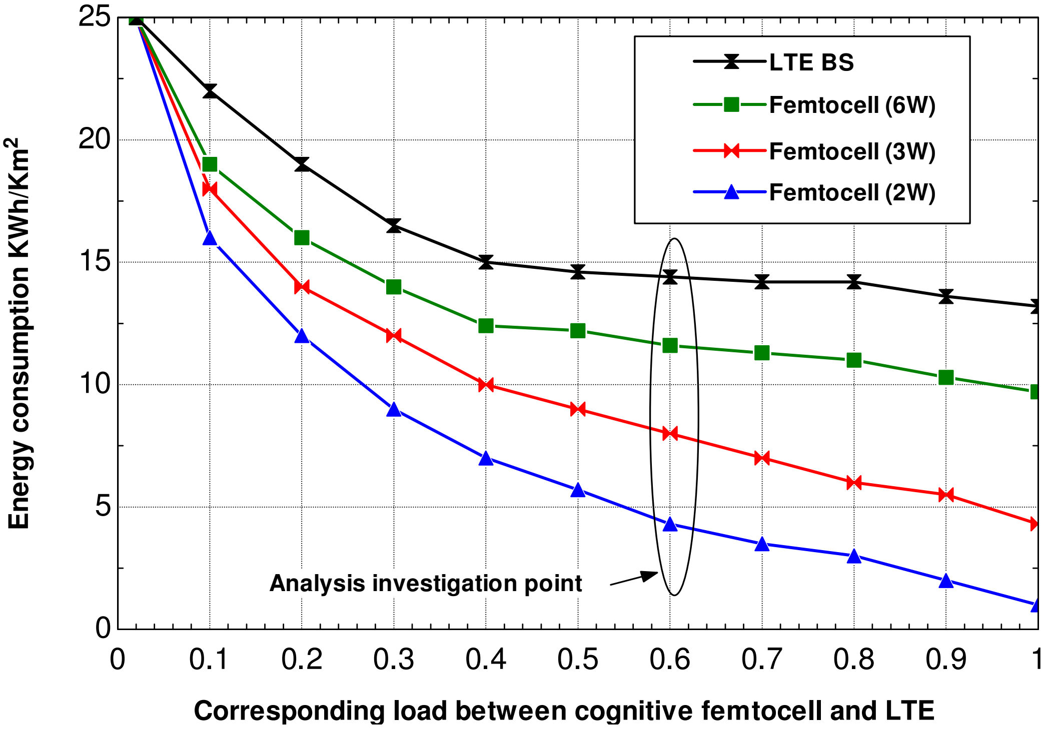


Figure 4.18: Energy consumption vs ratio connection of LTE-femtocell

These figures offer a significant inducement for cellular network operators to devise approaches to dynamically manage the resources in their networks, so as to obtain very large energy savings. Numerical results reveal that for current network design and operation, the power consumption is mostly independent of the traffic load. This highlights the significant potential for energy savings by improving the energy efficiency of BSs at low load. Furthermore, the results have proved that by using cognitive femtocell the spectrum resources can be saved efficiently for the LTE subscribers.

4.11 Conclusion

In this chapter, some features in the evolution of cognitive networks were discussed from the power management, coverage planning, and power consumption perspectives. Firstly, novel algorithms of power control were proposed in order to model the self-organisation on the system of MAC layer base stations. This work focused on the impact of pilot power feature for femtocell BS base on the spectrum resource allocation. Adaptive power control was introduced to optimise the coverage of cognitive femtocells and reduce the power consumption. The other parameters of investigated are: power efficiency and cell coverage area for future cognitive networks that employ femtocell stations and evaluating the ISD optimum value performs this. Additionally, a developed power consumption model is considered with system performance metric that employed evaluations of the potential improvements through the use of femtocell base stations.

Finally, this chapter examined the potential daily energy savings when deploying cognitive femtocell along with LTE base stations with different values of transmitted power. The proposed models help to reduce the overall energy consumption by approximately 17% of the cognitive network.

4.12 Reference

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Chapter 5

Novel Mobility Management for LTE based Femtocell Networks

In the previous chapters, power management of LTE femtocell networks was addressed by adopting fairness based power consumption and capacity efficient planning in femtocell systems. These approaches helped to improve capacity but did not help in mobility management when unnecessary handover took place due to FBSs deployments.

In this chapter, a novel mobility control management framework is proposed to reduce the time of connection consumed during admission of mobile user that is moving from macrocell to femtocell and from femtocell to macrocell transmission domains. The proposed mobility scheme consists of a new handover signaling flow policy coupled with a base station network selection solution. The licensed spectrum access is offered for cognitive radios using Markov chain model in order to reduce termination probability, blocking probability and traffic overhead. On the other hand, a novel handover initiation Call Admission Control (CAC) procedure is introduced to improve local handover management and reduce unnecessary handovers between femtocell and LTE base stations. A novel solution is proposed to reduce numbers of handovers and achieve seamless connection techniques. The challenges and solutions presented in this chapter provide the necessary solutions to maintain services and the requested quality of service.

5.1 Introduction

LTE-femtocell architecture enables various opportunistic accesses in the next generation cellular broadband systems. This architecture combines the conventional femtocell idea with the infrastructure-based overlay Cognitive Radio Network (CRN) paradigm [1]. The accomplishment of a seamless switching between various femtocell base stations from one side and macrocellular network from the other side is a key challenge for femtocell network deployment. The handover procedures in cognitive femtocell networks differ from the existing handover schemes due to the configurability features of femtocell stations.

The initial stage occurs prior to handover that is called network acquisition, which contains the network topology advertisement and UE, scanning, as show in Figure 5.1. At this stage, the UE investigates and collects information about neighborhood base stations that surround the macrocell BS. During the scanning phase, the UE seeks to connect to the target BS at suitable numbers of handovers. In the first step the mobile user measures the downlink signal strength after cell selection. In this step, possible target BS is selected according to the quality of the received signal and the requested QoS. The results of scanning are used in the next stage of handover procedure called handover process. This involves processing the measured data and sends the measurement reports to the serving LTE node. Then, handover decision and re-connection process can be initialised if all other conditions and requirements for handover are met. Performing the synchronisation to the new target BS ends the handover process. However, before the synchronisation is done, the connection(s) to the previous serving BS has to be closed first [2]. UEs with various velocities moving through the femtocell network usually lead to perform some unnecessary handovers especially for high-speed users. These cause a reduction in the overall system capacity and service delivery. Conventional handover methods cannot promise a good enough handover performance for multiservice under different mobility in macrocell and femtocell mixed environment. In fact, unnecessary handovers have become a heavy burden and degrade the communication performance of broadband wireless systems leading to major reductions in user’s QoS [3].

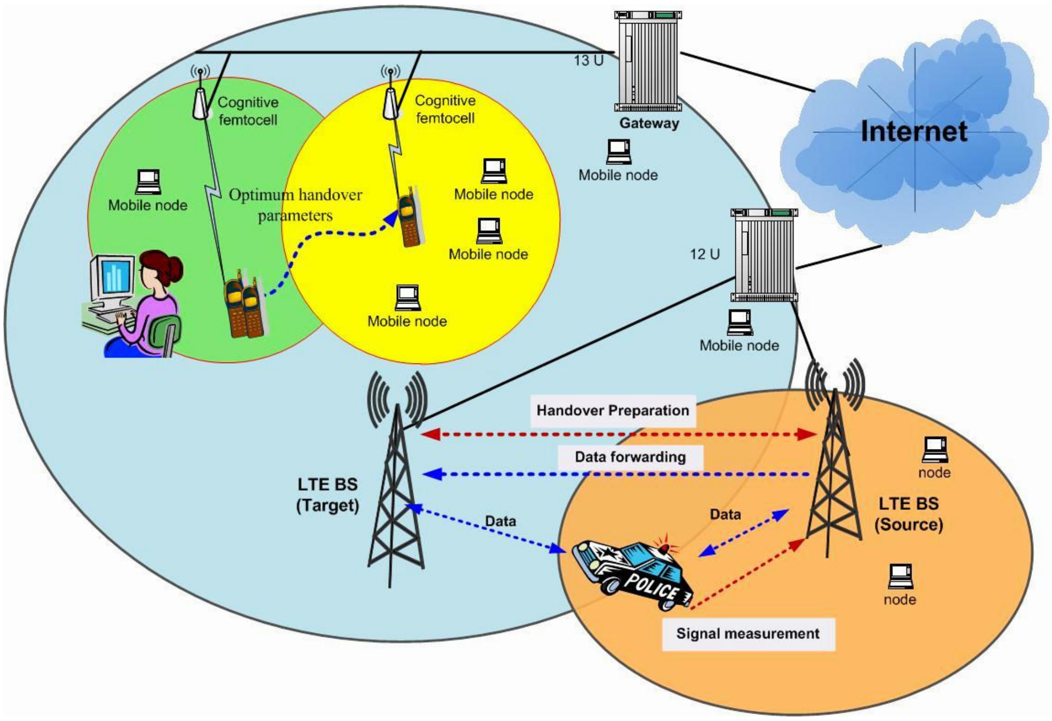


Figure 5.1: Handover procedure in 3GPP-LTE

In order to address the previous mentioned problems, a seamless spectrum handover scheme has been proposed in [4] to reduce not only the probability of cell outage, but also the total number of handovers. Although the proposed scheme can avoid service disruption and can reduce redundant handovers, it is focusing on propagation characteristic and changes in path-loss rather than managing the handover connections.

Existing results of the mobility management had been widely developed in LTE two-tier macrocell-femtocell networks [5, 6, 7]. Different parameters have been considered with special focus on: interference, velocity, RSS and QoS level in handover. The proposed handover strategies between femtocell and macrocell for LTE-based network are introducing a hybrid access mode. That can lead to universal model of handover that reduces the handover failure probability.

A handover management function for femtocell systems, which analyses interference between femtocell clients and macrocell clients, was presented in [8]. As a solution, a control mechanism was developed to handle the incoming non-registered mobile users entering the coverage of a femtocell BS with reduced signaling. This allows reducing interference, signaling overhead, packets latency, and unnecessary handovers.

In [9], handover between macrocell and femtocell are evaluated for LTE based networks. In this work, the authors modified the signaling procedure of handover at the femtocell gateway while they're proposed handover algorithm is based on the UE's speed. Improved QoS has been achieved due to the reduction of unnecessary handovers and the predication of any future handovers. On the other hand, self-configuration and self-optimisation techniques in LTE networks have been approached in [1]. The proposed evaluations show that a higher performance can be achieved with distributed mobility load balancing approach that reduce the handover interruption for LTE networks.

In this chapter, a new handover mechanism is presented based on the decision made by the entity named CAC function in order to save spectrum resources for LTE macrocell access. The CAC identifies the thresholds to make the optimal decision about handover towards target BS. This chapter proposes also the handover signaling flow schemes as well as the decision rules for the CAC model. The mobility management considers the speed of the mobile users as the criterion for handover actions. Markov chain model is used to predict the probability of user's data arrival in order to analyse the system performance as a function for different services and downloading demands. This strategy is able to predicate the characteristic of user's velocity and reduce the handover's interruption time during re-connection in order to utilise the available resources efficiently. This approach is based on the assumption that in the near future cognitive stations will have the ability to make decisions in a collaborative way.

5.2 Handover procedure

The handover procedure is divided to the following sections, namely: cell discovery, measurement, handover decision, and handover execution. Handover is made when an active user in the source cell could be best served in the target cell.

Admission control, handover, and load control are closely joined resource management functionalities as is shown in the Figure 5.2. Admission control with the feedback from the load control functionality decides whether an incoming call (new or handover call) should be accepted or blocked. Admission control then informs the load control about the change in load conditions due to admission of a new or handover call. If an incoming call cannot be served in the originating cell, and if an adjacent cell can serve the call, the call is immediately handed over to the adjacent cell [10].

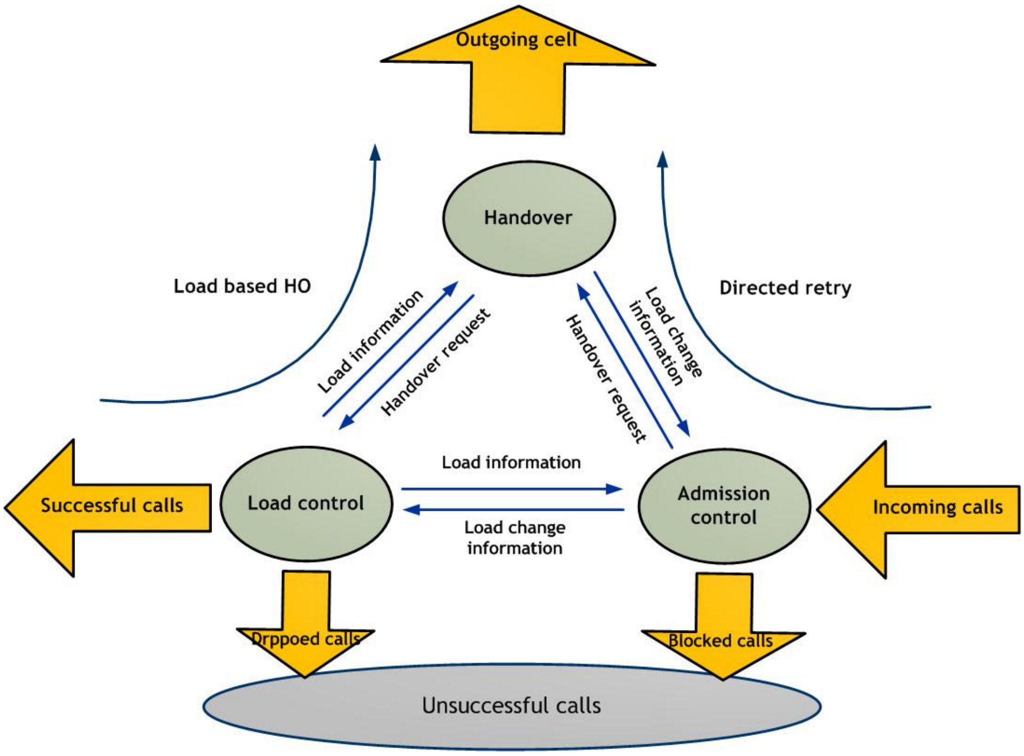


Figure 5.2: Admission control procedure

5.2.1 Cell Discovery and Measurement

The role of cell discovery and measurement is to identify the need of handover and this part includes the following steps [11]:

- ***Neighboring cell discovery***: It is a preliminary step to be considered before carrying out the signal strength measurement. The UE can learn about its neighbours by scanning different channels or via the provisioning information from its current BS.

