STUDIES ON RESOURCE ALLOCATION TECHNIQUES TO MITIGATE INTERFERENCE IN MACRO-FEMTO CELLULAR NETWORKS

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CERTIFICATE

Certified that this thesis entitled **"STUDIES ON RESOURCE ALLOCATION TECHNIQUES TO MITIGATE INTERFERENCE IN MACRO-FEMTO CELLULAR NETWROKS**" submitted for the award of the degree of **DOCTOR OF PHILOSOPHY** in **ELECTRONICS AND COMMUNICATION ENGINEERING** of the Pondicherry University, Puducherry is a record of original research work done by **Mr.V.M.S.N. PAVAN KUMAR CH.,** during the period of study under my supervision. Further certified that to the best of my knowledge the work reported herein does not form part of any other thesis or dissertation on the basis of which a degree or award was conferred on an earlier occasion of this to any other candidate.

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DECLARATION

I hereby declare that the thesis titled **"STUDIES ON RESOURCE ALLOCATION TECHNIQUES TO MITIGATE INTERFERENCE IN MACRO-FEMTO CELLULAR NETWROKS"** submitted to the Pondicherry University in fulfillment of the requirements for the award of the degree of **DOCTOR OF PHILOSOPHY** in **DEPARTMENT OF ELECTRONICS AND COMMUNICATION ENGINEERING** is a record of the original research work done by me under the supervision of **Dr.S.TAMILSELVAN**, Associate Professor, Pondicherry Engineering College, Puducherry and that the work has not been submitted either in whole or in part for any other degree or at any other university.

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ABSTRACT

Cellular communication has witnessed tremendous growth during the past couple of decades. It plays an inevitable role in day-to-day life and in modernizing the human society. Throughout the evolution of cellular networks, many standards have come into existence, with the intention of meeting the growing need of ubiquitous, greater quality voice, data and multimedia services. Besides, next generation cellular networks are in the necessity to offer seamless services even at the cell-edges and indoor provinces where the requirement for the cellular services is never the less. Though there is a growing demand for higher data rate services everyday, the conventional macrocell is unable to provide better coverage extension to cell-edge users. To handle indoor and outdoor traffic growth, the recent heterogeneous network has emerged with an answer in the form of smallcell technology.

The large macrocell coverage is divided into many smallcells, there by bringing the base stations closer to the users. Deployment of many low power smallcells offer higher throughput to indoor network users and offload the voice and data traffics of macrocell network. Among the smallcell family, femtocell network has gained significant importance towards future cellular networks. Eventually, most of the industry and research people concentrate in shaping the next generation heterogeneous network with femtocell technology. An investigation on femtocell technology reveals that the technology has got some challenges to be addressed. In practice, improper access mode selection, random and dense deployment of femtocells and seamless mobility of macrouser has led to serious challenges like interference, backhaul bottleneck and handoff mechanisms respectively. This research work focuses on avoiding co-channel interference, which is a serious issue in coexisting macro-femtocell networks through efficient resource allocation methods.

The first part of the research deals with Inter-Cell Interference Coordination (ICIC) technique called as Efficient Frequency Reuse (EFR) technique to reduce the interference among co-channel femtocells. This technique consists of two algorithms namely primary subchannel allocation algorithm and interference known

resource allocation algorithm. In the proposed EFR Scheme, the available subchannels are divided into primary and secondary subchannels (PSCs and SSCs) with different power levels. PSCs are orthogonal to each other, the interference can be reduced by assigning the PSCs to the users located in the cell edge and SSCs to the users located in cell center regions. Allocation of subchannels can be done based on the neighbor table construction, interference graph and conflict resolution. After subchannel allocation, resources can be allocated based on the interference known resource allocation algorithm. Results prove that the presented EFR technique is giving greater performance over the conventional frequency reuse techniques like Fractional Frequency Reuse (FFR) and Soft Frequency Reuse (SFR) in terms of Spectrum Efficiency, Network Interference, Spectrum Utilization, Fairness Index, Number of iterations, Throughput, and Outage Probability.

With the intention of avoiding the cross-tier co-channel interference, the second part of the research work proposes a Paraunitary Filter Bank (PUFB) based Spectrum Sensing (SS) algorithm to sense the subchannels on Orthogonal Frequency Division Multiple Access (OFDMA) based macro user signal. The PUFB algorithm senses the idleness of the subchannel present in the Macro Base Station (MBS) range by matching up the energy level of the signal received with the threshold value of the Received Signal Strength (RSS). The performance of the proposed PUFB based spectrum sensing method is carried out for different multipath fading channels and compared with conventional Energy Detection (ED) technique. The Receiver Operating Characteristics (ROC) curve is considered for judging the entire detection process. The results show that PUFB method has better detection capabilities than ED method. To reduce the co-channel interference in the cross-tier macro-femto cellular networks, this spectrum sensing technique is employed in the Femtocell Access Points (FAPs), to sense the idle macro subchannels for assigning to the femto users. The results were analyzed for all the three access modes of femtocells called open, closed and hybrid access in terms of throughput of FUs, Interference factor of MUs and Macro and femto sum throughput of the network. Hybrid access mode provides optimal results in terms of throughput for both macro as well as femto users.

So as to provide incentive mechanism for both macro and femtocells in the hybrid access cognitive femtocell networks with perfect spectrum sensing, a price bargaining based resource allocation technique has been proposed in the third part of the research work. In this research technique, ensuring the performance of the Macro Users (MUs), the MBS reserves a part of spectrum, and with the aim of enhancing the performances of the Femto Users (FUs), the Femto Access Point (FAP) gets numerous spectrum resources. In the presented technique, so as to spur the FAP for serving the cell-edge MUs, the MBS allots a part of subchannels to the FAP. The negotiation process between the macro and femto base station is modeled as a price bargaining game and corresponding resource allocation among FAPs was formulated as the Stackelberg game to produce the best possible solution. From the simulation outcomes, it is proved that the MBS as well as the FBS could gain in terms of network utility and throughput.

The last part of the research work focused on an incentive mechanism for both macro and femtocells in the hybrid access cognitive femtocell networks with practical spectrum sensing. In which the network service provider and the femtocell both will get the benefits in terms of network utility and throughput. This problem for cognitive femtocells was modeled as a joint problem of sub-channel as well as power allocation, considering sub-channel assignment fairness, less user data rate need, imperfect spectrum sensing and interference limits of cross-tier and co-tier users. From the simulation outcomes, it is proved that the presented technique does well when compared to the previous methods in regard to cognitive femtocell capacity as well as sub-channel reuse effectiveness.

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V.M.S.N. PAVAN KUMAR CH.

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LIST OF ABBREVIATIONS

AFR	-	Adaptive Frequency Reuse
AWGN	-	Additive White Gaussian Noise
BER	-	Bit Error Rate
BPF	-	Band Pass Filter
BS	-	Base Station
CAGR	-	Compound Annual Growth Rate
CAPEX	-	Capital Expenditure
CCI	-	Co-Channel Interference
CCU	-	Cell-Centre User
CDF	-	Cumulative Distribution Function
CDMA	-	Code Division Multiple Access
CEU	-	Cell Edge User
CMFB	-	Cosine-Modulated Filter Bank
CR	-	Cognitive Radio
CSI	-	Channel State Information
CTCCI	-	Co-tier Co-channel Interference
DFR	-	Dynamic Frequency Reuse
DL	-	Downlink
DoS	-	Denial of Service
DRAMA	-	Dynamic Resource Allocation Management Algorithm
DSA	-	Dynamic Spectrum Allocation
DSL	-	Digital Subscriber line
DSP	-	Digital Signal Processing
DTV	-	Digital Television
ED	-	Energy Detection
EFR	-	Efficient Frequency Reuse
ENP	-	Estimated Noise Power
EPC	-	Evolved Packet Core
1G	-	First Generation
5G	-	Fifth Generation

FAP	-	Femtocell Access Point
FBS	-	Femtocell Base Station
FBSE	-	Filter Bank Spectrum Estimation
FC	-	Femtocell
FC_ID	-	Femtocell Identity
FFR	-	Fractional Frequency Reuse
FFT	-	Fast Fourier transform
FI	-	Fairness Index
FMOS	-	Femtocell and Macrocell Overlaid System
FMS	-	Femtocell Management System
FU	-	Femtocell User
FUE	-	Femto User Equipment
4G	-	Fourth Generation
GPS	-	Global Positioning System
GSM	-	Global System for Mobile
HeNB	-	Home e Node B
HNB	-	Home Node B
IA	-	Interference Avoidance
ICI	-	Inter-Carrier Interference
ICIC	-	Inter Channel Interference Coordination
ID	-	Identification
IEEE	-	Institute for Electrical and Electronics Engineers
IKRA	-	Interference Known Resource Allocation
IM	-	Interference Mitigation
IP	-	Internet Protocol
ISI	-	Inter Symbol Interference
ISM	-	Industrial Scientific and Medical Research
KKT	-	Karush–Kuhn–Tucker
LoS	-	Line of Sight
LPNs	-	Low Power Nodes
LTE	-	Long Term Evolution
LTE-A	-	LTE-Advanced
MBS	-	Macrocell Base Station

MC	-	Macrocell
MED	-	Multiple Energy Detectors
MF	-	Matched Filter
MIMO	-	Multiple Input Multiple Output
MMSE	-	Minimum Mean Square Error
MOOP	-	Multi Objective Optimization
MU	-	Macrocell User
MUE	-	Macro User Equipment
OAM	-	Operation, Administration and Maintenance Server
OFDM	-	Orthogonal Frequency Division Multiplexing
OFDMA	-	Orthogonal Frequency Division Multiple Access
OPEX	-	Operational Expenditure
PBG	-	Price Bargaining Game
PC	-	Power Control
PFR	-	Partial Frequency Reuse
PIC	-	Parallel Interference Cancellation
PPP	-	Poisson Point Process
PR	-	Perfect Reconstruction
PRB	-	Physical Resource Block
PSCs	-	Primary Sub Channels
PSC-SC	-	PSC Self-Configuration
PSO	-	Particle Swarm Optimization
PU	-	Primary User
PUFB	-	Para Unitary Filter Bank
PUFBMC	-	Paraunitary Filter Bank Multi Carrier
QAM	-	Quadrature Amplitude Modulation
QMF	-	Quadrature Mirror Filter
QoS	-	Quality of Service
RA	-	Resource Allocation
RB	-	Resource Block
ROC	-	Receiver Operating Characteristics
RSS	-	Received Signal Strength
2G	-	Second Generation

SCA	-	Sub Channel Allocation
SFFR	-	Soft Fractional Frequency Reuse
SINR	-	Signal-to-Interference-plus-Noise Ratio
SNR	-	Signal-to-Noise Ratio
SS	-	Spectrum Sensing
SSCs	-	Secondary SCs
SU	-	Secondary User
3G	-	Third Generation
3GPP	-	Third Generation Partnership Project
TDM	-	Time-Division Multiplexing
UFR	-	Universal Frequency Reuse
UL	-	Uplink
UMTS	-	Universal Mobile Telecommunication System
VoIP	-	Voice over Internet Protocol
Wi-Fi	-	Wireless Fidelity
WiMAX	-	Wireless Interoperability for Microwave Access
XTCCI	-	Cross-tier Co-Channel Interference