- ***Signal strength measurement***: This method allows a UE to handover only if the current signal is sufficiently weak (less than threshold) and the other is the stronger of the two. The effect of the threshold depends on its relative value as compared to the signal strengths of the two BSs at the point at which they are equal [12]. The UE should synchronise in frequency and in time with its neighboring cells before it measures their radio link quality. The signal strength is averaged over time so that fluctuations due to radio propagation can be eliminated. Besides the measurement taken by the UE, the network itself makes measurements such as the uplink quality, BER of the received data, etc.

- ***Reporting of measurement result***: After the measurement, the UE sends measurement results to the network periodically or based on trigger events.
- ***Information gathering***: Besides the physical link quality related parameters, in heterogeneous environments, the UE is required to collect other information such as the terminal capabilities, service experiences status, context information, etc. to assist the vertical handover decision.

5.3 Mobility Management

Mobility management is very important part of 4G mobile wireless network architecture. In this framework, an open challenge is to design solutions that can take full advantage of different mobile IP based technologies to support the desired mobility of heterogeneous terminals, and at the same time provide the necessary QoS guarantees. There are additional requirements for performance and packet-level QoS that should be taken into account when trying to design a handover management scheme, including [13]:

- ***Fast Handover***, i.e. this ensures that UE can receive data packets at its new location/channel within a reasonable time interval (at certain time counter) in order to reduce the packet delay as much as possible. This is extremely important for real-time services.
- ***Seamless Handover***, i.e. any handover algorithm should minimise the packet loss rate.
- ***Routing Efficiency***, i.e. the routing path between corresponding access point and UE should be optimised in order to exclude possible redundant transfers.

Therefore, it is critical to analyse the expected free resources in different areas prior to any domain-based mobility management actions. This helps to decide what happens to a mobile host moving within one domain or between different domains. This future analysis for spectrum usage is known as the spectrum forecasting.

5.3.1 Handover Management Operations

Handover management refers to the control functionality of a UE access point in network in order to maintain a connection with the moving mobile during active data transmission. The structure of operations of handover management is shown in Figure 5.3 and includes [14]:

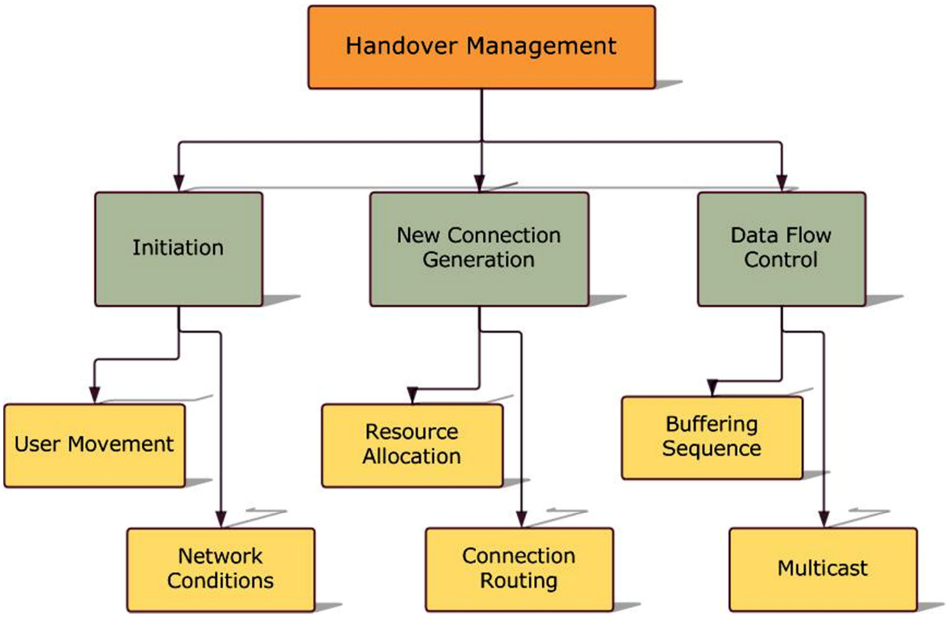


Figure 5.3: Handover of management operations

- ***Handover Triggering***, the handover process is introduced due to some conditions that may include signal strength, overload, bandwidth insufficiency, a new better connection becoming available, flow stream characteristics, change in network topology, etc. Triggering may even happen according to a user's explicit control or investigational advice from local monitor software.

- ***Connection Re-establishing*** is the process to generate a new connection between the UE and the new base station and/or link channel. The main task of this operation is to discover and assess any new connection available. This behavior may be based on either a network-active or a mobile-active procedure, depending on which one is needed to locate the new resource essential for the new establishment of connection.

- ***Packet Routing*** changes the delivery route of the subsequent data to the new connection path after the new connection has been successfully established. An efficient strategy is necessary for the management of potential wireless overlay architecture and mobility within the framework. This is clarified in Figure 5.4.

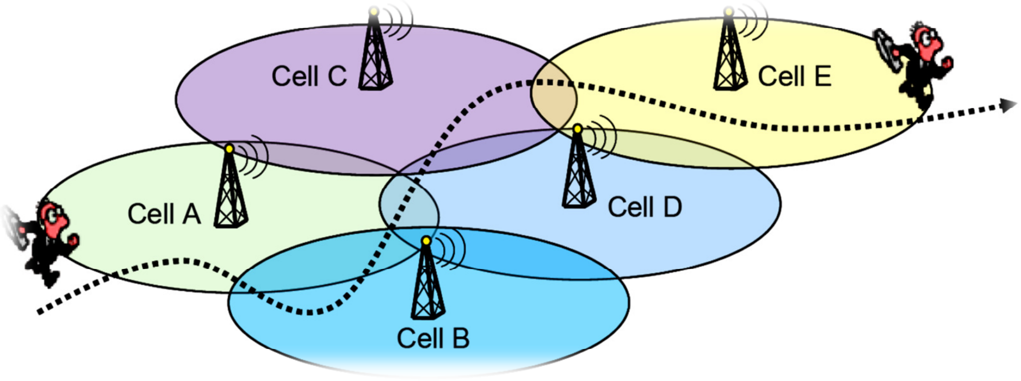


Figure 5.4: Handover routing from node A to node E

5.3.2 Location management

Location management locates roaming terminals in order to deliver data packets to them despite the fact that their locations may change from time to time. The essence of location management is constituted by the mechanisms of mapping the name of a mobile node to its address. Operation of location management includes [15]:

- ***Location registration***, also known as location update or tracking, i.e. the procedure that the mobile node informs the network and other nodes of its new location through special messages by updating the corresponding location information entries stored in some databases in the networks.

- ***Location calling***, also known as locating or searching. In most cases location information stored in databases is only the approximate position of a mobile device. Location calling is the procedure that, when calls/packets need to be delivered to the target mobile device, the network tries to find the mobile device's exact locality.

5.3.3 Mobile IPv6 Network Layer Performance

Handover management is responsible for maintaining the active sessions of the Mobile Host (MH) as the mobile moves across the coverage area of various BSs. Here, the handovers that are considered are those resulting due to the change in the network layer (IP) connectivity of the host. However, this is not always the case since a change in link-layer connectivity does not necessarily result in an IP handover. A handover control protocol should ensure that handovers are fast and smooth. Therefore, they should be performed without significant delays and without loss of packets. A requirement that is also dependent on the provided service [16].

Mobile Internet Protocol Version 6 (MIPv6) improves multiple aspects of MIP, such as inherent mobility, security and route optimisation, but also preserves its most important disadvantage, having Home Agent (HA) as a single point of failure. Moreover, the required update messages used in MIPv6 can prove to be an additional overhead in case of the increased Mobile Node (MN's) mobility since this often results in changes of the Access Network (AN) [17]. Mobile IP introduces three new functional entities:

- ***Mobile Node***. A host or router that changes its point of attachment from one network or sub-network to another. A mobile node may change its location without changing its IP address; it may continue to communicate with other Internet nodes at any location using its (constant) IP address, assuming link layer connectivity to a point of attachment is available.

- ***Home Agent***. A router on a mobile node's home network that tunnels datagrams for delivery to the mobile node when it is away from home, and maintains current location information for the mobile node.

- ***Foreign Agent***. A router on a mobile node's visited network that provides routing services to the mobile node while registered. The foreign agent tunnels and delivers datagrams to the mobile node that were tunneled by the mobile node's home agent. For datagrams sent by a mobile node, the foreign agent may serve as a default router for registered mobile nodes.

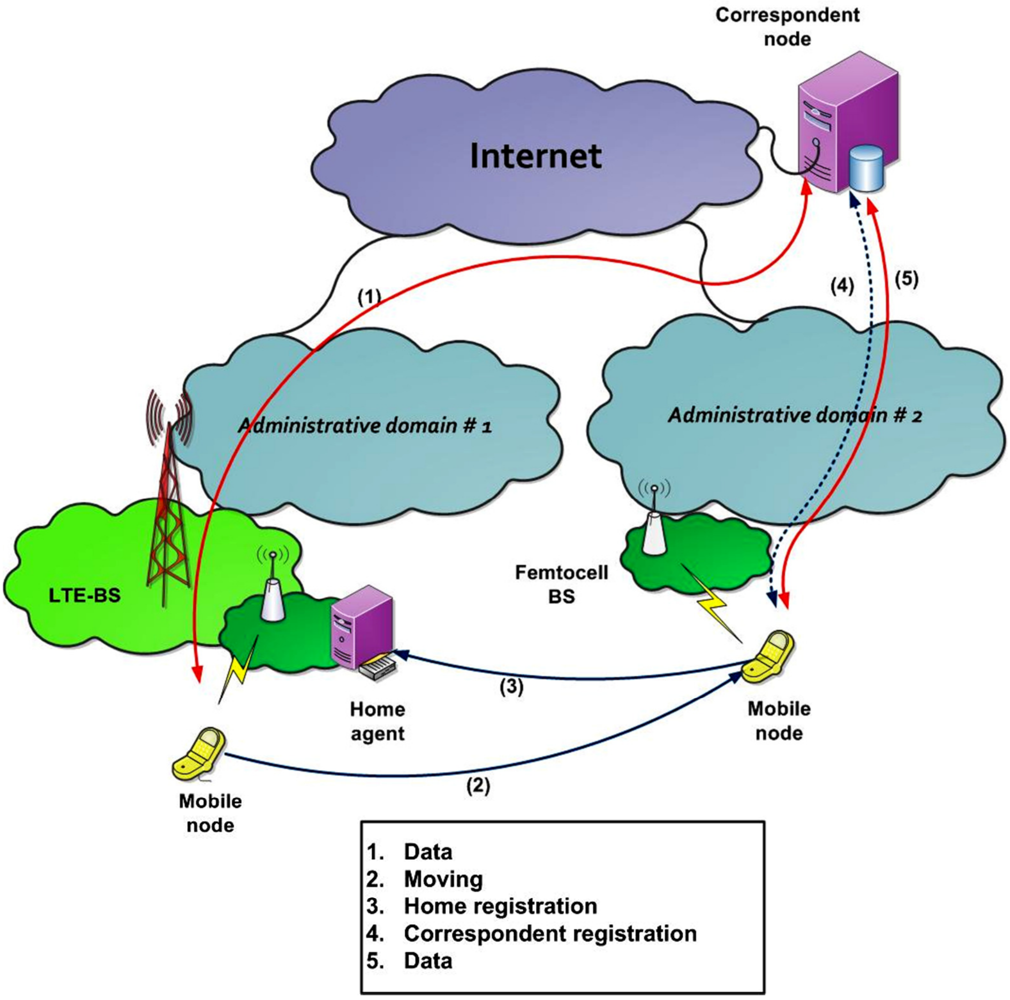


Figure 5.5: Mobile IPv6 architecture and operations

The functionality of the MIPv6 is presented in Figure 5.5. Again, no mobility support is needed as long as the MN stays in the HN (1). Once the MN moves out from the Home Network (HN) to a Foreign Network (FN) (2), it can obtain its Care-of Address (CoA) refers to a "second IP address" via either state full like DHCP for IPv6 (DHCPv6) or stateless address auto-configuration procedure. Newly obtained CoA must be registered at HA (3) and Correspondent Node CN (4). The correspondent node is connected to the Internet" using binding update messages. Both HA and CN must maintain the list of the current MN’s bonds. As soon as the MN’s bonds are updated, the packets can be routed directly from the CN to the MN’s CoA and similarly in the opposite direction, so that the triangular routing is avoided (5). In the case where the communication between CN and MN is established, when the latter is already in the FN, the first packets from the CN are tunneled via the HA to the CoA, like in MIP, until the binding update process is completed.

Fast Mobility (FMIPv6) attempts to make the handovers proactive if it is possible to obtain information about the candidates for the new access router from the co-operating access routers before disconnecting from the old access router. More recently, network-based IP mobility solutions where the terminal is not directly involved in managing IP mobility (e.g., Proxy MIPv6 (PMIPv6) are also being introduced in wireless networks [13].

To reduce the signaling and speed up the handover for movements within the same Administrative Domain (AD), the MIPv6 local mobility scheme has been used in the proposed system network.

5.4 Mobility Management in LTE Zones

The future cognitive LTE-femtocell network is to be deployed in coexistence with the other primary networks. Therefore, the positions of the femtocell BSs are decided by many factors such as the transmission power, coverage range, used channels, and number of expected end-users, in order to avoid interfering with primary networks. It is supposed that not all femtocells would have the accessibility to landline connections as the LTE BSs. The main reasons for having fibre connections to the LTE BSs are [18]:

- The LTE BSs are the main providers for services in the cell and they are connected to the backbone fibre networks and not fibre terminal edges or DSL connection. This provides the LTE stations with the highest speed for data transfers using the fibre network.
- The fibre connections are not as replacement for the wireless links between cognitive BSs. Fibre is used to support the network as an alternative for wireless links only when there is no way to formulate an

efficient and reliable wireless link.

- The cost of using fiber in cognitive network especially LTE base stations should be taken into consideration when choosing the installation positions and the numbers of femtocell BSs.

The best strategy for installing the cognitive BSs is to place them within the known boundaries of the primary bases stations. This is to simplify the spectrum trading between the primary and cognitive networks and also to make it easier in dealing with temporary licenses issued from local spectrum entities. Thus, a new network system of multi-access cognitive networks emerges to improve the cognitive communications performance and reliability. Figure 5.6 shows a big sized cognitive LTE-femtocell network with variable numbers of deployed femtocells.

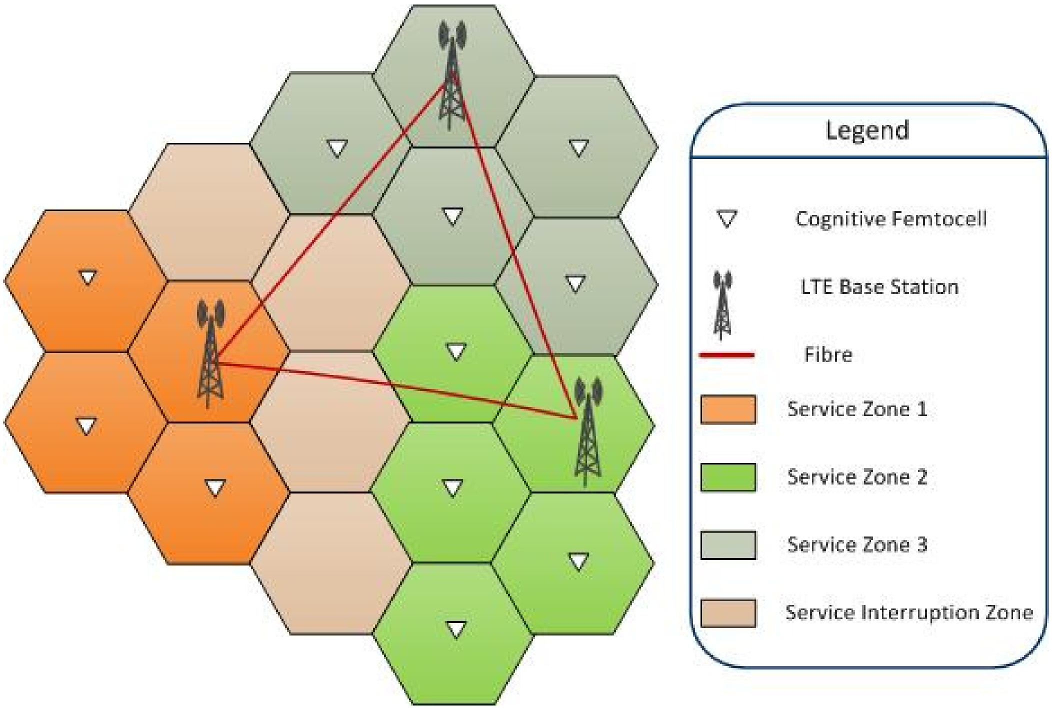


Figure 5.6: Multi-access networks of femtocell and LTE base stations

The LTE cells will allow neighboring cognitive femtocells to use fibre connections for data exchanges in severe wireless situations. This is likely to happen whenever a cognitive BS fails to establish a link with remote sites of the network [19, 20]. These groups of LTE and femtocell BSs share the same spectrum band and the network is divided into different zones of services. In each zone, LTE acts as the master for all other cognitive femtocells. This division makes it easier to achieve local resources sharing between each zone femtocells while LTE cell as a main backbone of communication networks. The spectrum channels are shared in a distributed way between the zone cells. The LTE exchanges data, information, and transmission requests with other zone sites using its landline connection and via the other sites LTE cells. The new network architecture can be defined as a new hybrid system for dynamic spectrum access using local, central-to-local, and global network resources management. The challenges of such multi-zoned setup in future cognitive networks can be summarised as:

- New handover models that allow femtocells located at the edge of LTE cells to migrate to a neighbour cell. In this way, the handover is happening to the femtocell with all its end-users in operation. This creates a new emerging model of dealing with one set of users who will need to be connected to another spectrum band while maintaining online transmissions. The main goal is to create a system that can respond and act to unpredicted wireless spectral changes and various numbers of users.

- Novel cognitive femtocells handover that is able to monitor the spectrum usage and make decisions to re-connect to another cell when there are more transmission opportunities become available. This should reduce the traffic loads and improve the accessibility to the free spectrum in local areas.

- More independent BSs those are able to reconfigure and adapt to various wireless spectral situations and network interfacing managements. This requires extended cognition engine designs for the cognitive Base Stations and new protocols for transferring knowledge between different network stations as in [21].

- Establishing temporal, local, flexible zones of neighboured femtocells. These formulations may ease the access procedure and mobility managements in smaller areas of one pool of spectrum channels.

- Reducing the complexity of dealing with main spectrum entities by establishing local governing units supported by protocols. The cooperation between various cells is necessary for the success of the proposed models.

The following section will investigate the criterion for the formulation of these zones, changes in the zones' sizes and boundaries, and one possible scenario for cognitive femtocell migration between these zones.

5.5 Femtocell Migration between LTE Zones

The zoned cell groups are proposed to be dynamically changeable formulations to hosts and release new cognitive femtocells. In other words, cognitive femtocells may join or leave LTE zones at any time as their wireless spectral situation change. These changes in wireless network may result from the dynamic activities of the primary users. Such changes may affect local wireless setting at certain femtocells and make it difficult to connect to other femtocells inside a definite zone. Consequently, a femtocell may decide to leave a certain LTE zone and join another one, according to the negotiations between the femtocell BS and other neighbored zones. The objectives of this cell migration are to attain the most efficient spectrum utilisation and the highest quality of service. The main assumption is that the coexistence between LTE and femtocell is done in a cooperative way and based on dynamic network management that can adapt to any real-time adaptation requirements [22].

In order to be able to formulate the proposed zones, there should be arrangements to share the necessary awareness on the wireless spectral and resource changes at the cellular and network levels. The best scenario is to supply information in two levels: global networks and local zone. In the global networks, information is spread between zones and independent cells, and vice-versa, to make them aware of the general wireless situation inside each area. As well as, each zone to its cells may provide this information. On the other hand, a local zone (x for example) may provide regulating data, changes inside a zone, and neighbored zones change to the cells grouped by zone(x). An IP address may be given to different zones on a temporary basis to simplify the way of providing services throughout the network. One suggestion is to use the LTE IP address as the zone address. Therefore, a new and fully dynamic network is created to various wireless events.

The disengagement process for a femtocell leaving from one zone to another can be performed through informing its zone. The cell takes the decision to leave a zone whenever it recognises that spectrum availability has changed and it is not possible to establish links with other femtocells as before. This can be performed by setting a linkage threshold for the number of link request iterations before making the handover decision. This might happen also when the reports received from local spectrum governing entities show a major change in the forecasted and presently accessible channels for cognitive communications [18]. However, it is necessary to set regulations that prevent femtocells from leaving zones just because they are turning selfish and they want to keep more resources for themselves. Whenever a femtocell is intending to leave the zone, all other zone femtocells are informed about this decision. Then all other zone femtocells may terminate their special *Local Zone Connections* with the leaving femtocell and re-direct their transmission routes using other stations. The migrating cell becomes free and can immediately join any other zone, as shown in Figure 5.7.

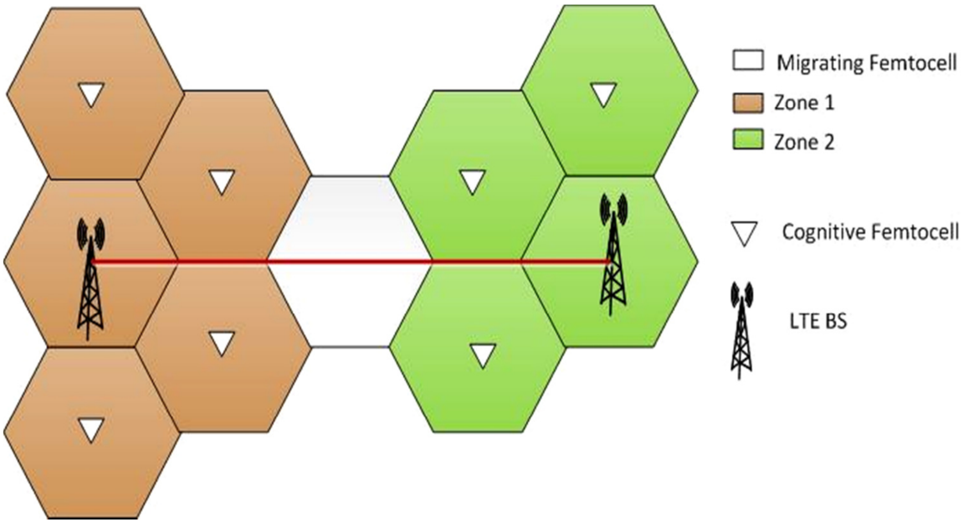


Figure 5.7: Femtocell migrations between two LTE zones

Here, there are two methods for joining the new zone, either the femtocell had negotiated this with the target LTE zone prior to its decision to leave the home zone, or it makes this decision after it becomes free. In both cases the femtocell will be able to attend the new zone only if it had the same wireless spectral and resources situations and there are no more obligations any more with the old zone.

Normally, LTE accepts the request issued by an individual femtocell to join its zone as long as this application follows the above procedures and gets more resources. The time taken for cell migration should be quick enough to prevent any interruptions in communications for the migrated femtocell and to prevent being trapped between two zones of services. At all times, the cell is still part of a bigger network infrastructure and operator services. This is in case the cell did not identify itself as an independent service zone. The local communications and re-directing of the services throughout the zone is changed as soon as the new femtocell is unified with the service area.

Handover management is a challengeable task when implemented in femtocell due to the dynamic spectrum access modeling. In addition, due to technological challenges and system operator requirements, the initial 3GPP specification for handover in femtocell focused on one direction only that is from FBS to LTE macrocell. Therefore, three possible handover scenarios are likely to occur in femtocell networks [23], as depicted in Figure 5.8:

- ***Hand-in:*** this scenario presents the handover where an UE switch out from macrocell BS to FBS.

- ***Hand-out***: represents the handover that is performed from FBS to macrocell BS.

- ***Inter-FBS Handover***: it corresponds to the scenario of handover from one FBS to another FBS. In this scenario all FBSs are assumed to be placed at the same location and served by the same service provider.

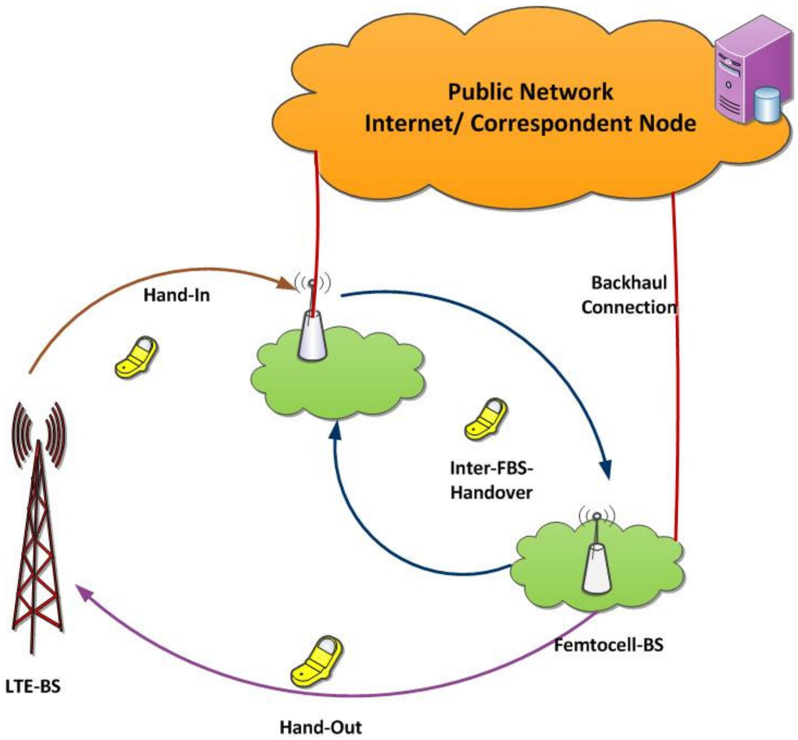


Figure 5.8: Handover scenario in femtocell networks

5.6 Handover Call Flow

This section proposes comprehensive handover signal flows for the small and medium scale deployable integrated LTE-femtocell network architecture. The Mobility Management Entity (MME) is the key manage node for LTE macrocell network. It provides the control plane function for mobility between LTE and other femtocell networks, and is responsible for choosing the right serving gateway for an UE and for authenticating them [2]. The serving gateway (SGW) supports users data and provide routing and forwarding functionality between LTE or FBS and packet data network. The proposed handover schemes optimise the selection/reselection management functionalities in the LTE-femtocell handover procedure. Moreover, the improve handover scheme is considered sensing mechanism to select the best free channel available.

During the information gathering stage, the UE collects the information about the handover candidates, and authentications are acquired for security purposes. In handover chosen stage, the best handover option is calculated. Finally, after deciding to make handover, the UE initiates handover. The handover procedure can normally consist of three phases:

- ***Handover preparation***: this phase where measurements are made and information about surrounding BSs is prepared from mobile user after scanning the neighboring cell BS. During the scanning process, the mobile user measures the channel quality or signal strength of each neighboring candidate BSs. However, the mobile user sends measurement report message to serving BS in order to select the best candidate BS. Accordingly, the mobile users of serving base station and target base station make preparation before the mobile user connect to the new cell. Then, handover decision is process when the serving BS offers the handover decision according to the received measurement report message from mobile user. The message is send from admission control to the target BS based on the QoS information. Finally, sending handover command to the mobile user.
- ***Handover execution***: in this phase the connection is starting to detach from old cell and synchronise to the new cell and accesses the target cell. In this stage, the mobile user desires to synchronise with downlink transmission and obtain downlink and uplink transmission parameters with target BS through gate-way router.
- ***Handover completion***: this phase includes the processes of handover confirm and path switch. Therefore, the serving gateway switches is the route of transport the data to the target BS. Thus, the serving gateway exchanges massage with MME and release resource base on reception of the release message, the serving BS can release radio and control of related resources. After that, target BS can transmit the packet data. The handover procedure is completed afterward, and the data broadcast between the mobile and the new serving BS can be started.

5.6.1 Hand-in Procedure

The handover from LTE BS domain into femtocell BS domain is quite demanding and complex since there are hundreds of possible targets FBSs. In hand-in procedure, the UE needs to select the most appropriate target FBS. The interference level should be considered as a basic decision parameter. Whenever the UE in the LTE network detects a signal from FBS, it sends a measurement report to the connected LTE-BS. Based on the measurement report, UE decides to perform handover, and the LTE-BS starts handover procedures by sending a handover request to the serving SGW. The handover request is forwarded from the source LTE BS to target FBS through CN. The CAC is performed only by FBS to check whether the call can be accepted or not. After that the FBS responds to the handover request. Then the packet data are forwarded to target FBS. Now the UE re-establishes a channel with the target FBS and detaches from the source LTE BS, and also synchronised with the target FBS. The proposed mobility fictionalisation is important to consider in handover decision to optimise the handover procedure. The authentication is checked in the preparation phase of handover, thus LTE to femtocell handover is more complex than existing handover between LTE macrocells. The signalling flow procedure of the proposed handover scheme from macrocell to femtocell is shown in Figure 5.9.