LIST OF SYMBOLS

λ_n	-	Achievable rate
w(t)	-	Additive white Gaussian noise
$\alpha(\leq 1)$	-	Adjusted factor
p_k^j	-	Allocated power on subchannel k
$H_0(z)$ and $H_1(z)$	-	Analysis filters
$\rho_{m,k}^i$	-	An indicator variable
$g_{m,k}^{(i,i)}$	-	Channel gain on subchannel k
h	-	Channel impulse
$\eta_{m,k}^i$	-	Channel Quality Indicator for each subchannel
$\downarrow N$	-	Decimation by a factor N
d_i	-	Degree of femtocell i
$x(n)$	-	Digital signal
$S_2[n]$ and $S_3[n]$	-	Filtered signals
$\lfloor k \rfloor$	-	Floor value of K
$H_1(z)$, if $H_0(z)$	-	Good high pass filter
$\rho_{m,k}^{(i)}$	-	Indicator variable
$I_{m,k}^{F(i)}$	-	Interference from femtocell
$I_{m,k}^{M(i)}$	-	Interference from macrocell
c_i	-	Interference price
$\uparrow$N	-	Interpolation by a factor N
S	-	Lognormal shadowing factor
$H_0(z)$	-	Low pass analysis filter
$G_i\lfloor . \rfloor$	-	Maximum clique
c_i	-	Maximum clique number
$\lvert H_0(e^{jw})\rvert$ and $\lvert H_1(e^{jw})\rvert$	-	Mirror images of Filter bank
H_0 and H_1	-	Noise-only and signal-plus-noise hypotheses
$\emptyset$		Null set
ω	-	Number of floors
N_i	-	Number of neighboring femtocells

$E(z)$	-	Paraunitary
α	-	Pathloss compensation factor
P_{ssc}	-	Power mask
P_{PSC}^{i}		Power mask on primary subchannels
P_{SSC}^{i}	-	Power mask on secondary subchannels
$R_{i,j}$	-	Practicable rate
λ	-	Predefined threshold
θ	-	Predefined threshold power level
P_{md}	-	Probability of misdetection
k_i	-	Primary subchannels assigned to each FAP
P_d	-	Probability of detection
P_f	-	Probability of False alarm
π/2	-	Quadrature frequency
$y(t)$	-	Received signal
$\widehat{X(n)}$	-	Reconstructed signal
R_m^i	-	Resulted rate
f_s	-	Sampling Frequency
F_i	-	Set of active users
N_i	-	Set of neighboring
A_{PSC}^{i}	-	Set of primary subchannels
A_{SSC}^{i}	-	Set of secondary subchannels
$U_0\ [n]$ and $U_1\ [n]$	-	Sub band signals
k_i	-	Target number
P_0	-	Target received signal power
$D(z)$	-	Termed as distortion transfer function
σ_0^2	-	Thermal noise power
K	-	Total number
N	-	Total number of samples
r	-	Transmission range
β	-	Transmit power ratio
$s(t)$	-	Transmitted signal
R	-	Transmitter and receiver
$X(t)$ and $Y(t)$	-	Two multipath components

$U_n(\cdot)$	-	Utility function
k_1	-	Utility function's
λ_i	-	Utility gain
$I_0(x)$	-	Zeroth order Bessel function

CHAPTER 1

INTRODUCTION

1.1 OVERVIEW

Telecommunication has passed through a long stretch beginning from Graham bell's wired telephone till the Long Term Evolution's (LTE) multimedia services. Traditional wired communication has left behind the long-living footprints with respect to radiation-less communication networks; in spite of the fact that its limited service cannot be extended to huge distances. In order to have the global spanning of communication networks, wireless communication saw their evolution during the year 1960. In comparison with wired communication, wireless communication has resulted in limited hardware and signal processing sophistications.

The cellular network, with a primary role to play in the society, has spanned the wireless communication to several generations, with the aim of guaranteeing all-round voice, data and multimedia services to all the network users worldwide. The First Generation (1G) cellular network has seen its development in the 1980's providing voice-only analog communication. Along with voice, the Second Generation (2G) has provided data, fax and message services to the network users. The 2G's digital phone instrument has brought in the cellular networks to multimedia computing and entertainment services via Third Generation (3G) technology. The high-capacity systems have transformed the 3G network into an everything-included network.

The necessity for anytime, anywhere services have moved the paradigm corresponding to 3G towards the Fourth Generation (4G). The objective of 4G is to maximize the capability and the speed of wireless data networks by making use of advanced signal processing techniques and Orthogonal Frequency Division Multiplexing (OFDM) methods that are available with the turn of the millennium.

Due to the application of Internet Protocol (IP) based architecture, the 4G networks accomplish lower data transfer latency in comparison with the 3G networks. The next successive Fifth Generation (5G) networks are one more high speed IP based networks, targeting the delivery of multimedia services with the rates of Terabytes.

The demand for data traffic is increasing exponentially due to the use of multimedia services and internet connected gadgets like tablets and smart phones. In the recent years, mobile data traffic almost doubled. As per the Ericsson Mobile Report 2013, in 2009 mobile data traffic exceeded voice traffic, and it is anticipated to rise steadily when voice traffic merely grows reasonably. At the end of the year 2019, the mobile traffic is 10 times that of 2013. The 2013 Cisco Visual Networking Index (VNI) report predicted that the global mobile data traffic will increase at a Compound Annual Growth Rate (CAGR) of approximately 70% for the duration of 2012–2017 [1]. According to Figure 1.1, a 13-time rise is anticipated at the end of 2017 with 11.2 Exabyte's produced for each month.

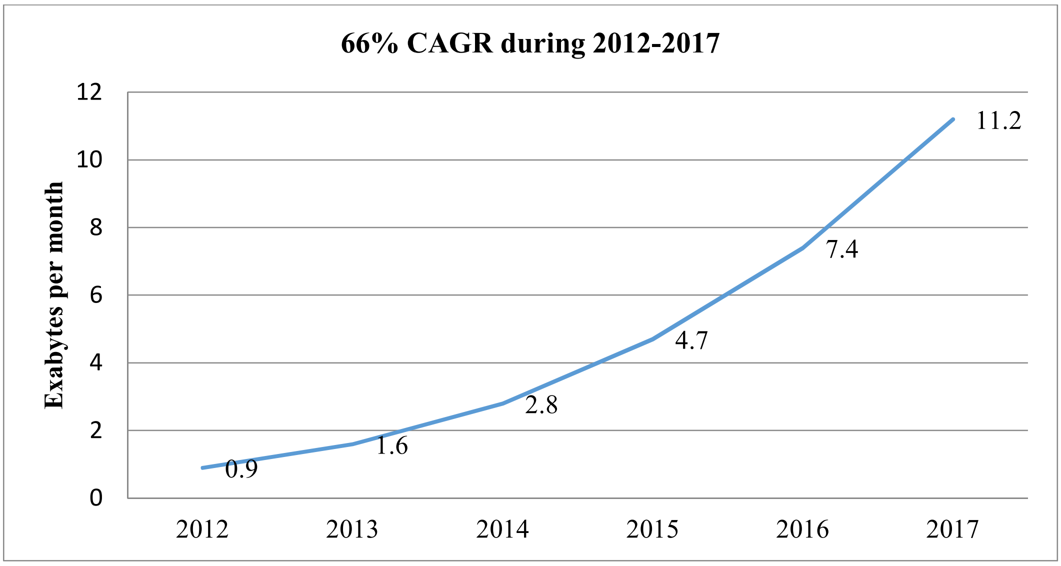


Figure 1.1 Growth of global mobile data traffic during 2012-2017 (Source: Cisco VNI Mobile Forecast, 2013)

Now a days, mobile phones are used in common place, and many users have devices that are double than a wireless computer with features like sending text messages, photos and files on the go. The growing popularity and user-friendly nature of mobile devices such as iPhone, Android phones, tablets, and other portable devices, have a great impact in the modern society, hence new mobile applications are coming online particularly in areas such as health care, education, transportation and commerce. In the world, India stands second in the telecommunication market and third in terms of internet users. As per Telecom Regulatory Authority of India (TRAI), subscriber growth of telephone has increased with a CAGR of 19.96 percentage, reaching 1058.86 million by the year 2016 as shown in Figure 1.2.

The demand and need for data wireless networks has triggered the design and development of new data oriented cellular standards.

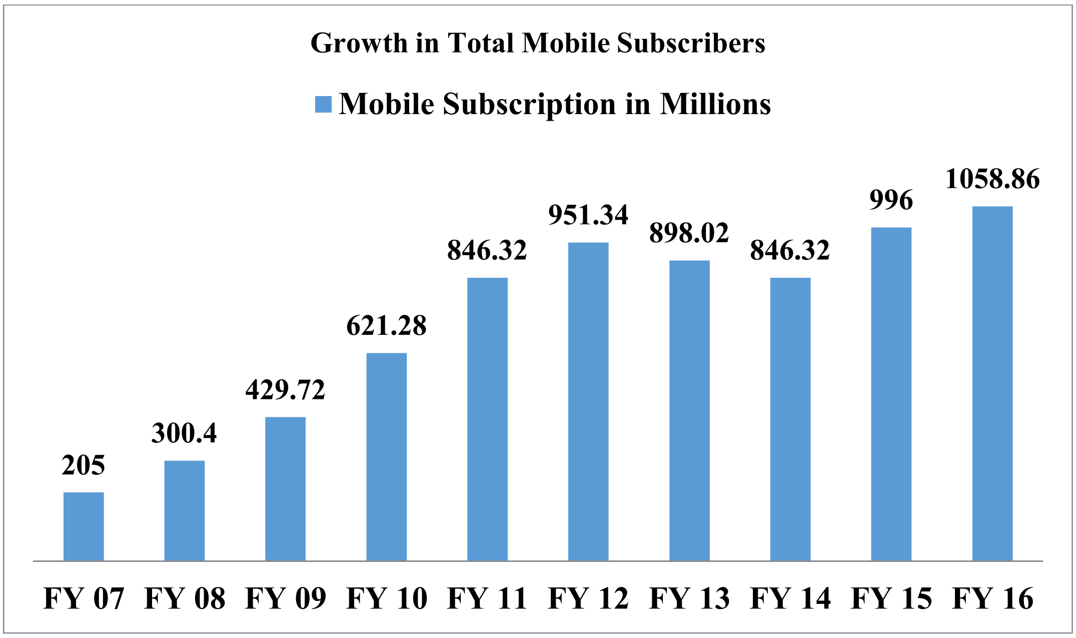


Figure 1.2 Mobile subscriber growth rate

(Source: TRAI, TechSci Research)

India, the second most popular country in the world, by 2017 is anticipated to pass the United States in amount of smart phone users. As Figure 1.3 shows, there were nearly 76 million subscribers using smart phone in 2013, and it is expected to rise to about 317 million by 2019. The statistics indicate that there will be a tremendous need for high-data rate support due to excessive data usage and demand by end users in wireless communication systems.