5.6.2 Hand-out Procedure

The handover procedure from FBS to LTE BS is relatively simple as compared with the hand-in scenario because there is only one candidate BS and UE has no other option to select the target cell. It means that in this scenario, complex target cell selection mechanism is unnecessary. The UE measures the Received Signal Strength (RSS), which includes path loss, antenna gain, log-normal shadowing, and fast fading averaged over all the reference symbols from LTE node, to determine which is stronger than FBSs-RSS, and the UE will connect directly without a complex interference calculation and authorisation check as in the hand-in scenario. After deciding for handover, the FBS starts handover procedures by sending a handover request to SGW. The CAC of the LTE node and SGW are to check whether the call should be accepted. Then the LTE responds to the handover request by starting to setup a new link between SGW and the target LTE, so that the packet data are forwarded to target LTE. At this stage, the UE needs to re-establish a channel with the target LTE and detach from the source femtocell, and also establish synchronisation with the target LTE. The mobile user starts to send a handover complete message to SGW. Then, the FBS disconnects the old link with the SGW. The signalling for femtocell to macrocell handover flows is depicted in Figure 5.10.

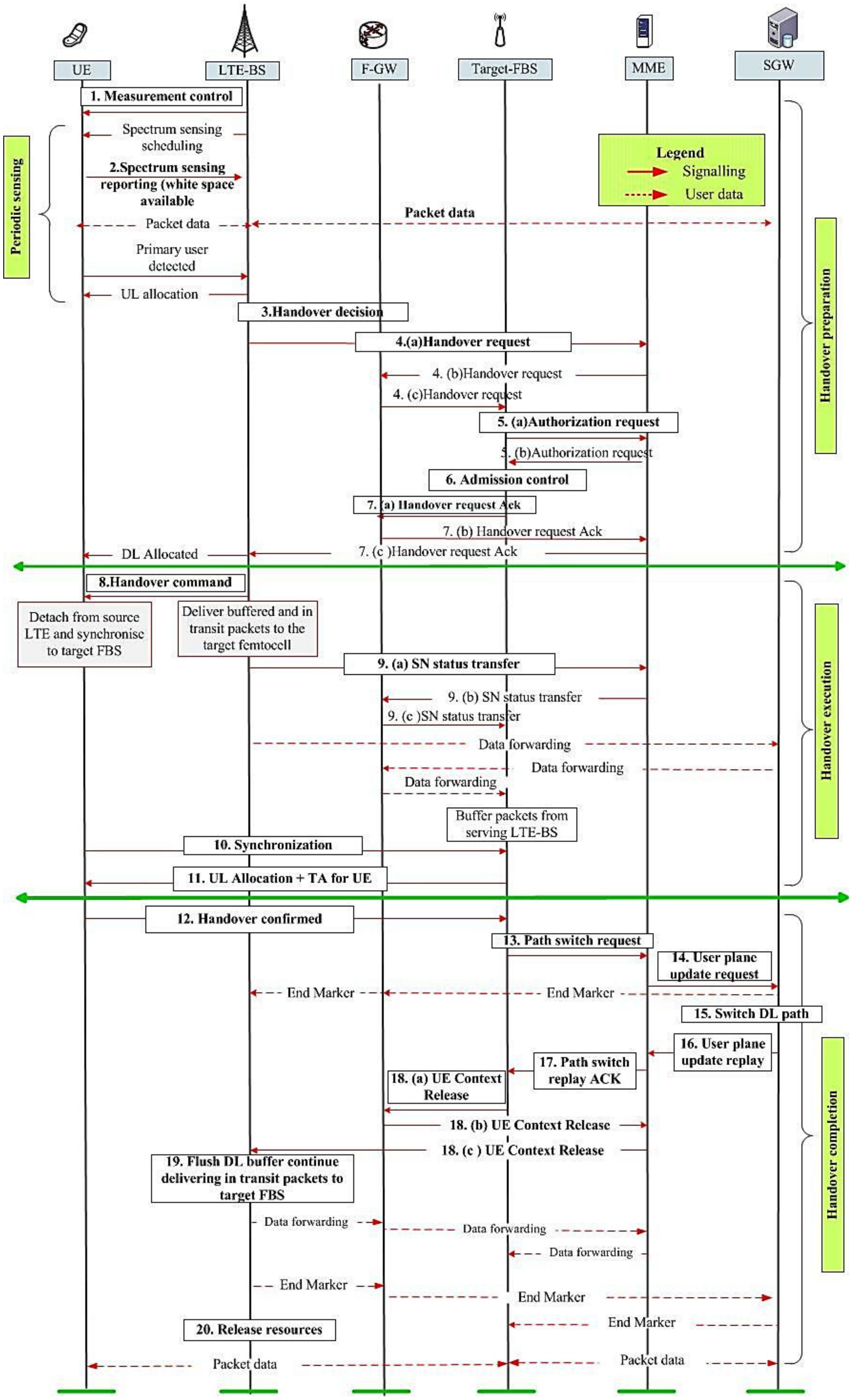


Figure 5.9: Handover from macrocell to femtocell

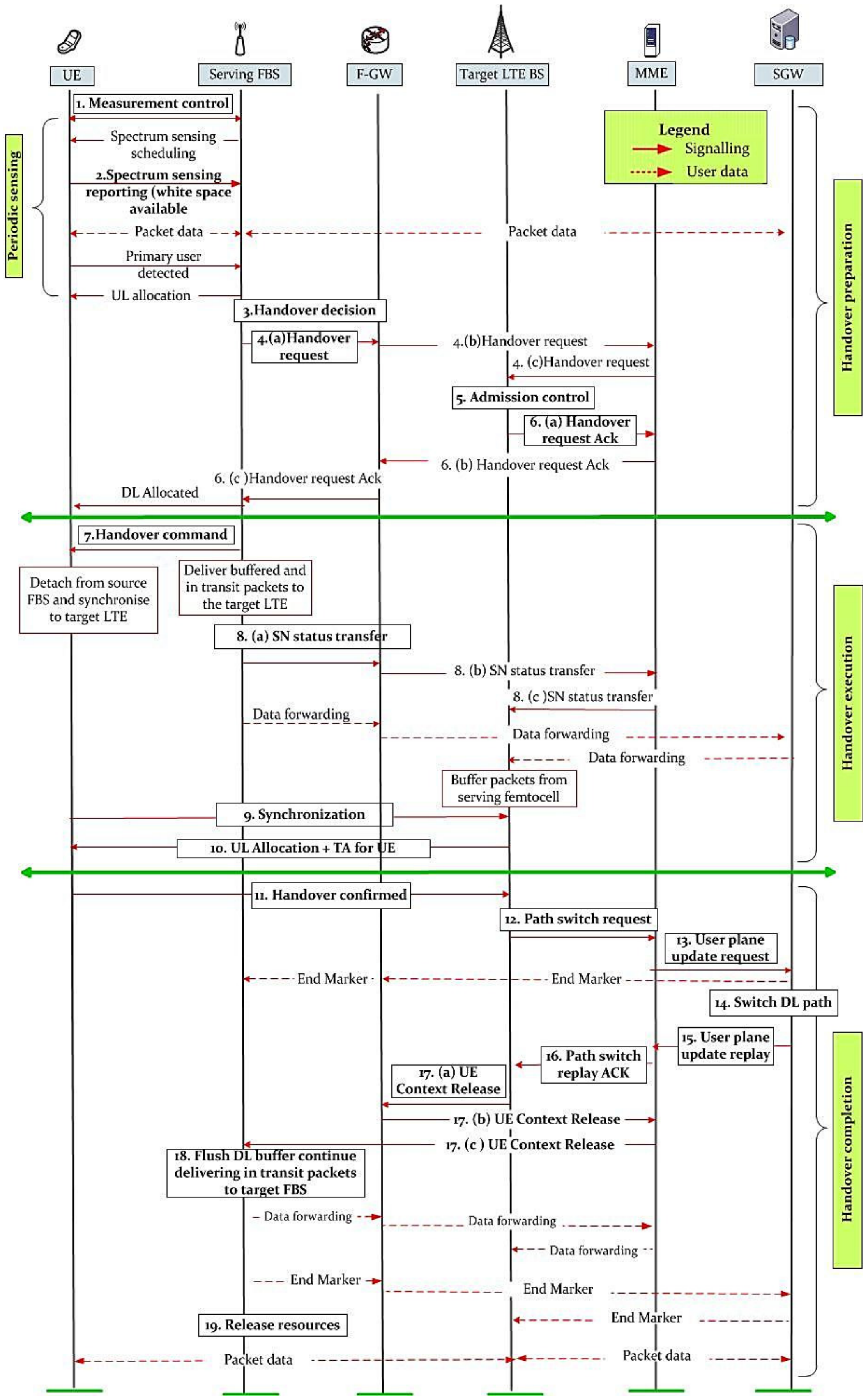


Figure 5.10: Handover from femtocell to macrocell

5.7 System Model

5.7.1 Markov Chain for Handover Decisions

The handover call arriving rate in diverse femtocell environments is hard to handle because of the frequent and unwanted handovers that causes significant decrease in the QoS. In LTE-femtocell overlaid networks, blocking a macrocell to femtocell handover call will not dropping that call. By reserving large amount of bandwidth for the macrocell to femtocell handover calls, bandwidth utilisation should not be sacrificed to reduce handover call blocking probability. The proficient handover scheme to enhance the bandwidth utilisation is performed by improving the handover call blocking probability using the CAC mechanism.

The queuing system with Poisson input as Markovian process (denoted by M) is considered in this work. The arrival of LTE-femtocell users' calls is based on M/M/1 queuing system. The queuing systems assumes that the number of arrival of packets (data network) for a given interval of time t follows a Poisson distribution process with parameter of product of λt, as shown in Figure 5.11.

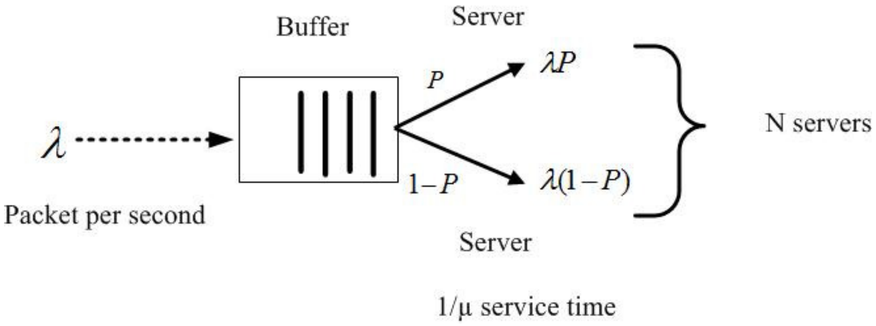


Figure 5.11: Multi server queues systems

The service time for each server is assumed to be a distributed function with an exponential distribution of service rate μ. The length of a data packet follows an arbitrary Probability Density Function (PDF). Due to the fact that the power of a transmitted signal is much higher than the power of the received signal in wireless medium, instantaneous collision detection is not possible for wireless nodes. The Poisson process theory has the ability to split every arrived call that is randomly routed with probability P to stream 1 and (1-P) to stream 2. Streams 1 and 2 are Poisson of rates Pλ and (1-P) λ respectively. For N arrivals within a time interval t, let the probability distribution function $P(n)$ is given as [24]:

$$P(n) = \frac{(\lambda t)^n}{n}\, e^{-\lambda t} \tag{5.1}$$

where λ denotes the arrival rate of customers in system, and n is presented number of servers. This assumption is a very good approximation for arrival process in real systems and we denote: λ_{hm}, λ_{nf} and μ to represent the average rate of handover call from macrocell to femtocell, the average originating new calls rate at femtocell area, and service rate respectively [24]. A system with the value of K less than N implies that the system gives more priority to macrocell-femtocell handover calls than the originating new calls at femtocell area, as shown in Figure 5.12.

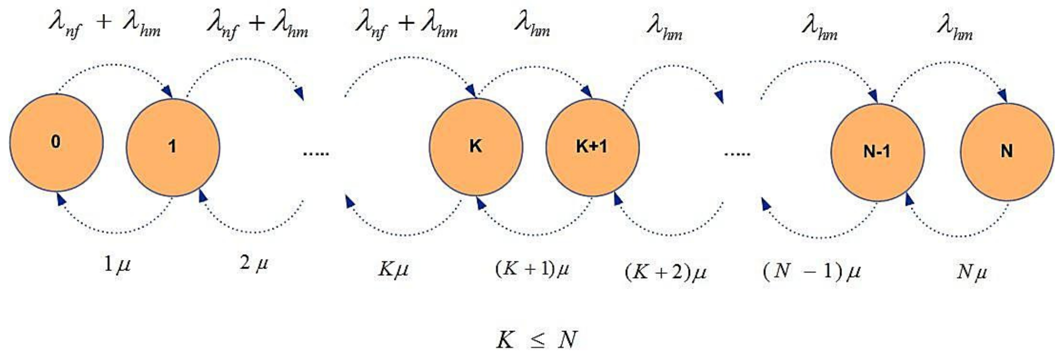


Figure 5.12: Markov chain model of LTE-femtocell handover scheme

The fixed value of K for all femtocell environments reduces the resource utilisation. Several schemes or techniques may be adopted to fix the value of K. For femtocell coverage area with a lower probability of handover call rate, then can use very close values of K and N. The system can also use a variable value of K to optimise both resource management and handover call blocking probability. Thus, the total arrival rate of the connection request of the system λ_j is [25]:

$$\lambda_j = \begin{cases} \lambda_{nf} + \lambda_{hm} & \text{for } 0 \le j < K \\ \lambda_{hm} & \text{for } K \le j < N \end{cases} \tag{5.2}$$

The blocking probability of the calls originating at femtocell area is

$$P_B = \sum_{i=k}^{N} \frac{(\lambda_{nf} + \lambda_{hm})^k .\ \lambda_{hm}^{i-k}}{i!\ \mu^i}\ P(0) \tag{5.3}$$

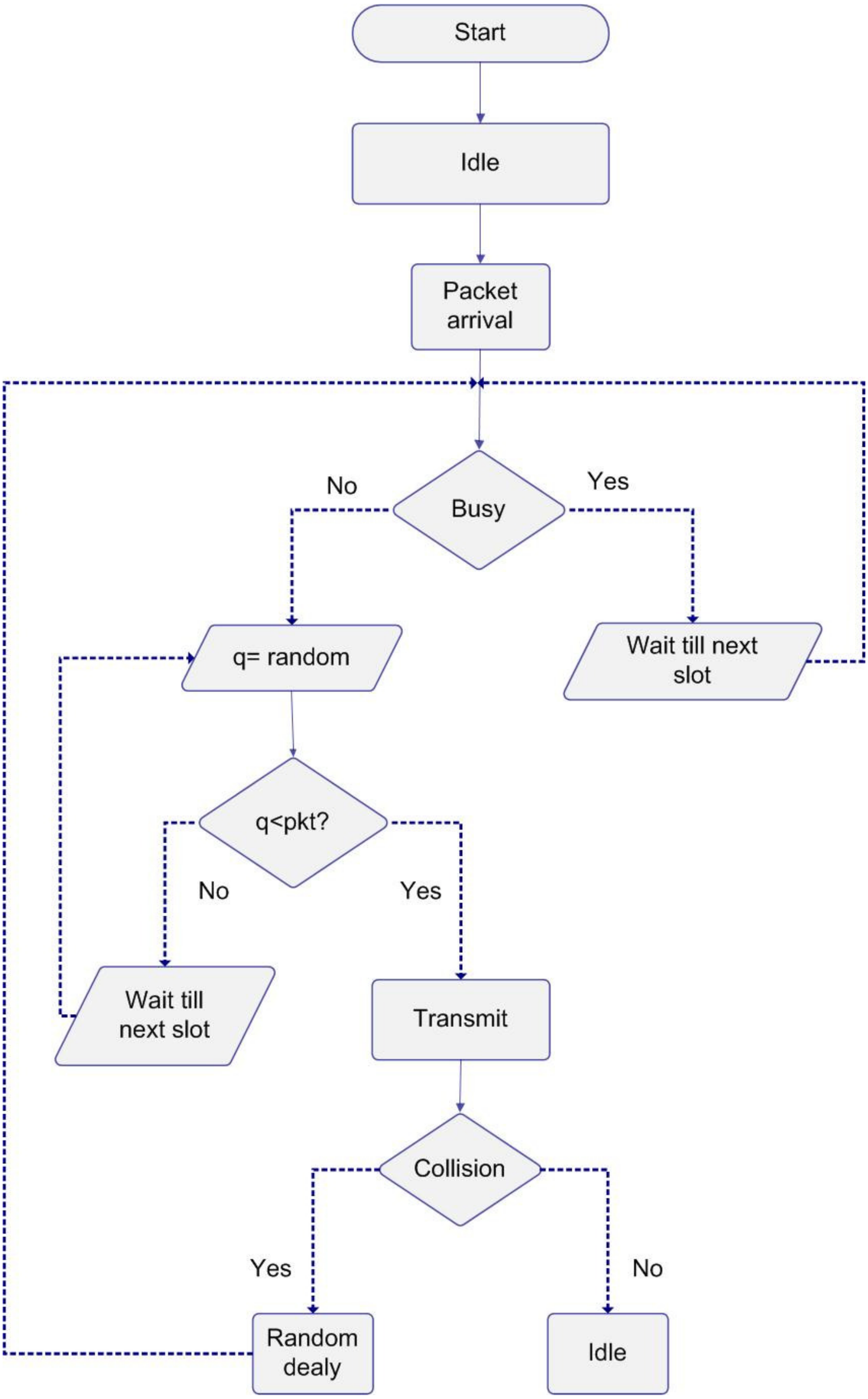


Figure 5.13: Markov model

Where N is the number of customers in the system, and K is the system total capacity or number of waiting customers. The mobility of each node is modeled by Markov chain on the quantised space derived from the above partition. The performance of this method has also been analysed using Markov model, as shown in the Figure 5.13.

This block diagram represents our OPNET developed project to interconnect Markov Chain to the LTE/femto system. Markov Chain is already included in OPNET functions to allow enabling QoS evaluations. This function is incorporated with the proposed scenarios of CAC to analyse handover models performance using data arrival predication.

The number of handovers that occurred in a particular state of the cognitive networks multiplied with the steady state probability of that state will give the handover probability of that particular state. Thus, handover probability of the networks is obtained by assuming the handover probabilities of all the states of the hierarchical networks. Hence, the probability of handover occurred in LTE/femtocell networks can be calculated as follows:

$$\mathrm{Probability}_{\mathrm{HO}} = \sum_{\forall_s} \mathrm{N}_{\mathrm{HO}} * \pi \,.\, \mathrm{N}_{\mathrm{calls}}\,(S) \qquad (5.4)$$

Where S is the probability of being in a state, as the Markov chain is irreducible, N_{HO} represents the total number of LTE/femto handovers that occurred at specific state. $\mathrm{N}_{\mathrm{calls}}$ denotes the number of services residing at a certain femtocell/LTE domain. Thus, observing the outgoing and incoming transitions for a given state ‘S’ and the steady state probability allow to evaluate the network performance for that change.

5.7.2 Novel Mechanism for Call Admission Control

In this section, a new CAC mechanism is proposed to monitor the necessary measured parameters on the cell and control the admission of incoming connections. The work is driven by a novel scenario where two groups travel across each other at specific speeds and the corresponding network spectrum availability changes frequently since each group has full access to spectrum channels. Unnecessary and common handover, as a result of very small transmission domains, is a serious problem for femtocell networks system. On the other hand, high speed user is expected to stay for a small time at different domains. This is a main source for the enormous numbers of unnecessary handovers due to the movement from macrocell to femtocell areas and back again from femtocell to macrocell areas. In wireless network systems, unwanted handovers decrease the capacity of the system as well as QoS. In this regards, the minimisation of unwanted handover is very essential to guarantee the success of LTE-femtocell system.

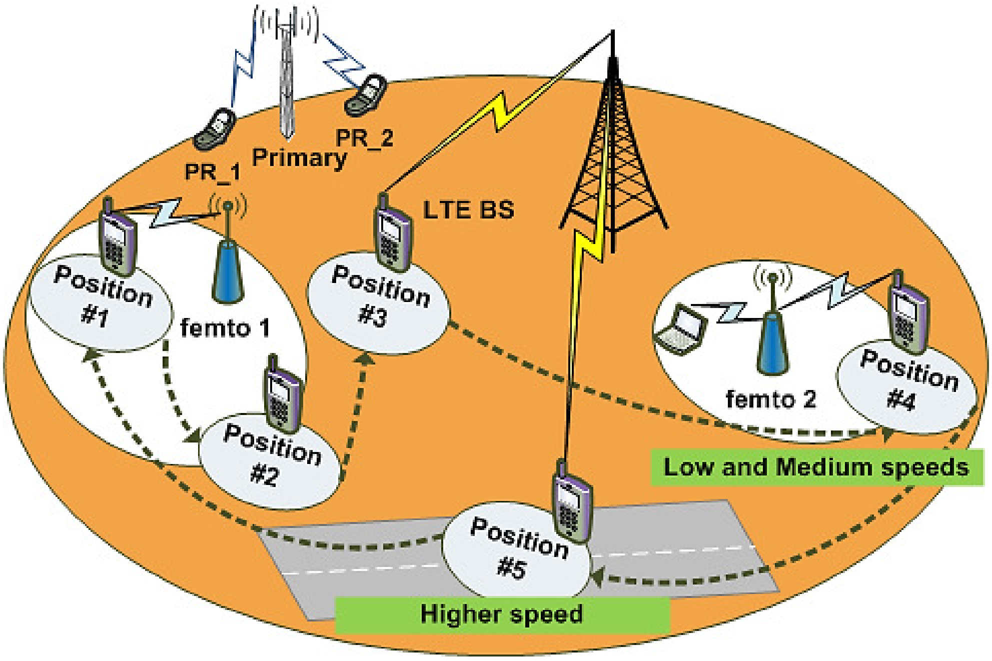


Figure 5.14: Handover decisions in the hierarchical system model

An efficient handover strategy takes into consideration the mobile speed, received signal strength (RSS), available spectrum, and interference level. This is performed using CAC algorithm, which has ability to reduce unnecessary handovers, decrease the interference level, and achieve the resource allocation utilisation. The CAC algorithm considers two phases: handover from macrocell to the femtocell (hand-in), and handover from femtocell to the macrocell (hand-out). While femtocell to femtocell (intra handover) is not considered. The CAC is considered threshold for three mobile speeds levels, as shown in Figure 5.14. Whenever an UE moves into a femtocell from a macrocell, it can detect the existence of an FBS and decide to switch into the femtocell network. In contrast, whenever a FBS user moves away from the femtocell BS, it issues a handover request whenever it detects that the strength from FBS is weaker than the strength from macrocell BS. Later, if the handover is approved by the macrocell BS, the mobile connection with the femtocell will be terminated and communications will be switched to the macrocell network.

The mechanism of the CAC is illustrated as follows: whenever a cognitive femtocell receives a handover request from the access service network gateways or from the UE, the femtocell makes a decision to allow the handover to take place according to the proposed CAC algorithm shown in Figure 5.15.

Since users with high velocity may pass through multiple FBS zones, it may not be possible to maintain a constant QoS over UE connection. Thus, the number of detected handovers (H) in a femtocell coverage area is a function of femtocell radius (r), speed (S) of the UE, and angle of movement (θ) with respect to the direction of FBS. The number of handovers can be expressed as:

$$H = F\ (r, S, \theta) \tag{5.5}$$

The decision of handover from LTE and FBS can be expression:

$$HO_{decison} = \mathrm{RSS_{femto}} \,.\, \mathrm{S_{UE}} \,.\, \mathrm{SIR_{femto}} \tag{5.6}$$

Where RSS_{femto} denotes to the Received Signal Strength Indicator (RSSI) from FBS, S_{UE} denotes to the velocity of UE, and SIR_{femto} denotes to the signal-to-interference at femtocell area. The value of RSS_{femto} is 1 only if the received signal level does not go below a threshold level for a specific time interval, else it is 0. S_{UE} represents 1 if the velocity of UE is less than a threshold velocity, otherwise 0. The value of SIR_{femto} is 1 either if the SIR at femtocell environment is greater than the threshold value or greater than SIR at macrocell environment; else its value is 0. Thus the value of decision parameter is either 0 or 1.

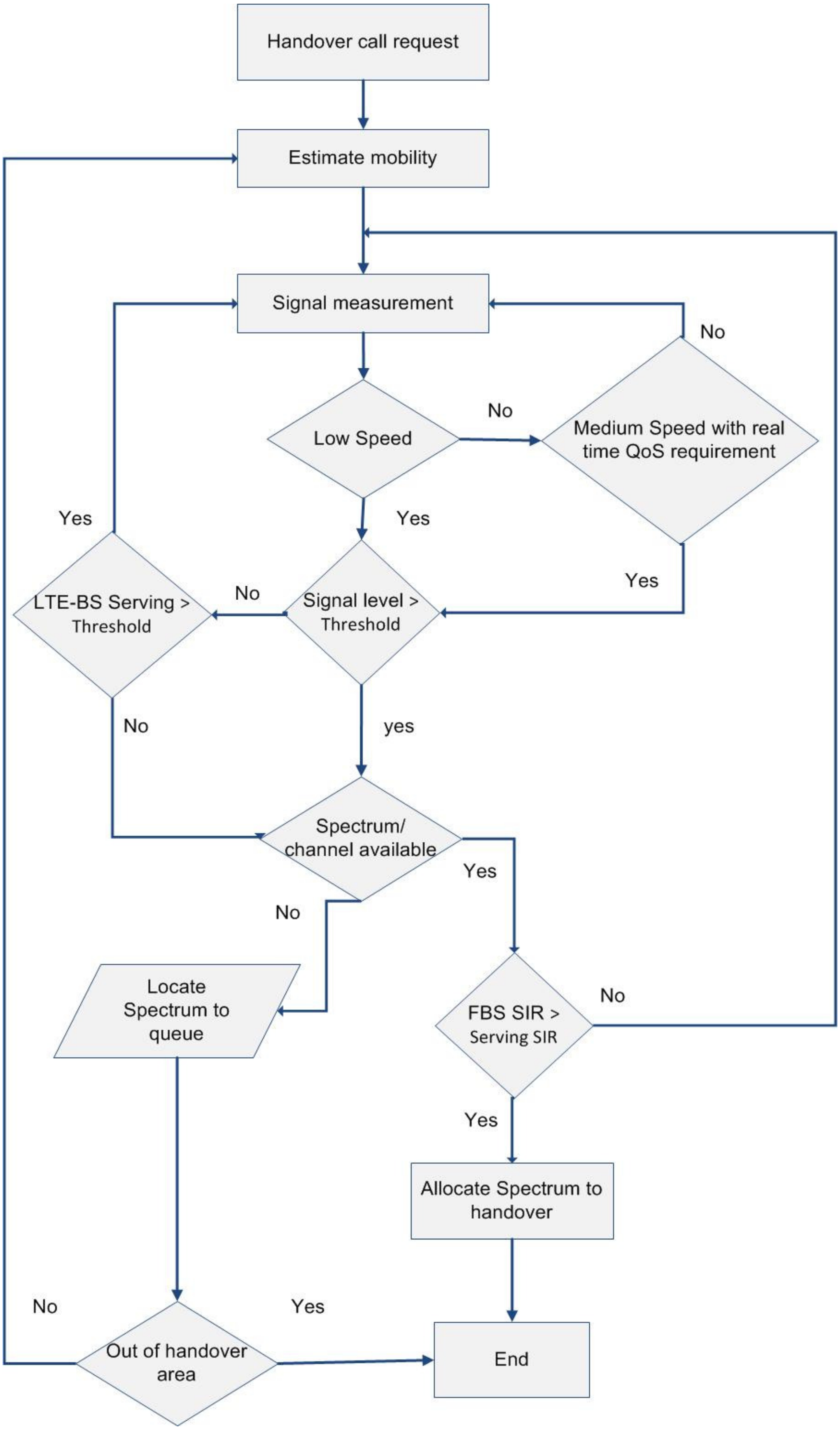


Figure 5.15: New CAC mechanism for handover call authentication

An admission for macrocell to femtocell handover is only accepted by FBS if the value of $HO_{decison}$ is 1. The threshold level of the signal is the minimum level of the signal that is required to handover a UE from LTE BS to femtocell BS. Sometimes UE receives a signal that is greater than minimum request level but during very short time the level goes down again due to the movement of the UE. Whenever a UE moves to femtocell BS coverage area, the UE must keep threshold level of the signal at the minimum threshold handover. A call can be accepted if, either SIR level in the target femtocell is higher than the threshold level or less than the SIR level of current macrocell area. Once, any of these conditions satisfied then the available channel is taken into calculation. Otherwise, the allocation of LTE-femtocell user is checked against any drop in their signal quality before handover may occur.

The handover threshold may be adjusted according to the service type, QoS requirement, and the velocity of the user, except for the mobile traffic required real time services [26]. Otherwise, packets can be buffered until handover performed and a channel becomes available. The thresholds for the CAC scheme can be then identified in terms of speed as: Low (Low mobile speed state: from 0 to 15km/h; slow walk, stationary), Medium (Medium mobile speed state: from 15 to 30km/h; speed equivalent to that of riding a bicycle), or High (High mobile speed state: anything above 30km/h, drive a car).

5.8 Cognitive Node Implementation in OPNET

In OPNET, a network is made up of individual nodes, and a node is made up of modules. The hierarchy of packet flows through the different modules in the node has been modeled using different layers in the networking system. These modules are composed of process models that define the module’s behavior and contain the C++ code functions of the program. The original IP process model of the node selected for femtocell performance evaluation in OPNET modeler is shown in Figure 5.16. The figure shows the different layers and port connections at the module level that performs the most basic general functions.