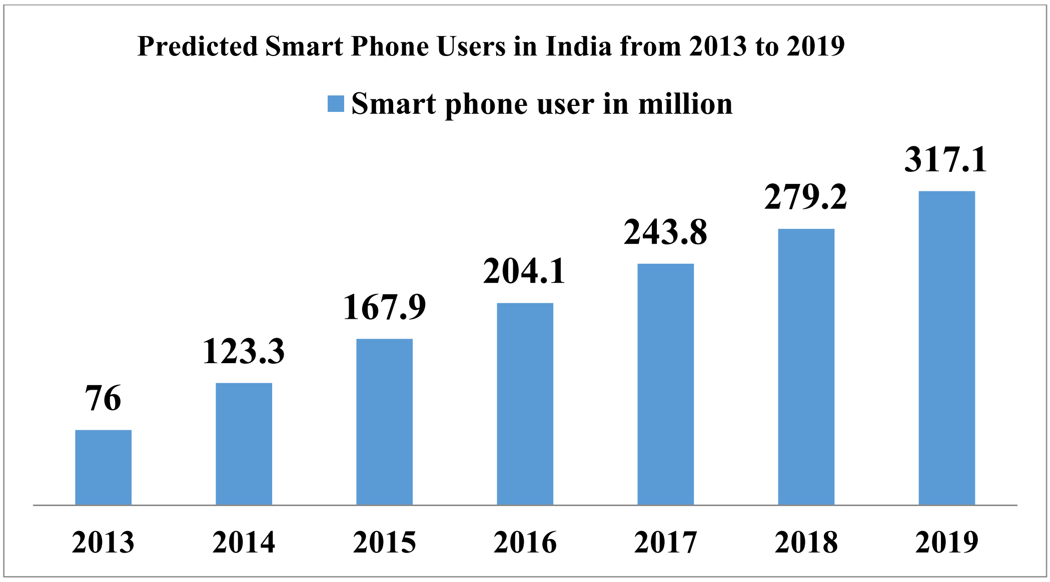


Figure 1.3 Predicted smartphone users in India from 2013 to 2019 (Source: eMarketer)

In the past few years, the cellular network has seen a proliferation in the network users and therefore, it is becoming tough for the network operator to include more number of users over the less amount of spectrum. A study carried out recently by Cisco has made a forecast that the requirement for wireless data traffic is increasing with a drastic pace and the demand on a monthly basis is anticipated to hit 6.3 Exabyte by 2016, which is, a 26-fold rise in the demand in data traffic in comparison with the year 2010 [2]. Moreover, certain studies indicate that greater compared to 50% of traffic generated by voice and 70% of traffic generated by mobile data come from indoor as well as business environments [3]. On the other side, a less indoor coverage is faced by business users of 30% and household network users of 45% [4]. Hence, in order to maximize the income for the network operator and to meet every kind of network users, a significant importance has to be bestowed in order to deal with baffling network user rise, spectral demand and indoor coverage requirements. It is interesting that all of the wireless network generations (1G to 4G) are greatly inspired, so as to cope up with the rising network traffics over the expensive spectrum.

Contradictorily, the Macro Base Station (MBS) yields very less coverage to both indoor as well as cell-edge subscribers. Since the MBS operation is at a greater frequency, the capability of short-wave signal to get through the walls becomes limited. Network operators would require 30,000 base-stations to provide a better geographic coverage in a hugely populated urban environment and the power utilized by every MBS are fixed to attain a moderate indoor coverage along the edges of the cell [5]. Research work has observed that MBSs are reasonable for 10% of global carbon-di-oxide emission and it is going to be twice over the coming decade [6]. Also, for linking the mobile devices to the core network, jumbo MBSs take up a power of 2.5kW to 4kW. Beyond this abundant power, only 5% to 10% of the power will comes out as a usable radiated signal and the rest of the input power gets dispersed in the form of heat.

Additionally, the real-time traffic that originates from heavy network users also lead to overloading of the MBS, creating greater service blocking possibility during peak hours. In order to deal with this situation, the cellular network is recreated into LTE based heterogeneous networks. As the name indicates, the co-presence of several small radius cells in the same geographical location and over the same group of frequency has resulted in the heterogeneous networks. The concept of overlaying the smallcells over the frequency of the already existing macrocell network not just gets over the spectral demand, but also yields improved indoor coverage for the network users.

1.2 SMALLCELL TECHNOLOGY

Femtocells belong to the category of low power base stations. One MBS per Macrocell (MC) is not adequate for satisfying the service demands of extensively spread outdoor and also indoor users. Therefore, in order to provide an efficient service to all the users, the huge MC coverage is split into several tiny cells, known as smallcells that brings the base station to the proximity of the users. Smallcells not just provides remarkable radio signal reception inside buildings, but also ensures high quality multi-media services to the users existing in shadow, edges and coverage holes of a network [1]. Frequency reuse happening between MC and small cell improves the network capacity and operator revenue. The overall spectral efficiency obtained by the overlaying of smallcells over the already existing MC network is much higher compared to what is attainable by just MC.

The process of smallcell deployment is customer-intensive since the smallcell owners do not need technical assistance in on-site locations. Smallcell subscribers experience a good signal quality from the plug-and-play base stations that are closely located and therefore, the user instruments need very less battery power. Therefore, smallcell technology becomes the solution to deal with the existing network issues such as network user density, spectral requirements, very limited indoor and cell-edge coverage, non-guaranteed service quality, high power consumption and green-vegetation hazard. Generally, the cells specify the coverage boundary or footprint, till where they can render service to the connected users. Depending on the cell radii and transmitted power, cells are divided into four primary kinds. Table 1.1 provides the list of the types of cell corresponding to the reducing cell radii and reducing transmit power level [7], and other parameters. Amongst them, femtocell, picocell and microcell are referred to as smallcells that are overlaid on traditional MC network.

Table 1.1 Comparison of different eNodeBs

Parameter	Femtocell	Picocell	Microcell	Macrocell
Coverage	Inside	Outside/ Inside	Outside	Outside
Number of Subscribers	4 to16	32 to100	200	200 to1000+
Output Max. Power	200 mW	2 W	5 W	40 W
Cell Max. Radius	10 to 60 m	100 m to 300 m	250 m to 1 km	1 km to 2 km
Backhual	DSL Cable, Optical cable	μwave	μwave, Optical cable	Microwave, Optical cable

It can be seen from the Table 1.1 that the Femtocell (FC) is the smallest of the cells and the picocell is the next smallest cell. Macrocells and microcells extend over a broader geographical location and they have the drawbacks such as tall antennas, greater operating power, huge path loss and fading effects. On the other side, pico and femto base stations are in very close association with their registered users, in which the possibility of signal attenuation and few other propagation losses are very low. Therefore, the service quality of picocell and femtocell is relatively greater compared to that of macrocell and microcell.

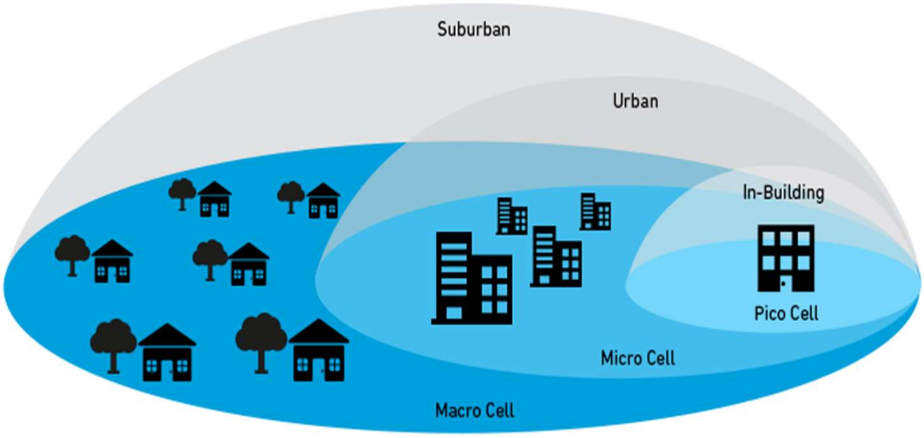


Figure 1.4 Illustration of various types of cells
(Source: Qorvo: Smallcell Networks and the Evaluation of 5G)

Figure 1.4 implies that FCs is desired for residential network users, picocells are advised for indoor enterprise users, while microcells and macrocell are suggested for big enterprises and huge geographical areas correspondingly. All of these cells are implemented over the same licensed band and are regulated by one single network operator. Vodafone, which is a globally popular service provider, deployed smallcells with the name of Full Signal in July 2010 [8], and it has deployed 25,000 picocell units and 100,000 FC units as on 2013 [9].

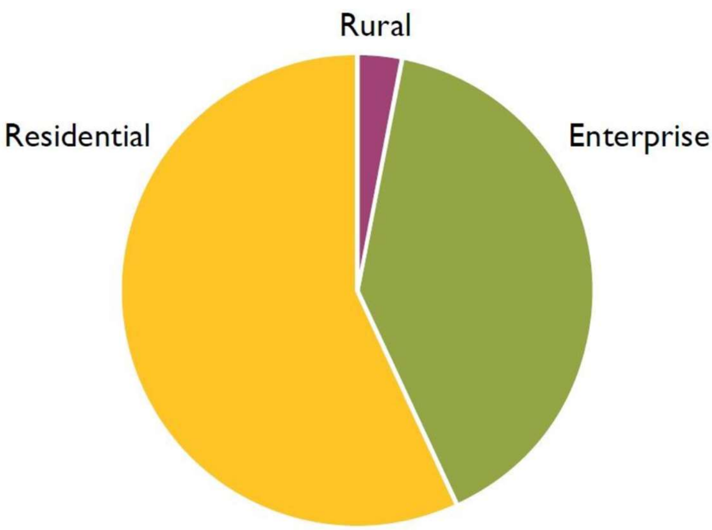


Figure 1.5 Illustration of smallcell deployment in the areas like residential, rural and enterprise environment
(Source: Informa Telecoms and Media)

With the assistance from these smallcells, the network operators are capable of extending high quality coverage to the house of the subscriber with no full powered cellular towers. Smallcells contribute towards the evolution of 4G standards and render backward compatibility to 3G, 2G and 1G technology. Therefore, smallcells are developed in order to provide maximum indoor coverage at lesser operating power with less path loss and fading effects. Important deployment in the residential areas, as illustrated in Figure 1.5, focuses on the takeover of FC technology (residential) in comparison with picocell (enterprise) and microcell (rural) technologies. Thus, FCs is desired by network users, who want indoor services with high quality.

1.3 THE BEST CANDIDATE – FEMTOCELL

Femtocell has created a space for itself among the smallcell family and many industrial and research personnel see FC to be the potential candidate for the next generation cellular networks.

1.3.1 Overview

Femtocells (FCs) are typically subscriber deployed base stations that offers guaranteed greater quality voice, data services to indoor devices, thus reducing the traffic of Macrocell (MC). FCs forms a small wireless coverage area and then makes the connection between the registered network users and the cellular core network via the broadband Internet access of the subscriber. The low power Femto Base Station (FBS) is similar to a simple wireless router visually. FCs can simultaneously provide service up to 4 registered network users and can also move with the owners. The low power nodes work over licensed frequency band and therefore render backward compatibility to traditional cellular standards and forward compatibility to next generation cellular networks. These solutions are cost effective since they render the same performance like MBS, and still have a complementary role to play with the power depleting MBS.