The node model in Figure 5.17 shows the modification model with a new module for handover management named as *Call_Admission_Control.* The modification was implemented by modified the IP layer system unit and incorporating the new handover technique with the call admission control.

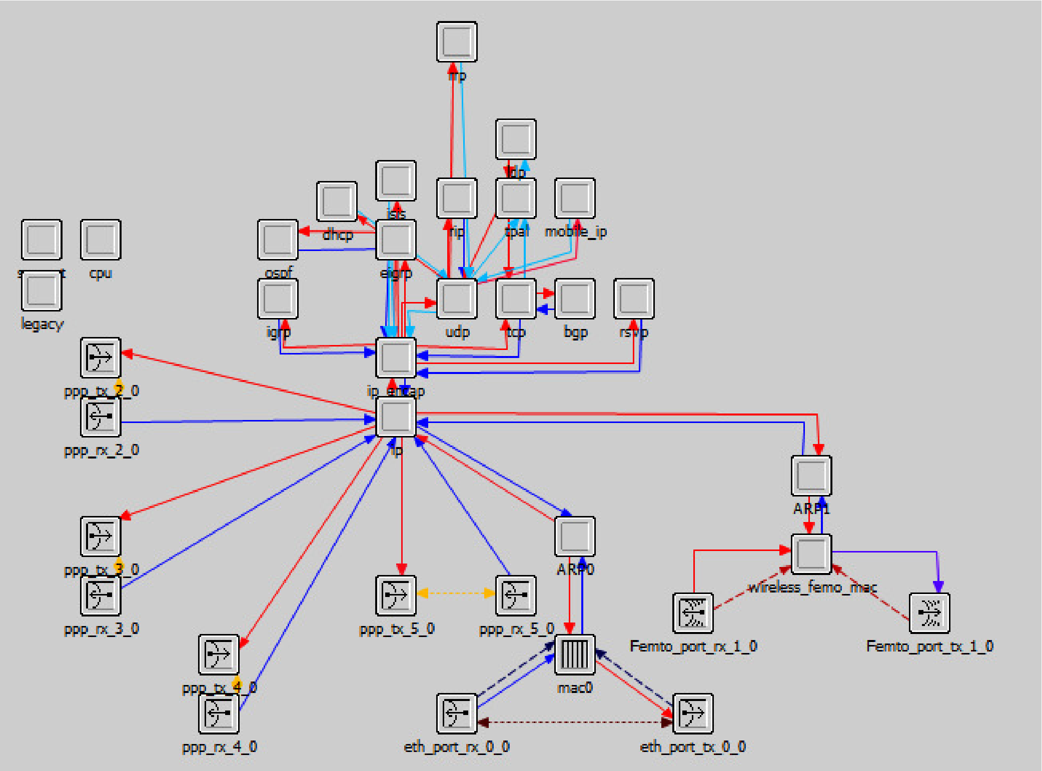


Figure 5.16: Node Process Model in OPNET17.1

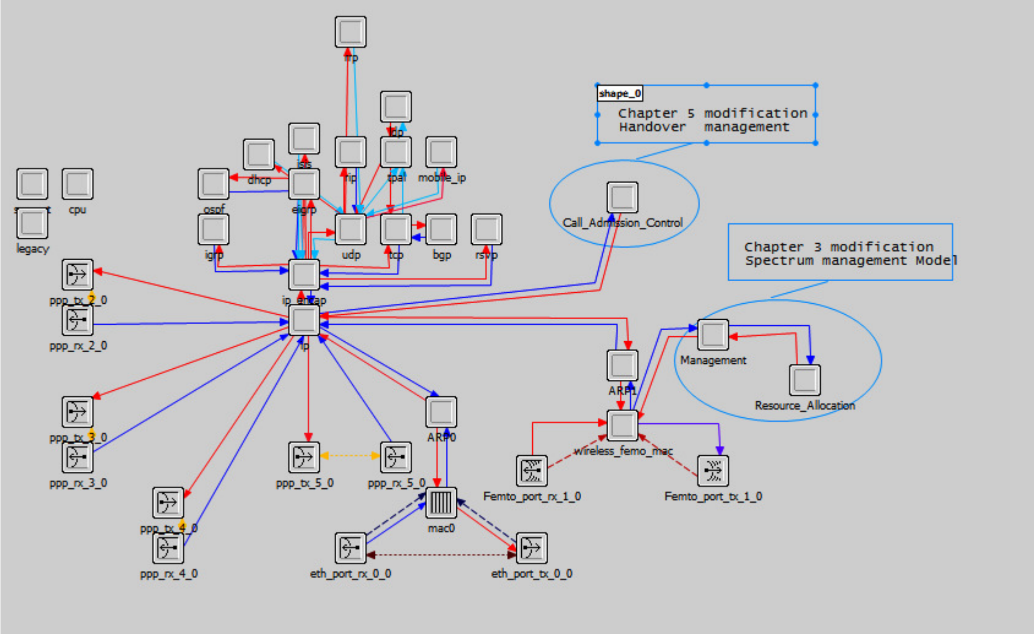


Figure 5.17: Node modification by adding admission control process

Figure 5.18 illustrates the process model level of the CAC module proposed in Figure 5.17. Once a handover request arrived to the FBS, the call scheme is invoked to decide to accept or reject the mobile phone registration. Initially, the activation of the process starts at the *"open"* state that initialises state variables and other interrupts. Packets are then forwarded to the *"call_admission"* process state that evaluates the eligibility of the mobile user to perform handover. This is decided by comparing the mobile speed to the thresholds setting. If the mobile speed is higher than the assigned limits for performing handover, the handover request will be declined and the call will be aborted and the process will be terminated and moved to *"end"* state.

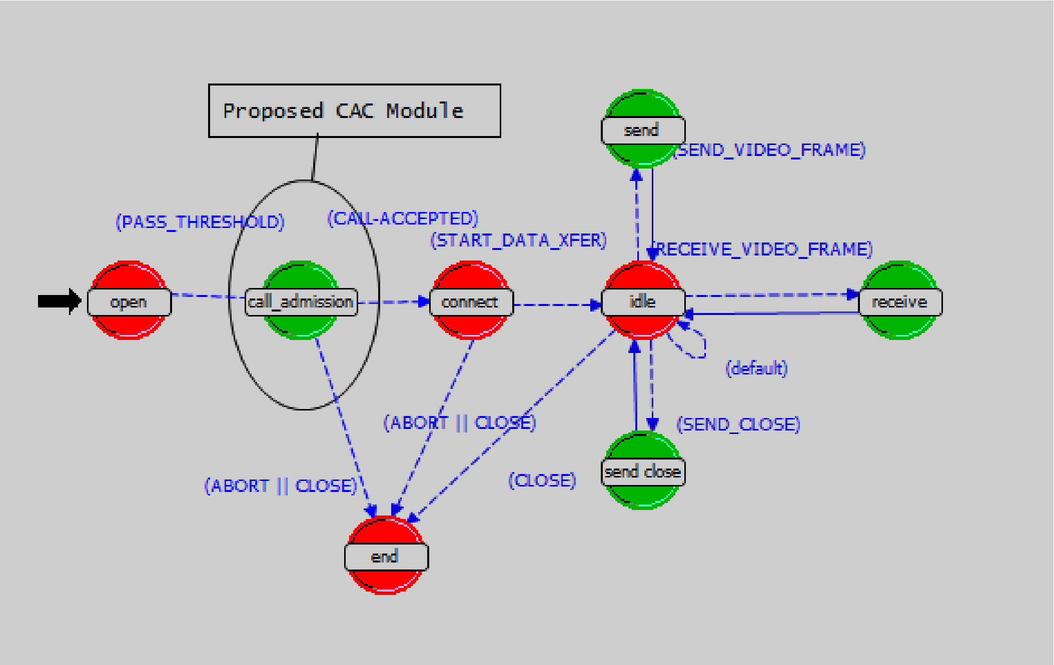


Figure 5.18: Call admission control "process model"

Otherwise, handover request will be approved and the call will be accepted and forwarded to the *"connect"* process state to start connection. If the connection failed to be maintained then the call will be terminated as soon as the interrupt *"ABORT || CLOSE"* is enabled and the process will be ended with "end" process state. If the connection is successful, the interrupt for data transfer will be enabled as *"START_DATA_XFER"* interrupt activated. Next, the "Idle" state will be activated to check if the video incoming packet from the "send" process state has the suitable framing size that matches the available transmission opportunity. As soon as the transmission completed, the *"idle"* activates the *"SEND_CLOSE"* interrupt to close the send process with "send close" process state. Similarly, the “idle” state is also responsible to check the incoming packets from the mobile user using the *“receive”* state and *“RECEIVE_VIDEO_FRAME”* interrupt. Once this completed, the *“idle”* state will close the connection using the *“CLOSE”* interrupt and *“end”* process state. The *“idle”* state has also another interrupt named as *“default”* that allow to add longer route to incoming packets while the *“idle”* is busy with certain process. This allows the *“idle”* state to handle one action at a time to prevent collision of services. The mobile speed is obtained by the pipeline code shown in algorithm 5.1.

Algorithm 5.1. C++ Code for Mobile Speed Calculating

```
    dra_propdel_mt (OP_SIM_CONTEXT_ARG_OPT_COMMA Packet *
    pkptr)
{
    double    start_prop_delay, end_prop_delay;
    double    start_prop_distance, end_prop_distance;
    double    start_prop_VELOCITY, start_prop_velocity;
  /** Compute the propagation delay separating the    **/
  /** radio transmitter from the radio receiver.**/
    FIN_MT (dra_propdel (pkptr));
  /* Get the start distance between transmitter and receiver. */
    start_prop_distance = op_td_get_dbl (pkptr,
    OPC_TDA_RA_START_DIST);
  /* Get the end distance between transmitter and receiver. */
    end_prop_distance = op_td_get_dbl (pkptr,
    OPC_TDA_RA_END_DIST);
  /* Compute mobile speed to start of reception. */
    start_prop_velocity = start_prop_distance / start_prop_delay;
  /* Compute mobile speed to end of reception. */
    end_prop_velocity = end_prop_distance / end_prop_delay;
  /* Place both mobile speeds in packet transmission data attributes. */
    op_td_set_dbl (pkptr, OPC_TDA_RA_START_PROPDEL,
    start_prop_velocity);
    op_td_set_dbl (pkptr, OPC_TDA_RA_END_PROPDEL,
```

```
            end_prop_velocity);
22:         FOUT }
```

In this code, the mobile speed is calculated by defining the distance and the time of transmission of the mobile to the femtocell base station. The calculated mobile ground speed *"end_prop_velocity"* is attached to the attributes of the transmitted packets. This is processed by the *"call_admission"* state in order to decide upon accepting handover requests.

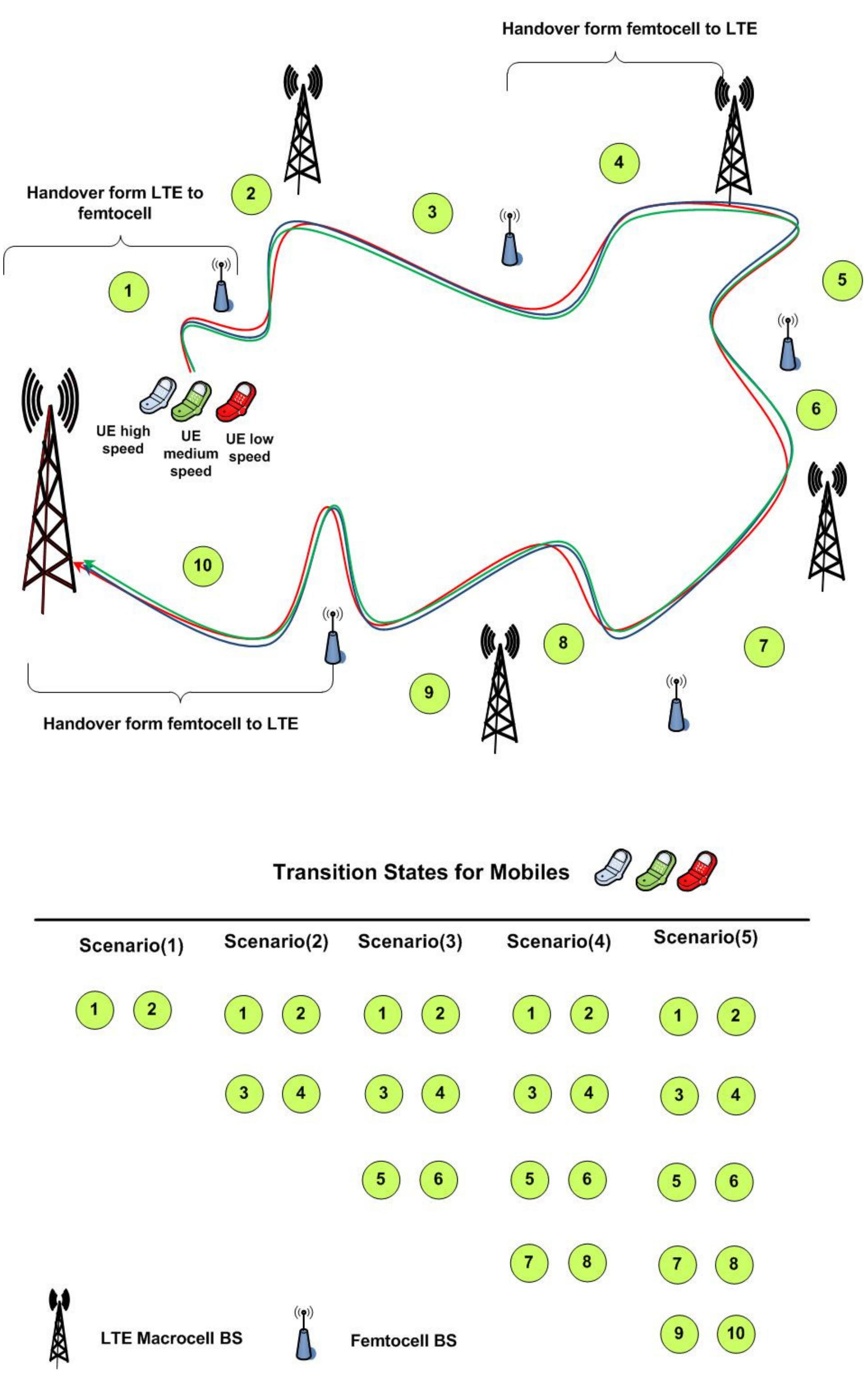
5.9 System Configuration

In this section, the simulation and results of system evaluations are presented in order to reinforce the advantages of the proposed CAC scheme using the Markov model. The performance of the new proposed system is evaluated and results obtained from several different scenarios are discussed.