One prediction is that the future LTE-A networks would have FCs to one among the vital members for the indoor cellular coverage. The overall capacity of the network can be improved three times of magnitude by means of Deploying FCs

[10]. The entire 4G FC market revenue is assumed to cross over $600 million in 2014. Greater than 5 million small cells were deployed already in addition it is anticipated to hit 90 million units by the year 2016. ARC chart has provided estimation that at the end of 2017, an overall 5 million small cells would get installed each year [8].

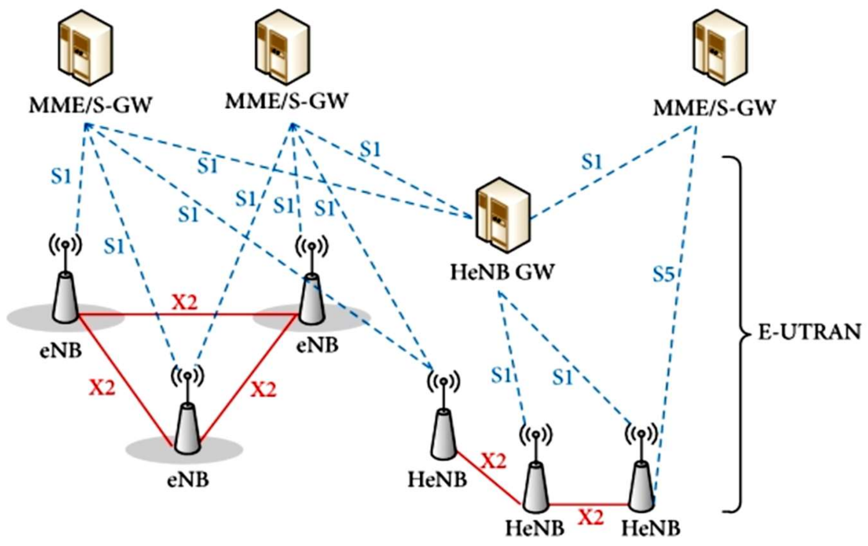


Figure 1.6. LTE-A Femtocell network architecture

Around the world, greater than 47 leading operators are already involved in the deployment of FCs in their already available network - serving public, enterprise and residential sectors [11]. Compared to the available MBS, the FBS takes up 40 times lesser power for delivering a signal to the indoor. This indicates that FCs can raise the site density along the edges of the cell and the indoor by 6.3 fold more than that of an MC network [12].

1.3.2 Necessity of Femtocell Networks

The FC network is pursued for the subsequent reasons: the capability of a cell is dependent on the cell radius. The entire cell capacity is inversely relative with the square of the cell radius according to the inverse square law. When the cell radius gets reduced by half, the cell capacity gets quadrupled.

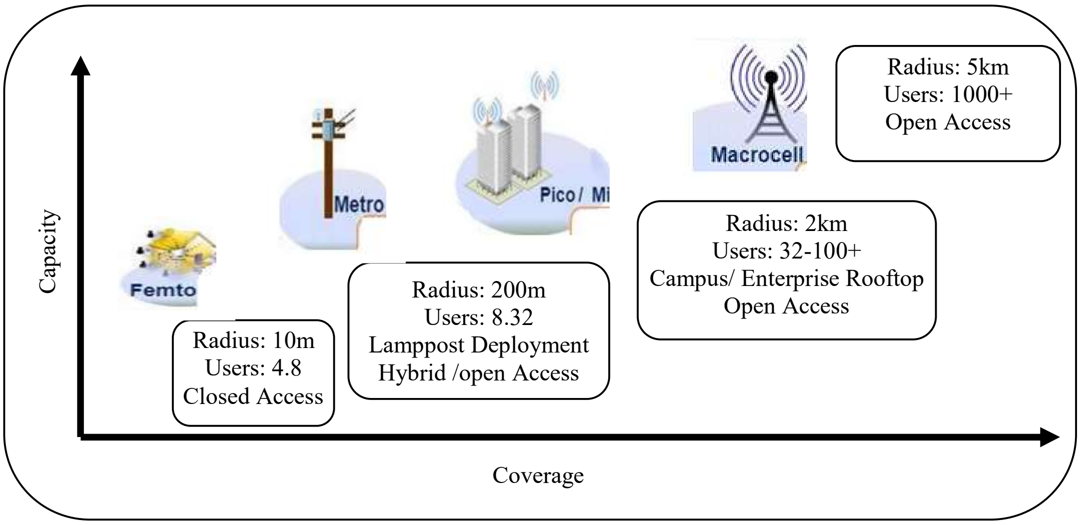


Figure 1.7 Relation between coverage and cell capacity for various cell types (Source: Radisys Trillium)

Lesser the cell radius, the more nearer the base station will be to its users. The signal deterioration is paltry in a scenario such as this, improving the received signal quality. Moreover, the registered users present inside the FC's coverage may have lesser mobility and fading effect and the aggregate throughput is higher in comparison with the MC network. Therefore, among the different cell types, the short range FCs are desired as the best candidate for attaining a greater cell capacity as illustrated in Figure 1.7.

From the spectral efficiency perspective, FCs contains a vital role to act in improving the cellular networks. The traditional cellular network concept, known as cell splitting [13] was introduced by LTE standard for enjoying the advantages of more number of users over a lesser spectrum. The huge MC coverage can be equally segregated into N sub cells and each one of them can possess the same set of frequency like MC, with additional care taken about frequency planning with efficiency. This concept improves the cell capacity by N times at the expense of network configuration and management processes.

Due to competition, FCs provides unending benefits such as offloading of the MC traffic, guaranteed high quality indoor services, spectral efficiency, network capacity, multiuser diversity, non-emission of greenhouse gas and omnipresent services to every user. Owing to its extensive application, industry people refer to the FCs to be the network in box, in-building coverage nodes, private network, plug-and-play base stations and low power access points. The FBSs are designed so as to provide support to 3G and 4G standards and are facilitated with Global Positioning System (GPS) for environmental sensing. Features like frequency planning, sleep mode activation, synchronous operations with the underlying MC network are accomplished via GPS equipped FBSs. Moreover, self-configuring and self-organizing characteristics in FC network largely decrease the task of supervision imposed on the network operator. FC operates as a stand-alone, network combining node, which enables the co-existence of cross-tier users in the proximity of FC by correct access mode selection.

1.3.3 Femtocell Network Model

The general FC network model is given in Figure 1.8.

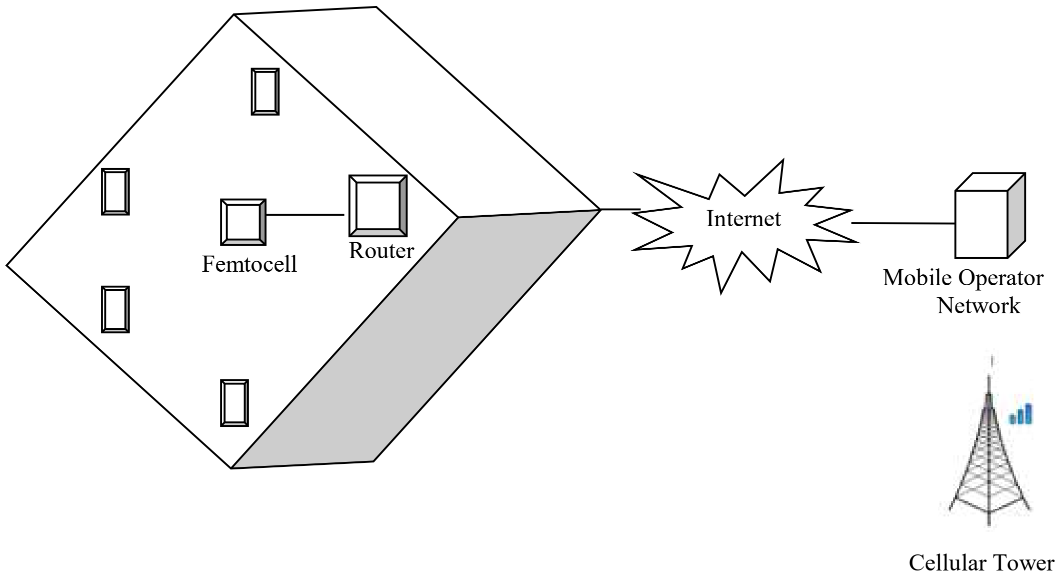


Figure 1.8 Femtocell network model

The Femto users (FUs) are seen linked to the core network via the FBS and Femtocell Management System (FMS), which is generally a central FC coordinator that helps in FC admission as well as management. It acts as an essential part of network operator cloud. Every FC or FBS could serve up to 3 to 4 FUs at the same time. The FBS helps the registered FUs in the transmission and reception of the required signal to and from the operator core network. Cognitive equipped FBSs can do the sensing and thus get adapted to the environment.

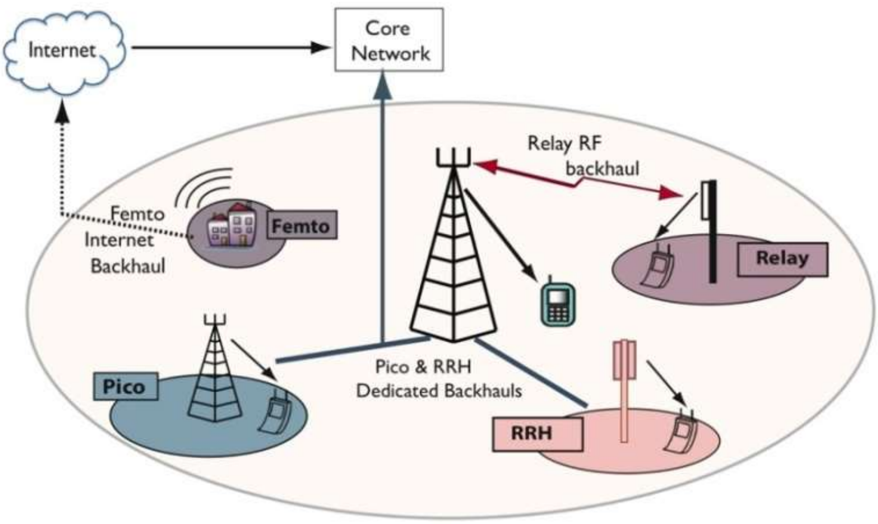


Figure 1.9 Heterogeneous network

The FUs own the FCs and therefore, the FBSs have the plug-and-play behavior with the mobility of the user. FMS sorts the FC clusters and renders service to the registered FUs present in the cluster. Owing to FC deployment in random, the coverage area of neighborhood FCs coming under an FMS might be overlapping. At any instant of time, every FMS is specified in order to take charge of a certain number of FCs. With a rise in the number of FCs, new FMSs are implemented in order to deal with the traffics that originate from newly create FCs.

It can be noted from Figure 1.9 that the spatially distant Macro users (MUs) and FUs are allocated with the same set of frequency. The total spectral efficiency as well as network capacity is increased by such a kind of frequency planning. The procedure of FC configuration is just as simple as the configuration of an IP modem. Once the FBS is switched on, it starts the scanning of the service network for a closely-related FMS. After tracing the presence of FMS's signal over the radio environment, FBS then forwards its distinct Femtocell Identity (FC_ID) to FMS and then gets itself registered to it. Once FC_ID authentication is done, the FMS allocates the radio parameters to the FC. When configured, FCs does a periodic broadcast of the FC_ID to announce their existence to the FMS and neighborhood FCs. Also, the self-configuring characteristic compasses the FC in scanning the environment and acquiring information regarding the neighbors by itself. The MC and FCs work under the same network operator and hence they are capable of reading and exchanging common chunks of information. The network consists of different types of nodes, power levels and protocols are called Heterogeneous Network (HetNet) [14], which is shown in Figure 1.9.

1.4 CHALLENGES IN FEMTOCELL NETWORKS

After identifying the benefits of FC, many of the industrial and business professional thought FC to be an integral candidate in smallcell family. Nonetheless, a flip side examination on FC technology shows that the technology has few issues also that to be dealt with. Practically, incorrect access mode selection, denser FC deployment and an extensive mobility of MU has resulted in critical issues such as interference, backhaul bottleneck and handoff mechanisms correspondingly [15]. Therefore, in order to satisfy with the demands of FC owners without impacting the revenue of the network operator, more emphasis should be on resolving the above mentioned problems.

1.4.1 Handoff Management

The traditional MC radio frequency planning techniques are not suitable for FCs, due to the mere substantial number of FC deployment and complicated neighboring list management. Communication with a big number of neighboring FCs for the purpose of handover would also be tedious with less radio resources being available. The handover tends to become more difficult with the co-existence of FCs having diverse access modes. If a mobile MU moves into the closed access FC coverage, then the MU might face service deterioration owing to poor handover. In addition, the amount of handover is big in open access as well as hybrid access modes, whereas the handover in closed access mode is not necessary [16].

Haijun *et al* [17] introduced a handover technique for LTE based MC and FC networks, which took the moving, speed and the QoS of a user into consideration. One more handover algorithm [18] considers the Received Signal Strength (RSS) and the velocity of user devices by making use of the mathematical notion of sets.

Handover processes adapted for Universal Mobile Telecommunication System (UMTS) based FC networks are also introduced in [19] that, in turn, minimizes the signaling overhead and also the number of handovers in FCs. However, complicated algorithms are required forgetting over the challenges related to handovers, so that it is ensured that there is no effect on the overall network quality by not so useful handovers.

1.4.2 Security

Rendering security to the femtocell networks is a significant issue. Security is dependent on access mode as well, and in open access mode, the external users also gets access to use the femtocell, and safeguarding of the user's confidential data holds much significance. The FC network is susceptible to several security risks. For instance, the confidential info of the subscriber moves through the backhaul internet connection. The data could be hacked, violating the privacy as well as confidentiality.

Femtocells are susceptible to Denial of Service (DoS) attacks. An intruder could do the overloading of the link present amid FAP as well as mobile core network. In these cases, the user of a femtocell could not have the intended services. Security is necessary for avoiding unregistered users to get access to the network as well as resources. Mainly, IP security is employed for providing security between the FAP as well as operator core network. Therefore, a security tunnel is used between the FAP as well as core network in 3GPP architecture. It is connected with a security Gateway. The security challenge will be very critical due to the rise in femtocell deployment. Hence, there is a necessity of elaborate research in this domain [20].

1.4.3 Access Mode Selection

The three access modes in an FC include open access, closed access as well as hybrid access modes. The closed access permits the registered FUs only to have access to the FC backhaul. The open access FC services all of the closely located network users with no reservation of any resource to FUs, while the hybrid access mode permits just a specific number of unregistered users to have access to an FC backhaul. Every FC is configured to function at any one among the access modes depending on the needs of FUs. The most desirable mode for an FC owner is the closed access mode. The FC owners buys the FBS, pays for the backhaul and they do not allow sharing of the resource with unregistered users. The unassociated users in proximity to the closed access FC will face a higher level of interference from the FC.

The open access is found to be the easiest mode for network operators. This access mode is exploited in open public places such as universities, shopping malls, and airports to yield a better coverage to the customers. Since the FCs provides service to a maximum of four users at one point of a time, the entering of a guest user may result in service deterioration to authorized FUs. A solution stated for the Interference Management (IM) is the hybrid access mode that permits a particular amount of external users to gain access to the resources. The overall number of the users permitted to have access to the FC has a direct effect over the performance of registered FC users [21].

1.4.4 Timing and Synchronization

In wireless system, timing as well as synchronization holds significance, and usually a crystal oscillator is utilized for serving as the internal clock, which aids in synchronizing between the transmitter and receiver. It also assists in maintaining a particular frequency alignment. The fault in synchronization as well as timing will result in Inter Symbol Interference (ISI) in OFDM systems. Designing these better quality oscillators in FAP leads to a rise in the femtocell expense.

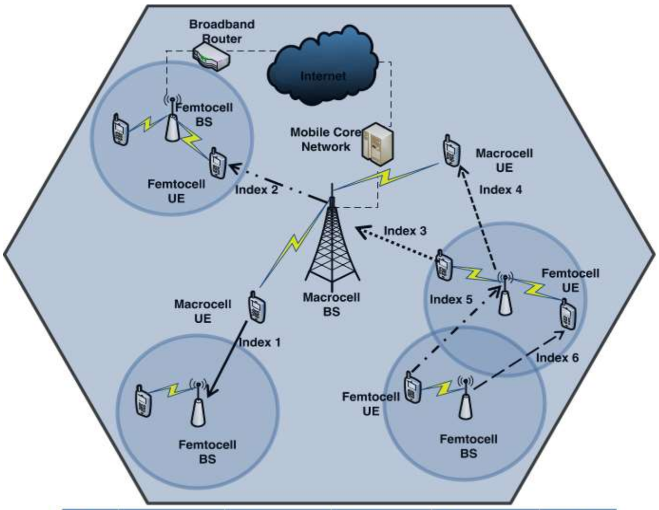
Timing as well as synchronization is needed in network usage monitoring, the tracking of security violations, session establishment, termination and event mapping. The amount of femtocells and the position of every femtocell become undeterminable as the network becomes denser. Also, the service provider contains limited control over the location as well as positioning of the femtocells. Beneath these circumstances, achieving time Synchronization tends to become cumbersome.

By means of the backhaul DSL, synchronization for the femtocells could also be achieved. But, because of the changing traffic, there could be undeterminable delays over the internet connection. The precision timing protocol IEEE 1588 over IP with a strong timing accuracy of 100 ns, in addition self-adaptive timing recovery protocols (for instance the G.8261 standards) [22]. One more probability is equipping the GPS with femtocell for synchronization, but the maintenance of a constant satellite indoor connection is as very hard. For synchronization with the remaining portion of the network, a femtocell could as well take assistance from its nearby femtocells [23].

1.4.5 Interference Management

The incorporation of FCs with the already available MC network has transformed the network into two-tier cellular network. The tier one includes the traditional MC network as well as the second tier includes the FC network. Frequency reuse is followed by a heterogeneous network such as this, for overcoming the spectral demand. Generally, frequency reuse is the similar group of resource is assigned to two users who are geologically located at a distance from one another [24]. Even though frequency reuse helps in improving the spectral efficiency, this circumstance may bring about co-channel interference, if the spatially distant cross-tier users, like an MU and co-channel deployed FU gets closer to it. This is mainly because of the mobility of MUs and the denser deployment of FCs. When two co-channel deployed users lie in closeness, due to their similarity in resource, prominent transmit power level and less amount of distance with each other, they might face serious co-channel interference.

The co-channel network users working at a greater power might deteriorate the radio link quality of the users working at lesser power. Two kinds of co-channel interference are experienced in macro-femtocell networks [25]. They include co-tier co-channel interference as well as cross-tier co-channel interference as shown in Figure 1.10. The term of cross-tier interference specifies the interference seen between nearby located MU and FC, while the co-tier interference specifies the interference observed between two adjacent FCs. Classifications of different types of interferences are shown in the Figure 1.11.



Index	Aggressor	Victim	Interference Type	Transmission Mode	Symbol
1	Macrocell UE	Femtocell BS	Cross-tier	Uplink	———>
2	Macrocell BS	Femtocell UE	Cross-tier	Downlink	—··—··>
3	Femtocell UE	Macrocell BS	Cross-tier	Uplink	··········>
4	Femtocell BS	Macrocell UE	Cross-tier	Downlink	--------->
5	Femtocell UE	Femtocell BS	Co-tier	Uplink	-·-·-·->
6	Femtocell BS	Femtocell UE	Co-tier	Downlink	– – –>

Figure 1.10 Types of interferences in macro-femtocell heterogeneous networks

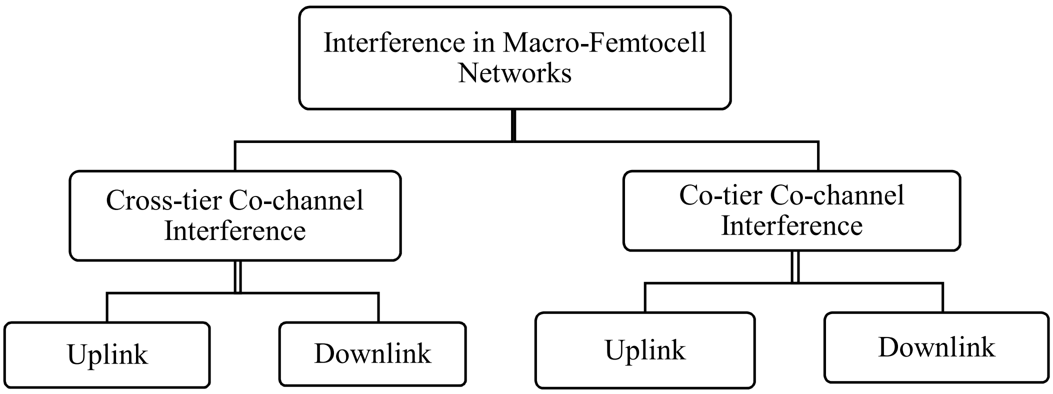


Figure 1.11 Different Types of interferences in Macro-Femto heterogeneous networks

Co-tier Co-channel Interference: In random as well as denser FC deployment, two nearby positioned FCs working at same uplink or downlink frequency bands might interfere with one another, where the wall isolation may not be sufficient for avoiding the interference. Such kind of interference is known as co-tier co-channel interference that, in turn, imposes a great effect on closed access FCs in comparison with the open access FCs.

The uplink co-tier co-channel interference is faced by FBSs, which are deployed in near proximity – for instance, the FC deployment performed in apartment blocks. The uplink of an FU's to its corresponding FC may be impacted by the strong signal in the uplink of an FU, which is camped in the coverage of the nearby co-channel FC. On the other side, the downlink co-tier co-channel interference is faced by FU along the edge of its home FC, whose required downlink signal can be submerged by the neighboring co-channel FC. These conditions exist when an FU faces interference levels in the order of 3mW to 5mW. In extreme conditions, with no co-channel interference mitigation, this can lead to dead zones. The dead zones are generally the geographical areas in which the network coverage is nil. One key solution for handling such co-tier co-channel interference is that the FC coverage has to be limited to indoor proximity by the management of the power level of FCs. More co-channel interference mitigation can be attained by doing a hand over of an FU to another carrier, in case it is available.