Performance of the proposed system is compared with the traditional scheme to approve the validation of the proposed CAC solution. The traditional solution employs an advanced admission control model that uses the default processing for handover requests at low and medium speeds [27, 28]. The following case studies describe the handover scenarios implemented in the OPNET17.1 modular. The aim of these five case studies is to evaluate the different approaches and technologies that can be used to reduce the numbers of handovers for mobile phones travelling between LTE and Femtocell transmission domains. The simulation parameters setting are presented in Table 5.1.

Table 5.1 Simulation parameters for handover project

Parameters Value	Parameters Value
LTE transmit power	40dBm
Femto transmit power	20dBm
Number of LTE	5
Number of femtocell	5
Number of UE	2



Transition States for Mobiles

Scenario(1)	Scenario(2)	Scenario(3)	Scenario(4)	Scenario(5)
1 2	1 2	1 2	1 2	1 2
	3 4	3 4	3 4	3 4
		5 6	5 6	5 6
			7 8	7 8
				9 10

Figure 5.19: Simulation scenarios for the proposed handover mechanism

Mobile users handover request are set to arrive according to Poisson process. The angle of UE movement is generated randomly and the position is used to update the UE speed according to algorithm 5.1. The connection time of a UE in the femtocell domain is calculated from the velocity and the movement direction.

Five scenarios were designed to examine the performance of a UE moves between LTE and femtocell domains each 120 seconds. Figure 5.19 shows the network topology of different scenarios that are used to validate the system handover mechanism. The network topology contains five LTE BS and five femtocell BSs and one mobile user. The user is moving at two different speeds of Low 5Km/h and Medium 20Km/h. The user will all follow the same trajectory of movement between the various LTE and femtocell domains at different speeds.

In order to evaluate the proposed CAC mode, five scenarios were developed to allow specific numbers of handovers. In each scenario, the case study involves four mobile speed comparisons: two for the proposed CAC model and the other two using the traditional handover scheme. These case studies show the performance of the system using the two speeds of low and medium as discussed earlier. The OPNET project model for scenario one is shown in Figure 5.20.

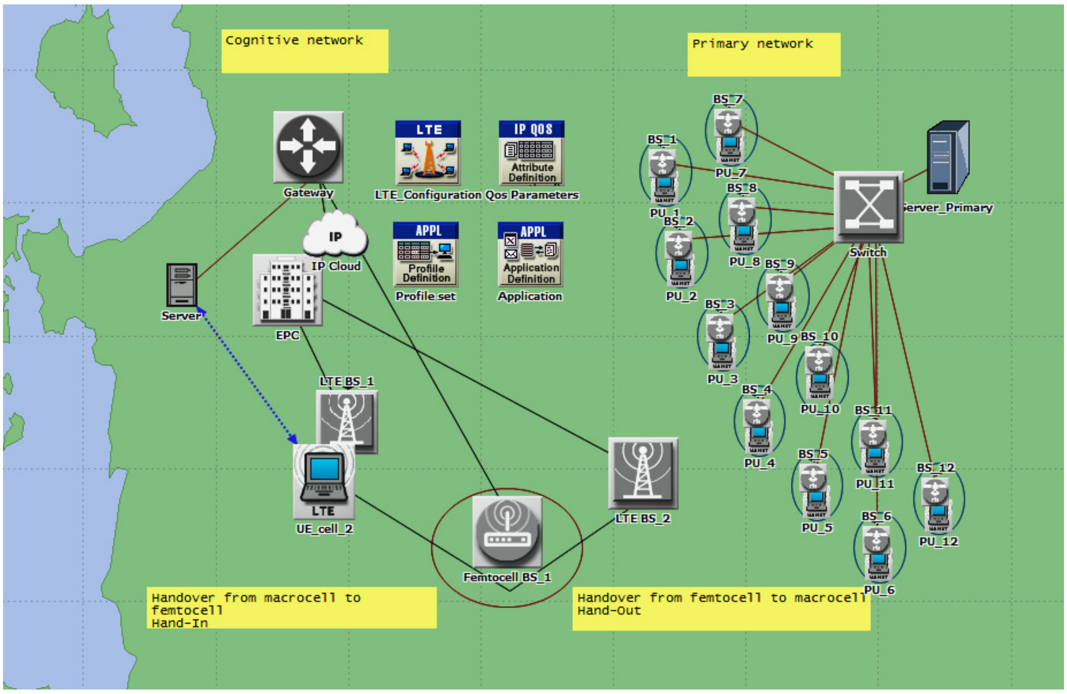


Figure 5.20: Scenario (1) for handover LTE-femtocell in OPNET17.1

5.9.1 Simulation Results

Simulations were conducted to validate the proposed handover scheme against the default traditional handover model.

Retransmission attempts are a traditional mechanism for detecting the congestion in the network; it can be compared to the packet loss indicator. The simulation results of the retransmission rate are given in Figure 5.21 in pkts/sec. The figure shows the number of handovers from macrocell to femtocell and femtocell to macrocell for the different scenarios. The proposed scheme shows a significant reduction in the numbers of re-transmitted packets as a function for the numbers of occurred handovers. This proves that the proposed CAC has eliminated many unnecessary handovers subject to the assigned threshold for speed determination.

The best results were obtained with the low mobile speed that is connected to base stations equipped with the proposed CAC than the medium speed. While higher numbers of packets available to retransmit are observed with the traditional scheme as there are too many packets to retransmit.

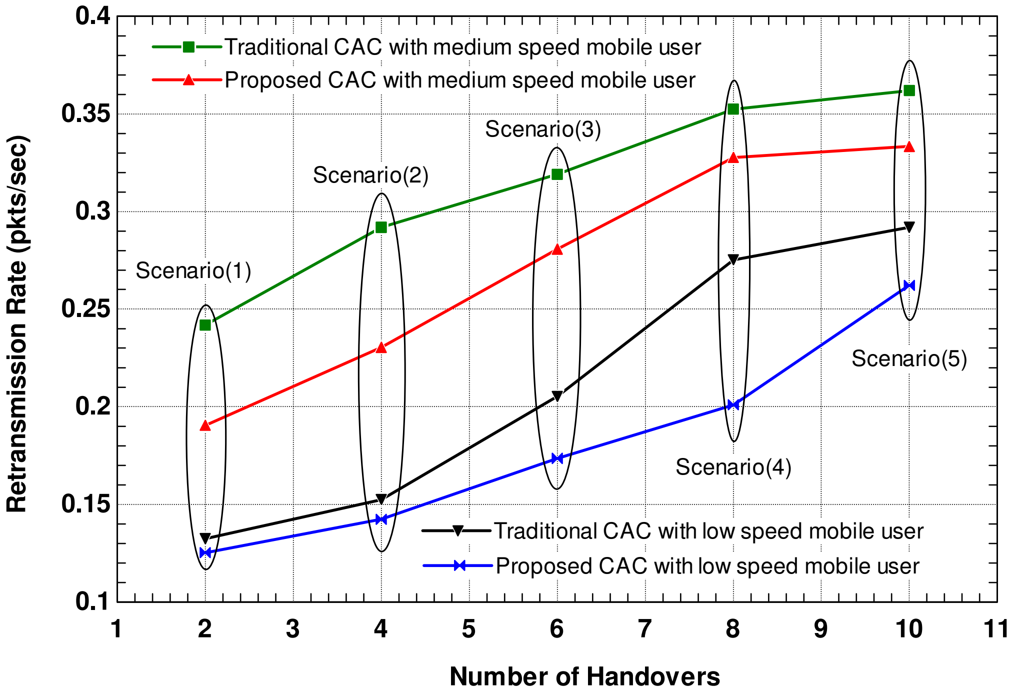


Figure 5.21: Retransmission rate vs number of handover

Figure 5.22 shows the handover latency/delay curves for successful handovers of the five simulated scenarios and two call admission case studies. The handover latency is the time consumed from the instant when the handover decision is made by the target BS to the instant when the UE terminates connection with its serving BS to launch the handover process.

This simulation part study the handover latency comparison of the different scenarios and combinations of them provides the basis for seamless handover within the LTE-femtocell network. The advantage for the implementation of the proposed mobility management scheme in the project's field trial is to speed up the handover latency and provide uninterrupted services for roaming users. Now, taking the figure into account that depicts the results of the handover latency scenarios, the proposed CAC with low mobile speed that has been taken the lowest part of the retransmission rate overhead, now is accomplished in advance when mobile user initially connects to the BS. This means that proposed CAC implementation features decrease the handover overall awaiting delay for a network with heterogonous design of BSs. Summarising the entire procedure shows that the proposed scheme depicts the best performances compared to traditional handover schemes.

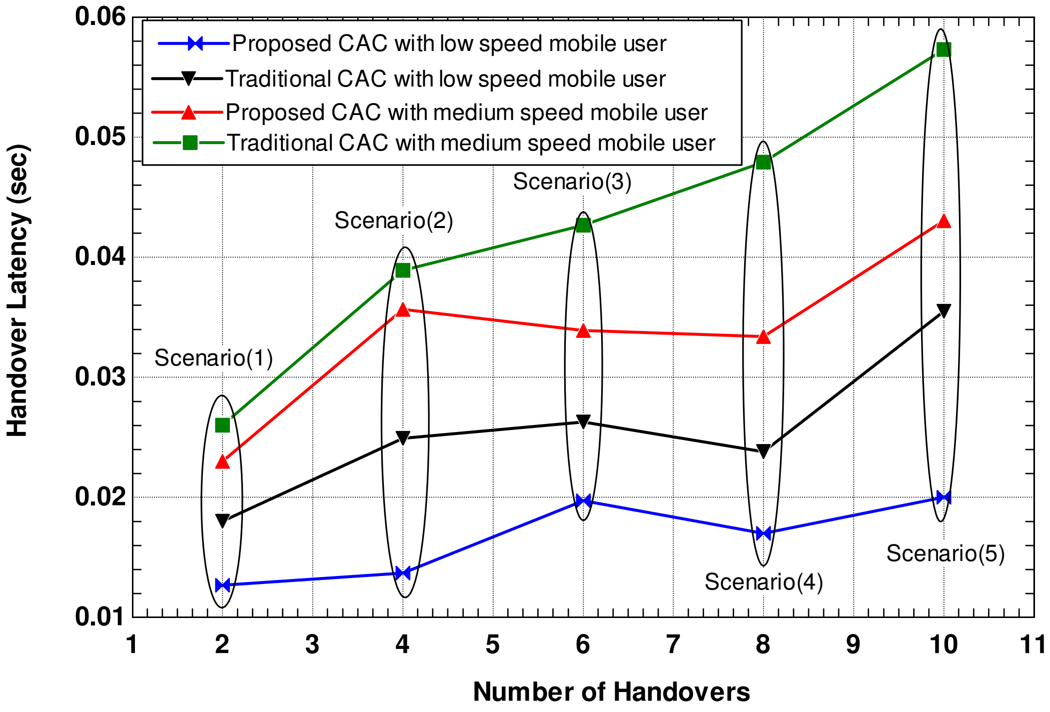


Figure 5.22: Latency of successful handovers

Figure 5.23 shows the throughput graphs for all the simulated scenarios as a function of the connection time. The figure depicts that there is a considerable increase in the throughput with the new scheme of CAC with the highest values with the low speed, followed by the medium speed. The traditional scheme results come at the late with the lowest throughput values. This proves that the new CAC scheme performs handovers with shorter time processing enabling the mobile user to start transmission earlier and then exchange more data compared to the traditional handover models. The same performance can be seen for different scenarios that employ the same network architecture with different numbers of handovers at longer trajectories.

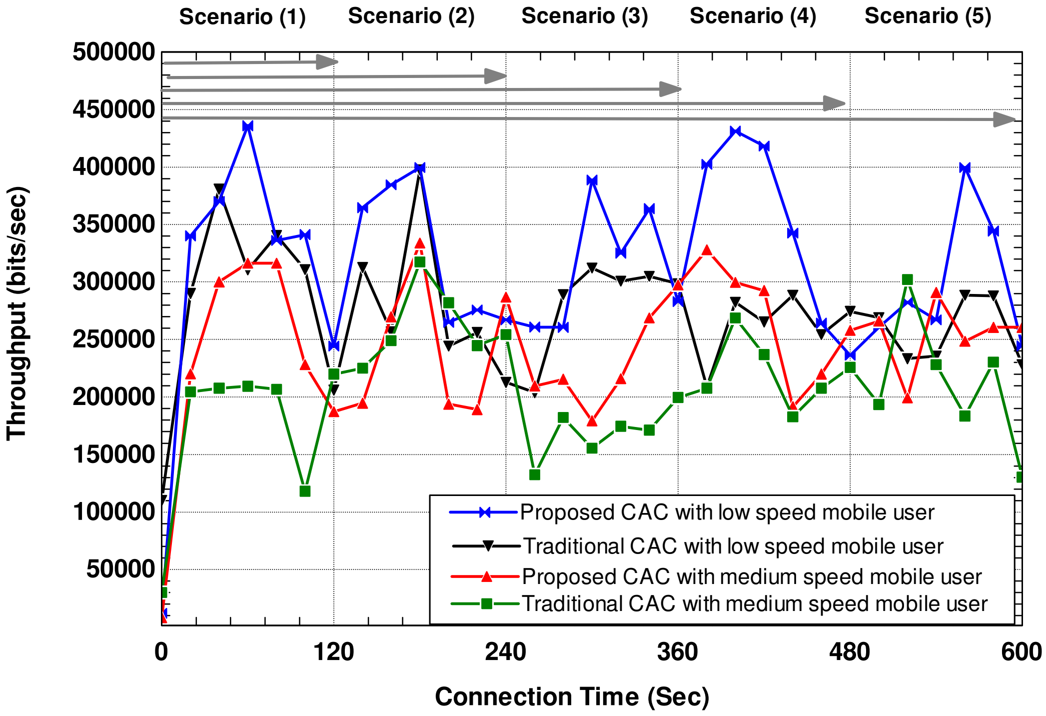


Figure 5.23: Throughput graphs for simulated scenarios

The main intension for introducing the new CAC scheme is to allow efficient resource allocation in a heterogeneous network that is composed of various numbers of LTE and femtocell BSs. The previous simulation results have proved the novelty of the given solution at the femtocell level. In order to investigate the given solution performance at the LTE level, the allocation of connection to the mobile user is studied to show the difference between various mobile speeds alterations. In this field, the LTE dedicated bearers carry traffic for IP flows that have been identified to require a specific packet forwarding treatment. Such dedicated bearer can be either GBR (Guaranteed Bit Rate) or non-GBR, where non-GBR bearers can suffer packet loss under congestion while GBR bearers are immune to such losses. These bearers are normally subject to admission control within the network. Therefore, the highest numbers of the admitted GBR can show clearly the time where a certain user application is the most connected to the LTE BS. This is shown in Figure 5.24 that shows the total number of admitted Guaranteed Bit Rate (GBR) bearers with the connection time. The figure shows that a mobile user with high speed has the highest GBR values followed by the mobile users with medium and low speeds respectively. This is due to the fact that the mobile users with low and medium speeds are connected to the femtocell BSs for the most of the time of the simulation in contrast to the high speed user that is always declined admission to femtocells connections and had to remain connected to the LTE BSs.