Cross-tier Co-channel Interference: If an MU is located near an FC which transmits with a greater power or if an FU positioned near the MBS transmits at less amount of power, there is an interference known as cross-tier co-channel interference. This issue tends to become more critical in closed access FC that strongly restrains a non-registered MU's uplink or downlink in its proximity. The uplink cross-tier co-channel interference is then experience, if the closed access FCs get deployed in the closely locality of MBS. Such FCs may face a potential interference owing to the dominant uplink power of the close by MUs, which may do the jamming of the uplink of FU related with the co-channel FCs.

Downlink cross-tier co-channel interference happens if the location of an MU is at the MC edge, in which the required downlink signal from the MBS is not strong. In addition, if an active MU hits the coverage of cell-edge deployed FC, then the resource similarity and maximum downlink power of FC may submerge the link quality of a closely located MU. Examinations reveal that the user instrument take 3% less than their time of transmission with maximum power, and this worst-case condition is anticipated to happen rather occasionally. Nonetheless, in order to deal with this challenge, the maximum downlink power of the FC has to be adjusted so as to yield a good compromise between the femtocell coverage and dead zone.

1.5 MOTIVATION

In order to get the FC network to be a potential candidate in the next generation cellular networks, the service choking issues such as co-tier co-channel interference as well as cross-tier co-channel interference has to be addressed by reliable interference avoidance algorithms.

The motivation of the research is to deal with the interference between co-tier and cross-tier deployed macro-femtocell networks. Aim at addressing the co-tier co-channel interference management as well as cross-tier co-channel interference management through flexible resource allocation and access mode, which are regarded as the most preferred remedies to handle co-channel interferences in OFDMA based femtocells [26]. In addition, focus on understanding the FC with hybrid access mode with practical spectrum sensing technique to provide minimum capacity and fairness index for all the users.

1.6 OBJECTIVE AND RESEARCH CONTRIBUTIONS

The objective of the research work is to reduce co-channel interference between macro-femtocell heterogeneous networks, with a special emphasis is on protecting the service quality of both MU and FU through efficient resource allocation techniques. As an overall, the flow of research work carried out can be pictorially represented as shown in Figure 1.12.

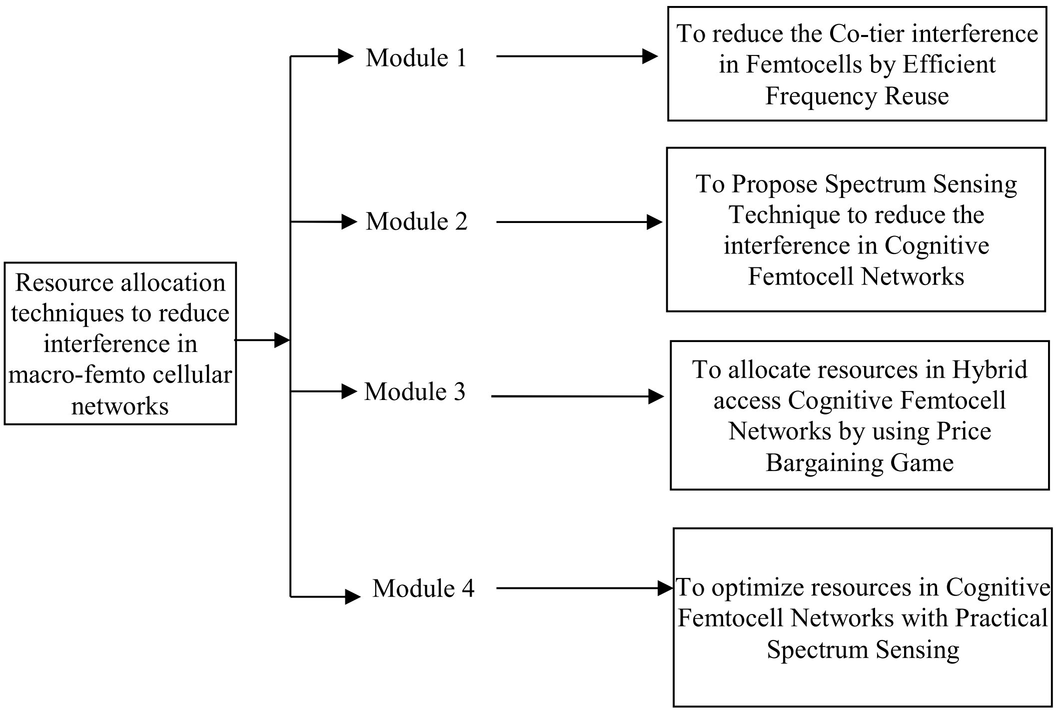


Figure 1.12 Overview of research work

1.7 ORGANIZATION OF THE THESIS

This thesis has aimed at resource allocation to alleviate interference in macro-femto cellular networks. The thesis consists of seven chapters based on the research findings published in peer-reviewed journal and conferences. It is organised as follows.

Chapter 1 deals with the evolution of smallcells with a brief introduction to the conventional and the LTE based cellular networks. Scope of FC networks compared with other cell types are highlighted as well. The challenges being faced by FC networks are discussed in detail. The objective and the organization of the research work carried out are also presented in Chapter 1.

Chapter 2 begins with the outline to the specialized research area called Interference Management in Co-existing Macro-femtocell Networks. Performance impairments in FC networks due to the effect of interference are addressed. An intensive literature survey on the research topic along with the challenges of the problem concerned are discussed.

Chapter 3 elaborates on proposed Inter Channel Interference Coordination (ICIC) algorithm called as Efficient Frequency Reuse (EFR). With a brief overview, the proposed algorithm is formulated in comparison with the existing Frequency reuse techniques. The performance analysis reveals that the EFR algorithm gives a vital improvement in reducing the co-tier interference in femtocell networks.

An introduction to Spectrum Sensing in a cognitive radio network is discussed in **Chapter 4**. The interference could be reduced by means of taking the MU as a primary user and FU as a secondary user. In this connection a Para unitary Filter Bank based spectrum sensing is presented here and the outcomes are matched up with the standard spectrum sensing technique and energy detection over different type of channels. The application of this Spectrum Sensing technique in macro-femto cellular networks with different access modes are discussed in this chapter.

Chapter 5 concentrates on dynamic spectrum allocation in hybrid access cognitive femtocell networks to spur the wireless operator as well as the FAP. The negotiation between the macrocell and femtocell are considered as a price bargaining game to increase the utility of the network are discussed in this chapter.

Chapter 6 deals with implementation of dynamic spectrum allocation in hybrid access cognitive femtocell networks with unsatisfactory spectrum sensing as well as minimum fairness index. Performance of the system is measured using fairness index, total capacity, average co-tier interference and average cross-tier interferences are elaborated in this chapter.

Chapter 7 concludes the thesis by summarizing the work. The major contributions of the research are highlighted and the possible future works based on the research carried out are indicated.

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

The Femtocells (FCs) act as a vital role in the subsequent generation cellular technology and it is evident that FCs can offer greater quality voice as well as data services to the indoor users. On denser FC deployment, the threat for co-channel interference becomes more and it must be avoided with the intention of enhancing the QoS in heterogeneous networks. The following discussion summarizes some of the interference handling solutions from various aspects of research domain namely maximum transmit power control, Frequency Reuse, Inter-cell Interference Coordination (ICIC), beamforming, spectrum sensing, alternate resource scheduling, flexible access mode selection and game theoretic approaches.

2.1.1 Review on Interference Management through Efficient Frequency Reuse

Several literatures have addressed the problem of interference in macro-femto cellular networks. Inter-cell Interference Coordination (ICIC) Techniques plays a vital role in giving solution to these problems.

Palanisamy and Nirmala [27] provided an extensive analysis on downlink interference conditions under co-channel deployment as well as an elaborate survey on downlink interference management techniques. It is found that smart sub channel allocation employing cognitive radio conception as well as transfer beamforming alongside codebook restriction, macrocell beam subset selection, Interference Canceling Block Modulation (ICBM), Generalized Autonomous Component Carrier Selection mechanisms have a primary role to play on interference management in OFDMA femtocell networks while, in Code-Division Multiple Access (CDMA) femtocells adaptive distributed power control, joint admission control with power control and Interference Avoidance (IA) technique could be utilized for managing interference.

Cao and Fan [28] concentrated on the challenges involving downlink power control for the self-organization of femtocell. Various downlink power control techniques have been exhaustively studied with practical Long-Term Evolution (LTE) system parameters. Downlink power control is capable of efficiently balancing the performance between macrocell and femtocell, and mitigating the interference or optimizing the coverage and capacity. This research work yields resourceful directions for network operators in realistic network planning, where a cautious balance has to be made in the maintenance of satisfying network performance and user Quality of Service (QoS) in HetNets.

Jo *et al.* [29] introduced two interference mitigation techniques, which regulate the femtocell user's highest transmitting power in order to mitigate the cross-tier interference experienced at a MBS. The open-loop as well as the closed-loop control controls the cross-tier interference lesser compared to a pre-defined threshold as well an adaptive threshold dependent on the Noise and Interference (NI) level at the MBS, correspondingly. The outcomes obtained from simulation indicate that both the techniques provide an efficient compensation for the reduction in uplink throughput of the macrocell BS and that the closed-loop control yields improved femtocell throughput compared to the open-loop control at a reduced expense of macrocell throughput.

Kurda *et al.* [30] investigated femtocell power control mechanisms for the mitigation of the interference faced by macrocell users whilst suppressing the femtocell throughput deterioration. System-level simulations indicate that the mechanisms improve the throughput of macrocell users whilst having a great performance maintained for femtocell users in comparison with a traditional power assignment. Also, the results indicate that the newly introduced prioritization weights let attaining the necessary level of macrocell/femtocell throughput balance.

Yi *et al.* [31] explored the setup of femto cells carried out within LTE cellular networks. Depending upon the present partial co-channel deployment configuration used for LTE Home eNodeB, a new mechanism of femtocell-known spectrum scheme is introduced for co-channel interference prevention amid macro as well as femto cells. The performance enhancement of the new mechanism is verified with the help of the results of simulation.

Widiarti *et al.* [32] suggested an interference mitigation mechanism dependent on the assembling of femtocells in one neighborhood location. The unwanted intervals available in Low Duty Operation (LDO) can be reduced by the newly introduced mechanism and leads to reduced interference to the neighboring cells. The evaluation and simulation results reveal that the newly introduced method offers better benefits when compared to the traditional LDO mechanism in IEEE 802.16m, with regard to reduction in interference and energy saving prospects.

Sahin *et al.* [33] introduced a co-channel framework for having OFDMA based macrocell-femtocell wireless networks co-exist. An avoidance technique, which mutually makes use of the spectrum sensing results in addition to the scheduling info got from the MBS, is presented. Also, the effect of ICI from the MMSs in the uplink is explained by simulations.