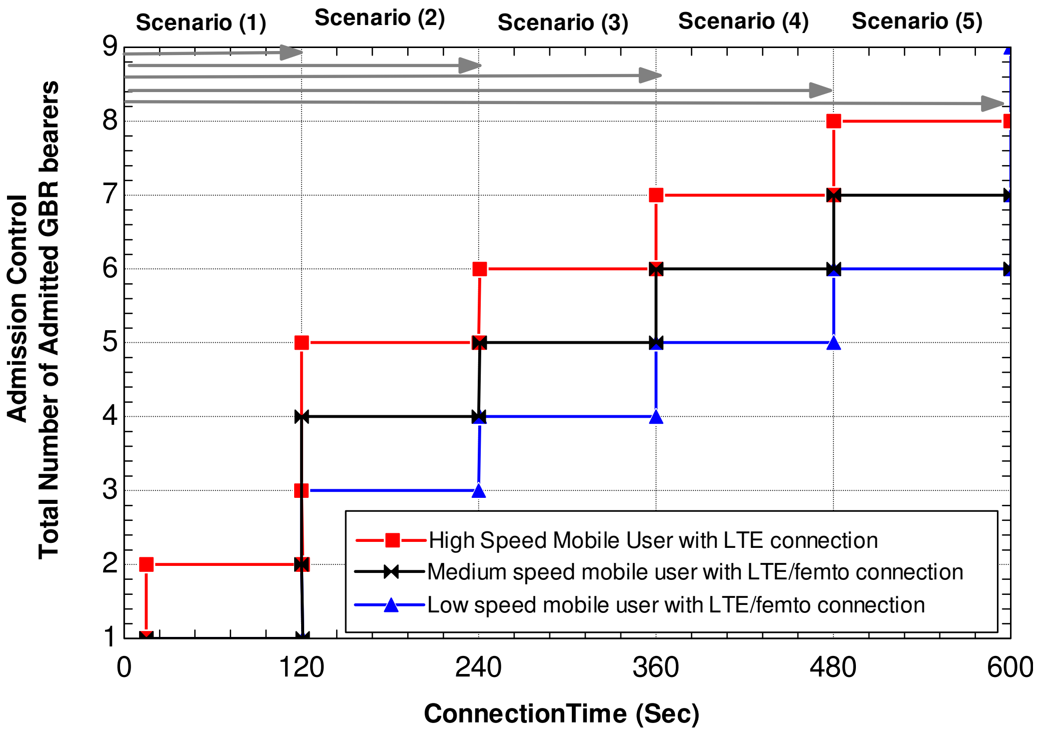


Figure 5.24: Total number of admitted GBR bearers with access time

In summary, the simulation results show clearly that the effectiveness of the proposed CAC algorithm for handover management increases the system performance significantly. That is achievable by reducing unnecessary handover in femtocell cognitive networks that is help to manage the network resources efficiently between femtocells and macrocells BSs. The comparison with the traditional scheme shows that the algorithm proposed in this chapter have a better performance in the rate of unnecessary handovers and the average number of handovers, especially in Medium and low mobile speed, for a small penalty of signaling overhead.

5.10 Conclusion

This chapter presents a novel handover management scheme for cognitive networks that employ two-tiers of LTE and femtocell BSs. The proposed handover selection mechanism allows femtocells to choose to connect to low and medium mobile speeds in order to attain better resource management. This is due to the fact that high speed mobile users stay only for short time within femtocell small range domains. In this way, new algorithms were developed at the network layer to set the thresholds for either admit/reject handovers requests from mobile users with different speeds. A new modification has been developed to allow calculating the ground speed of mobile users and attach it to the packets attributes to enable the functioning of the proposed CAC. The performance of the proposed scheme has been evaluated and the results show major improvements in the system performance for the LTE-femtocell network compared to the traditional handover schemes. The proposed model for handover is a promising solution for applications that employ cognitive femtocell as part of their architecture in future open access networks.

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Chapter 6

Conclusions and Future Work

The on-going increasing demand for wireless based services nowadays makes it necessary to define new policies and standards in order to manage the available radio resource. These should be applied in a way that makes the wireless environment matching this high evolution in wireless devices and technology.

The overall goal of this thesis was to design and implement a novel cognitive LTE-femtocell system that solves the drawback of spectrum resource allocation in cognitive networks. The given solutions allow low power consumption and higher capacity for the 4G networks. Upon proposing different methodologies in this thesis along with the performance evaluations of those approaches, it is strongly felt that there is a scope for further potential developments related to the work done. The difference between this thesis proposal and other literature is that most of the other researches relay on one-layer approaches. In this field, some techniques focus on spectrum sensing or dynamic spectrum access, whereas this thesis proposes an optimised system that involves a cooperative scheme between PHY, MAC, and NET layers. As a result, incorporating cognitive radio and femtocell systems has fulfilled the research aims. Apart of this proposed work done in this thesis, there are some other research issues and related avenues that need to be explored based on the current research. Therefore, this chapter consists of two parts; a summary of research done in each chapter and the possible future work related to the contributions of each chapter in order to make further extensions and potential approaches for further improvements.

6.1 Conclusions

The key outcomes that can be concluded from the solutions addressed throughout this thesis are as following:

In Chapter 3, fundamental properties and current research challenges of spectrum resource management in cognitive femtocell networks were presented in details. In particular, this part has investigated novel spectrum management techniques such as spectrum decision, spectrum access, and spectrum sensing by proposing novel effective algorithms and network functionalities modifications.

Firstly, the problem of spectrum resource allocation is analysed for emerging networks based CR systems. Secondly, a probabilistic analysis is conducted for contiguous free channels in the dynamic spectrum network to set requirements for the profiles of DSA simulations. The critical entities that are able to deal with new challenging problem of how to make decisions on spectrum access were developed and computationally integrated in order to access free channels on distributed basis. Therefore, the particular distribution of the total number of free channels available is important to assure faire access to different nodes in the studied network infrastructure.

Each of these spectrum management functions relies on cooperative operations where cognitive femtocell subscriber can determine their actions based on exchanging information and negotiations with other femtocells. This chapter has also presented a priority queuing policy for spectrum utilisation. The framework was developed to assign different traffic profiles to the available transmission opportunities by determining the BER and time delays of each application request.

The work presented in this task shows an efficient model for dynamic reconfigurable access to the spectrum provided by a competent decision making that significantly improve allocation of resources in cognitive radio systems. This model of instantly accessing short transmission intervals by considering the traffic type raises a novel approach to allow advanced management of the newly deployed small transmission domain stations of femtocells in LTE networks. This results in higher deliverable of transmitted data and better usage of the scares recourses available to multi-tier cognitive networks.

The thesis work also studied the self-organisation coverage of cognitive femtocell BSs in Chapter 4. The focus was to develop new algorithm for adaptive pilot power control scheme based on mobile user position in order to improve the network energy efficiency. Also, this chapter has investigated potential energy savings gained from deploying femtocells along with LTE base stations in the mobile network system by proposing a developed power consumption model. Numerical analysis offers an insight of the resulting network performance when utilising power management. The different pilot power control techniques of the LTE-femtocell system is simulated in a cooperative spectrum access network. Performance evaluation results show that the proposed algorithm uses the position of an active femtocell UE to control the pilot power which results in a significant reduction of the power consumption compared with fixed pilot power schemes. This new model of adjusting the transmission domain allows reducing the transmitted power of femtocells or any other base stations that employ such technique. This leads to more power efficiency in the future networks and reduce the probability of interference. Such an application will be a promising approach for the mobile green networks in the intension of saving energy in combination with other methods that can be used for the same purpose.

In Chapter 5, a novel call admission control model was proposed for mobility management in two-tier network that employ femtocell and LTE BSs. The dissimilar spectrum availability and multi-cell/sub-cell LTE networks require a novel mobility management framework to reduce unnecessary handovers for mobile users. The solution involves a novel call admission control scheme based on a Markova chain dynamic channel policy that prioritises handover requests over new call requests. With this Markova chain method, this system was able to decrease the numbers of handover and call dropping probability while increasing the call blocking probability.

The proposed solution involves femtocells approving call admissions from mobile users at low and medium speeds while assigning higher speed mobile phones to the LTE BSs. This helps to reduce the unnecessary and redundant handovers for mobile users moving between LTE and femtocell domains. However, the scheme attempts to make adjustment between the benefits of decreasing both the handover failure ratio and the unnecessary handover ratio. Simulation results show that the proposed method improves the overall cell capacity and minimising QoS degradation.

As a result, an efficient investigation and monitoring of the mobile user speed can improve the recourse allocation and lead to a novel service delivery in heterogeneous networks. This solution is vital for multi-tiered networks where various mobile users travel between different domains and at different speeds. Therefore, precise prediction of the mobile users transitions allow to allocate the suitable channels to the right users and minimise the interruption time while performing handovers.

Cellular communication design that covers the above issues was developed based on the method of network listening and cognitive radio configuration. These allow new opportunities for transmissions and better investment of the available recourses in coexistence of heterogeneous networks. Future mobile networks are supposed to be more software dependent and the optimisation algorithms can be easily applied to hardware equipment, which offers strong radio configurability for radio spectrum management.

6.2 Future Work

There are some other research issues and related avenues that need to be explored based on the current work. Therefore, this section provides some possible future work that can be related to the contributions of each chapter in order to make further future extensions. The following are the proposed work that will be pursued for completion of this Ph.D. thesis.

6.2.1 Adaptive Spectrum Sensing

Realising an efficient spectrum sensing is a critical factor in order to identify unoccupied channels that can be utilised by the cognitive radio. The spectrum sensor makes a series of measurements and then computes these measurements to determine if the channel is free or not. Chapter 3 proposed some analysis of spectrum occupancy as well as the quality of free channels with respect to its adjoining neighbours but there is a need to expand this work to exploit other new methods of spectrum sensing and sensing controlling schemes.

6.2.2 Capacity Improvements in LTE with Power Control

In chapter 4, a novel adaptive a power control procedure is assumed to reduce the power for a transmission in such a way, that another flow can initiate in the same time space. Hence, adaptive adjustment of transmission power has the potential to reduce the overall power consumption in wireless stations. Ideally, a transmitter should be configured to use the highest transmission rate and the lowest possible transmission power. For future work, as there is more than one client sharing a radio medium, this reduces the capacity that a channel can provides to any of its users. Two approaches can be used to improve the channel capacity in cognitive radio networks: spatial reuse through power control and use of multiple channels.

6.2.3 Adaptive Coverage and Handover

The network overhead arising from handover between LTE and femtocell base stations is a serious challenge for any practical deployments of large numbers of femtocells. One method of minimising frequent handover events is to enable femtocells to dynamically adapt their coverage radius depending on their channel band conditions, and numbers of users served by each femtocell. The problem of determining the optimal femtocell coverage radius as a function of the available excess backhaul bandwidth, the time-varying channel strength and cellular user mobility is an open area for further research.

6.2.4 Controlling Radio Interference in OFDM Femtocell

The deployment of femtocells is combined by the major challenge of controlling the interference from femtocell onto the LTE macrocell coverage area. Therefore, a novel interference control method is needed as the macrocell and femtocell links adaptively allocate their power across the same sub-bands jointly. This can be achieved by effectively coordinating the transmission zones in the tier BSs and allow transmissions at the no-adjacent channels to reduce any interference in the future networks.

Appendix A

Channel Negotiation in Cognitive Radio Network

The direct impact of dynamic adaptations made by the cognitive procedure to the cognitive radio itself and other radios can be avoided by prior agreement with other radios on specifications and parameters to reach a successful communication link through a process of negotiations. Meanwhile, any changes in protocol layers above the physical layer initiate influence on other nodes in the network. Therefore, cognitive radio negotiation process should be expanded to include all nodes that may be impacted by the change. Cognitive networks are supportive in nature, since the performance is referenced to the end-to-end objectives and nodes within a single cognitive element must cooperate to approve decisions that are based on negotiations to manage the route of the transmitted data.

The cognitive radios use control schemes to obtain information about the un-occupied licensed channels and to negotiate channels availability with other cognitive users through the contention based algorithms, such as IEEE 802.11 distributed coordination function (DCF) [26] and Carrier Sense Multiple Access (CSMA) [27] protocols. The negotiating phase involves exchanging the Request-to-Send (RTS) and Clear-to-Send (CTS) packets over the control channel.

The pseudo code for the MAC protocol that allow secondary users to negotiate the channels availability is given in below, where $No_{free_{ch}}$is the number of identified free channels; $Pro_{free_ch}$is the profile of identified free channels [29].

The cognitive radio transmits a packet to negotiate with other nodes if there are any available free channels on regular basis. Once a channel is identified, the transmission profile is updated by the adding this new channel to the list of the available free channels. Then, the updated profile is used to map the channels allocation between different nodes and the formulation of any links between different bases stations in the field. Probably, a channel is allocated to certain application when the bandwidth of that channel matches the QoS and transmission requirements.

Algorithm: Negotiation Code for CR [29]

```
Initially: $No_{free\_ch}$:= 0, $Pro_{free\_ch}$:= Ø, send notification:= 0
Reporting phase:
For Control transceiver:
Listens on the control channel
Upon receiving a beacon at k-th mini-slot
$No_{free\_ch}$ := $No_{free\_ch}$ + 1 //Update number of un-used chs.
$Pro_{free\_ch}$($No_{free\_ch}$) := k //Update list of un-used chs.
Upon Informed by SDR that j-th channel is idle
Send a beacon at j-th mini-slot
$No_{free\_ch}$ := $No_{free\_ch}$ + 1 //Update number of un-used chs.
$Pro_{free\_ch}$ ($No_{free_{ch}}$):= k //Update list of un-used chs.
For SDR transceiver:
Senses channel j which is decided by the sensing policy.
if channel j is idle
Notify Control transceiver that j-th channel is idle
Negotiating phase:
For Control transceiver:
Upon receiving RTS
Update the channel it will sense according to sensing strategy
send CTS to source node
Upon receiving CTS
Update the channel it will sense according to sensing policy
if destination address is myself //negotiation is succeeded
Set send notification:= 1 at the end of this phase
if the outgoing queue is not empty
Contend to send RTS to the destination node
For SDR transceiver:
if send notification = 1
send notification:= 0
Transmit the data packets over all the channels in $Pro_{free\_ch}$
```