Jin *et al.* [34] devised a potential Power Control (PC) method for mitigating the Aggregate Interference (AGGI) from active femtocells observed during uplink transmission. MBS determines the interference allowed for each femtocell and then to avoid the cross-tier interference observed in HetNets. The algorithms make the best advantage of large-scale channel info as well as shadowing changes in order to ensure the macrocell uplink channel quality. As a result, these algorithms improve the overall cell throughput.

Kim and Lee [35] suggested a technique that makes use of frequency reuse equipped pilot sensing in order to minimize the cross-tier co-channel interference amid macrocells and femtocells. Simulations were carried out with the aim of studying the effect of femtocells overlaid macrocells concerned with throughput and probability of outage. The results of comparison indicate that the newly introduced technique could form a solution for deploying the femto cell systems in macro networks.

Lee *et al.* [36] introduced an IM technique in the LTE with femtocell systems making use of FFR. The results of simulation reveal that the newly introduced technique improves the overall/edge throughputs as well as decreases the likelihood of outage in the entire network, mainly for the cell edge users.

Juang *et al.* [37] inspected the consequence of femtocell interference on the available macrocells with Fractional Frequency Reuse (FFR). Rather than making use of sophisticated transmission methods by collaborating several Base Stations (BSs), this performs the adaptive configuration of the FFR pattern to prevent interference due to femtocells, based on density and the areas of femtocells. The results of simulation indicate that the newly introduced femtocell BS implementation can help in efficient reduction of the downlink interference to macro-cellular networks.

Zhang *et al.* [38] suggested a cognitive-based IM solution to be used for LTE-Advanced femtocells through the sharing of calculated path loss info amongst the adjacent and choosing the component carriers based on the projected mutual interference. The results of system-level simulation indicate that the newly introduced method could efficiently prevent spectrum collision and considerably enhance the entire network capacity.

Guruacharya *et al.* [39] focused on the power allocation in downlink is observed in a cellular network with a two-level hierarchy. The leaders are supposed to possess sufficient info to take the response from the followers when those techniques are being formulated. In order to characterize such a kind of communication like leaders and followers, Stackelberg equilibrium is created, In the case of Nash games, the association between the upper and lower sub-game equilibrium is examined.

Sivaraj and Palanisamy [40] introduced new transmit power control techniques employing soft computing approaches for tuning the transmission power of femtocell access point corresponding to the instantaneous Channel Quality Indicator measurement report obtained from the user device. The data rate of femtocell user is evaluated with constant transmission power and then same is analyzed with neuro-controller tuned and fuzzy logic controller tuned transmission power of the working femtocell access point. The result of simulation validates the efficiency of the newly introduced power control techniques by exhibiting a considerable increase in data rate of user even at the femtocell edge. Therefore, the femtocell users QoS is enhanced, and also the femtocell access points get deployed at the middle of the coverage area of MC and the same may result in an enhancement in the entire network potential.

Chandrasekhar *et al.* [41] presented a distributed utility based SINR adaptation at femtocells for alleviating the Co-channel cross-tier interference at the macrocell due to co channel femtocells. The algorithm guarantees that, a mobile user accomplishes the target SINR even though 100 femtocells and needs a worst scenario SINR decrease of just 16% at the FAPs. These outcomes are an aspiration behind the designing of power control techniques that need reduced network overhead in cross-tier networks with a shared spectrum.

Oh *et al*. [42] took the merged usage of transmit power control as well as beamforming for femtocells into consideration in heterogeneous wireless communication environments. At last, the results of simulation indicate that the newly introduced method is very efficient with channel uncertainty present.

Han *et al.* [43] carried out the optimization of the femtocell network with limitations in such a manner that, the service connectivity with a FBS gets protected in the focused indoor area when the signal that is discharged beyond the building, acting as interference to the users located in outdoor.

Xiao *et al.* [44] suggested a new quasi-access technique that lets the interfering MUEs to have a connection with the interfered FAP when only through uplink. It considerably mitigates the uplink interference at the FAP and also its neighbor FAPs, and simultaneously, be advantageous to the macro-tier.

Yeh *et al.* [45] developed and analyzed IM algorithm through power control in the cellular systems along with the overlaid femtocell. The outcomes of simulation indicate that FAP power back-off aids in lowering the outage probability of macro-user at the expense of FU rate decrease. FAP power control could be regarded a strong Interference Mitigation solution.

Liu *et al.* [46] suggested a probabilistic power control mechanism for the femtocells. A distributed algorithm is formulated in order to compute the powers of femtocell users. The numerical outcomes indicate the efficiency of the newly introduced outage probabilistic technique as well as the distributed algorithm.

Li *et al.* [47] presented the interference mitigation through downlink power control Macrocell Femtocell overlay. As the co-channel interference arises from co-channel cells, a combined resource management, power control in addition to the admission control process is advised so that the precedence of the macrocell users is as well guaranteed. The outcomes of simulation indicate the efficiency of the newly introduced methods.

Lopez-Perez *et al.* [48] offered a framework for studying Worldwide Interoperability for Microwave Access (WiMAX) macro-femtocell hybrid conditions. A detailed description about the desired radio coverage prediction as well as system-level simulation scenarios is presented. The simulations along with numerical outcomes for two different diverse kinds of access techniques (private as well as public) in the DL are also provided.

Claussen and Pivit [49] introduced an economic multi-element antenna solution for reducing the core network mobility signaling over the earlier published outcomes making use of just a single antenna. Self-optimization techniques are introduced, which can perform the combined selection of a suitable antenna pattern in addition to the optimization of the pilot power. This lets having a good match of the coverage of femtocell with the shape of each house as well as yields an enhancement in indoor coverage and signaling of core network results from events of mobility.

Liang *et al.* [50] explored a self-organization technique for Resource Block assignment with limitations of QoS to prevent the interference of co-channel and co-tier. The greedy algorithm is designed to resolve the problem of resource allocation. The simulations also indicate that the rejection ratios of all the QoS classes are less and mostly lower than 10%. Also, the newly introduced scheme enhances the PRB efficiency by more than 82% in scenarios of low-loading and 13% in high-loading scenario.

Kim and Oh [51] presented a Universal Frequency Reuse (UFR) technique, which focuses on an efficient reuse of a spectrum resource allocated in a cellular environment. At first, the system allocates the entire spectrum resource to all the cells, with an intension of entire resource can be reused with no limitations in the total cells like in the mobile systems having a frequency reuse factor of 1. Therefore, the newly proposed system can always keeps ICI at a minimum level, and supposing improved spectrum reuse efficiency in return. At last, elaborate computer simulations are performed for verifying the efficiency of the newly introduced reuse system, with an assumption of an OFDMA based cellular system. It is clear from the simulation outcomes, the UFR system yields fairly good spectral efficiency, with no regard to omni-cell as well as 3-sector cell systems.

Novlan *et al.* [52] highlighted on analytical evaluation of the two important types of FFR deployments. First one is Strict Fractional Frequency Reuse and second one is Soft Frequency Reuse (SFR), with a Poisson Point Process (PPP) for modeling the location of base stations. Depending upon the analytical expressions, SINR-proportional resource allocation mechanism is introduced and it is observed that FFR yields maximization in the sum-rate and also the advantage of enhanced coverage for cell-edge users.

A variety of approaches have already been introduced in the available literature. Interference mitigation approaches are divided into two foremost groups including multi-antenna methods and IA via ICIC. One general ICIC method is the interference avoidance, so as to guarantee that the ICI stays within permissible limits; the assignment of the different system resources to the users is controlled.

2.1.2 Review on Spectrum Sensing Methods in Cognitive Femtocell Networks

With the intention of dealing with CCI in Macro-Femtocell network, an FBS has to sense the channel, obtain knowledge regarding the existence of co-channel MU and in accordance change the resource and the maximum transmit power level. This aim could be satisfied by cognitive radio technology that helps the FU in dynamically adjusting the radio parameter when interference is experienced. The integration of cognitive radio technology with Femtocell will be an additional benefit in handling scenarios of interference in Heterogeneous networks [53].

Mariani *et al.* [54] evaluated the performance of the Energy Detection along with Estimated Noise Power (ENP), dealing with the model of the threshold and providing the conditions for SNR wall presence. For the ENP-ED, analytical expressions for the design problem are derived. Afterwards, this analysis is applied to CR systems in which the rapid sensing has been done through energy detection.

Choi *et al.* [55] suggested the application of the sequential detection framework to the Cyclostationary feature detector. Unluckily, a straightforward application cannot accomplish an adequate gain, which is what the sequential detection is expected to do. In order to resolve this issue, a new detector is designed, considering the cyclic phase of the cyclostationary signal. The results of simulation indicate that the newly introduced detector decreases the average detection time nearby by half. The novel detector can be used for the CR systems, which work in the frequency bands, where the PUs impose long interval and sensing time.

Hwang *et al.* [56] demonstrated a detection mechanism for CR, which is depending upon the Bussgang theorem. By using the theorem over the signal received, the new approach calculates the statistical difference between the Gaussian noise and the primary user signal. The outcomes indicate that the new approach offers robustness to the uncertainty in noise and operates quite well in extremely SNR ratio.

Bagwari and Tomar [57] suggested the comparative analysis made between the newly introduced cyclostationary feature detector and Multiple Energy Detectors (MED) based Spectrum Sensing (SS) methods. Numerical outcomes indicate that MED performs better than cyclostationary feature detection by an amount of 36.1 % at - 8 dB Signal to Noise Ratio (SNR) in regard to Probability of Detection alarm (P_d).

Li and Jayaweera [58] introduced a new non-parametric, multivariate quickest detection technique for CR employing energy along with cyclostationary features. Moreover, a parallel on-line rapid detection/off-line change-point detection algorithm is developed in order to attain self-awareness about fake alarms as well as detection delays for the purpose of automation in the future. The performance simulation reveals enhancements in regard to lesser detection delays and considerably greater percent of spectrum usage.

Lu *et al.* [59] suggested a new pilot-aided spectrum sensing method for OFDM systems. The chief concept is dependent on the basic nature, which subcarriers taking pilots contain diverse 1^{st} as well as 2^{nd} order statistical properties. The new scheme performance is analytically derived in regard to the Probability of Detection (P_D) Probability of False Alarm (P_{FA}). But, the 2^{nd} order statistics dependent technique yields improved performance for bigger normalized Doppler shifts.

Li *et al.* [60] dealt with the DL cross-tier interference of cognitive femtocell networks, a distinct draw back in the femtocell network performance. Specifically, a novel joint access and power control mechanism is introduced for alleviating the cross-tier interference, maximizing the system throughput and yield QoS guarantee for macrocell users as well as femtocell users. Depending on the cognitive radio technology, the access control mechanism provides a good improvement on the performance of cognitive users near to femtocells. The combined distributed access and power control algorithm is resolved by means of game theory. The results of simulation indicate that the newly introduced joint cognitive access and power control mechanism boosted the network throughput and limited the cross-tier interference under many real-time scenarios.

Li *et al.* [61] studied a technique of managing the cognitive interference in user-deployed 3G femtocell networks. Every femtocell identifies cognitively an interference signature from the network environment as well as smartly designates the correct channel patterns for reducing interference. The results of simulation reveal good channel SINR enhancement by the implementation of opportunistic channel scheduler. The scheme provides a new perspective of independent spectrum management dependent on cognitive interference recognition and adaptive channel management.

Wang *et al.* [62] used a variety of cognitive radio based techniques for enhancing the interference collaboration for femtocell networks. First, spectrum sensing and statistical analysis is applied for estimating the cross-tier interference amid macro cells and femtocells. On the basis of this, interference coordination is examined taking two types of spectrum sharing techniques into consideration. At last, a cognitive relay mechanism is introduced for improving the performance of interference coordination.

Cheng *et al.* [63] examined the already available distributed information acquisition techniques, and cognitive radio is revealed to be the most potential solution for two-tier heterogeneous networks. Hence the opportunistic interference mitigation techniques, inclusive of radio resource allocation orthogonally in the time-frequency as well as spatial domains of antenna, in addition to the interference cancellation through new decoding methods are studied. In accordance with the information gathered by cognitive radio technology, the current innovations like game theory and the Gibbs sampler have been investigated with the intention of decreasing cross-tier as well as intra-tier interferences. Performance analysis indicates that substantial performance enhancement can be typically accomplished, and thus the possibility of using cognitive radio in mitigating interference is demonstrated.

Atapattu *et al.* [64] highlighted on two fusion techniques: data fusion and decision fusion. Under decision fusion, false alarm probabilities as well as the precise detection are got under the generalized "k-out-of-n" fusion rule with errors in the reporting channel subjective to fading. After that, the analytical structure could be expanded to channels having Nakagami-m multipath fading as well as log-normal shadowing.

Lai *et al.* [65] designed cooperative SS to be as a non-cooperative game. Mixed strategy nash equilibrium of the formulated SS game is obtained by means of the derivation of the sensing probabilities of SUs. Numerical outcomes show that SUs with restrained coordination are capable of achieving improved results compared to the performance of the Nash equilibrium and by means of selecting the optimal sensing scheme.

Yucek and Arslan [66] studied a sensing technique for detecting the idle spectrum to be used for opportunistic transmission through the estimation of the RF transmission parameters belonging to primary users. The primary users are recognizing by matching the priory information regarding their transmission behavior with the features acquired from the received signal. Then the application of the newly introduced sensing technique to WiMAX mobile stations for discovering the active channels during the initial network entry is also explained in the form of a case study.

For the purpose of spectrum sensing, Khambekar *et al.* [67] suggested a mechanism, which uses the guard interval of OFDM symbol at the transmitter. The outcomes of simulation indicate that the mechanism is deployed with no effect on the Bit Error Rate (BER) under different channel conditions, and the identification of incumbent Digital television (DTV) signal can be done in the OFDM guard interval. Moreover, for dealing with the imperfections in the transceiver practically, the improvements to the circulant convolution preserving scheme is developed.

For signal detection as well as preprocessing for signal classification, Kim *et al.* [68] introduced Cycle frequency Domain Profile (CDP). The signal characteristics are acquired from CDP employing a threshold-test technique. For the purpose of classification, a Hidden Markov Model (HMM) is utilized for processing the extracted signal characteristics owing to its reliable pattern-matching potential. It is observed that, even at low SNRs, the CDP-based detector as well as the HMM-based classifier could identify and categorize the incoming signals.

Cattoni *et al.* [69] introduced a scheme that addresses the issue of information extraction and management for cooperative Cognitive Radio Terminals, so as to conduct the Spectrum Sensing tasks in a distributed manner. The new solution is dependent on Distributed Detection theory that is assisted by a Cognitive Modeling of Terminals.

Song [70] suggested a dynamic channel allocation method which inside and outside country as a method to mitigate interference. The elaborate analysis on the spectrum sensing mechanism is necessary for more effective usage of such a scheme. Therefore, this work presents cooperative spectrum sensing mechanism that is investigated inside and outside country and explains its result and the direction of the future work.

Salman *et al.* [71] introduced a near field source localisation method by which the cognitive femtocell detect the active femtocells operating in the licensed band and it would provide added info inclusive of the amplitude, range, angle and operating frequency of a particular femtocell.

However, the above mentioned cognitive associated cooperative decisions, impacts the throughput of femtocells in the network. For dealing with the issues like sensing of channel in low SNRs, hardware complexity, synchronization errors, and structure convergence, in this research work, a Paraunitary Filter Bank based spectrum sensing (PUFBMC) technique with power optimization for handling co-channel interference among macro–femto cellular networks has been studied. This approach monitors a channel by computing the energy of the received signal, so that the existence of a macro-cell subscriber over the desired channel is determined.

2.1.3 Review on Dynamic Spectrum Sensing and Resource Allocation Methods in Macro- Femto Networks

Xiang *et al.* [72] investigated about a basic novel paradigm by inclusion of CR in femtocell networks. Also, the newly introduced approach is capable of converging very rapidly with a normal value of just five iterations, and it can attain around two percent additional average capacity compared to the fixed power control mechanism. The results of simulation show that cognitive radio facilitated femtocells can attain greater capacity compared to the femtocell networks that do not use agile spectrum access. The results from simulation as well indicate that the newly introduced approach without using any iteration could accomplish approximately double of the average capacity with the help of the coloring technique when the number of available channels is not greater than five.

Li *et al.* [73] discovered the optimal sensing policy within the class of myopic policies. It comprises of two important steps (1) Design of a centralized SS architecture which lets the entire accessible primary spectrum holes to be exploited;

and (2) Introduction of sub-optimal myopic sensing policies with minimum complexity deployments and performance near to the myopic policy.

Baldo *et al.* [74] studied about a Dynamic Spectrum Access technique that lets the users to have opportunistic and effective access to the channels that are available for communications. An assessment of the novel solution is carried out in order to evaluate its performance with regard to another system as well as scenario parameters; the results obtained indicate that the novel solution is practical, has the capability of rendering satisfying performance, and desirable for implementation in practical systems.

Bose and Natarajan [75] took a WiMAX network into consideration having both MBS and low-power FAPs. In contrast to the conventional ED scheme, a cyclostationary-based SS is more efficient when handling with inaccurate knowledge of channel and signals. In addition, this technique has more efficiency compared to ED at low SNR ratio.

Le Treust and Lasaulce [76] presented a decentralized multiple access channels where every transmitter desires to selfishly increase the efficiency of energy transmission. Transmitters are supposed to freely select their power control policy and have interaction multiple number of times. Both the analytical and simulation outcomes are offered in order to differentiate the performance of the newly introduced power control policies with that existing policies such as one-shot and stackelberg games.

Buzzi and Saturnino [77] suggested a game with non cooperative power control for attaining maximum energy efficiency with a minimum fairness imposed on the maximum obtained powers of the SUs. The game taken into consideration is revealed to accept a distinct Nash equilibrium, also in the case, where the energy efficiency is increased as per both the transmission power and selection of the linear uplink receiver. Numerical simulations affirm the mathematical results over the presence and distinctness of the Nash equilibrium, confirming the efficiency of the outcomes received through the huge system analysis, and indicates that secondary users offer an advantageous effect on the entire network throughput, at the cost of a modest decrease in the performance of the PUs.

Ko and Wu [78] examined two important design challenges in OFDMA femtocell networks, i.e., resource allocation and access control. The contributions made are threefold: 1) develop a resource allocation scheme, which collects the actual sensitive traffic information of selfish users. 2) The newly introduced technique attains an effective and reasonable resource sharing. 3) Depending on the new scheme, incentives are created for the subscribers for sharing their femto base stations with the public users. This enhances the total system performance further.

Ahmed *et al.* [79] suggested a scheme for OFDMA femtocells based on Dynamic Resource Allocation Management Algorithm (DRAMA). The newly introduced mechanism focused on the satisfaction of the Femtocell Access Point (FAP) owners and lets the available resources to be utilized to the maximum depending on the congestion existing in the network. The performance characteristics indicates that more number of random users get connected to the FAP with no compromise made on the satisfaction of the FAP owners permitting the macrocell in getting a huge number of users offloaded in a thick heterogeneous network.

Le *et al.* [80] suggested an optimal design based on Semi-Markov Decision Process (SMDP) for the admission control. Also, a new distributed power adaptation algorithm in femtocell is devised that, in turn, converges to the Nash equilibrium of a respective power adaptation game reducing the energy consumed by the femtocells whilst still having the individual cell throughput maintained in the network.

Marshoud *et al.* [81] introduced a game-theory based hybrid access motivational model. The newly introduced model motivates the femtocell owners to share the resources with MUs, and therefore, resource allocation with more efficiency can be acquired. The resource allocation is optimized by the Genetic Algorithm (GA). Simulations are carried out where a modified form of the Weighted Water Filling (WWF) algorithm is exploited in the form of a standard. The newly introduced model, in comparison with WWF, attains more efficiency with regards to resource allocation in terms of the throughput of the system and resource usage.

Liu *et al.* [82] explained about a iterative algorithm between sub channel and power allocation known as the distributed resource allocation is proposed that needs no cooperation among the two-hierarchy networks. At last, a macrocell link quality protection process is suggested in order to ensure the QoS of the macrocell UE to prevent critical cross-tier interference from femtocells. The results of simulation indicate that the newly introduced algorithm is capable of achieving excellent performance gains in comparison with the pure water filling algorithm.

Ha and Le [83] suggested the formulation for the problem of uplink resource-allocation and introduced an optimal exhaustive search algorithm. Afterwards, the new algorithm is extended in three diverse directions, which are the, resource allocation with rate adaption for FUs, downlink context, and hybrid access mechanism where few MUs are permitted to connect with neighboring FBSs to enhance the performance of the femto tier. At last, the simulation results are studied for demonstrating the necessary performance of the newly introduced algorithms.

Sundaresan and Rangarajan [84] studied a new solution based on the location-based resource management for balancing the maximal reuse from FCs. The extensive analysis suggests that along with rendering enhanced indoor coverage, and diligently developed resource management solutions, which leverage spatial reuse, femtocells offer a great capability of increase in two-fold system performance.

2.1.4 Review on Imperfect Spectrum Sensing and Resource Allocation Methods in Macro-Femto Cellular Networks

But, as far as the best of the literature, resource allocation for cognitive FC network with combined consideration given to interference management, imperfect spectrum sensing, and interference uncertainty has not been addressed in the earlier works.

Gao *et al.* [85] examined the energy efficient resource allocation mechanism for OFDM based CR networks along with practical spectrum sensing. The results of simulation indicate that the newly introduced resource allocation mechanism can attain a greater energy efficiency compared to the one that maximizes the potential of the CR networks. At the same time, it can safeguard the general communication of every PU in comparison with the approach that does not consider sensing errors.

Chai *et al.* [86] focused on the maximization of both the fairness and capacity among the users. The optimization problem of resource allocation is devised and after this, an immune clonal based algorithm is introduced. The resource allocation problem is resolved by isolating the power and subcarrier allocation in two steps.

Zhu *et al.* [87] dealt with the Spectrum Allocation (SA) challenge in multi-tier CR networks. As a result, a suboptimal SA algorithm comprising of two parts is proposed: a subcarrier allocation realized by the immune algorithm, and a power control part making use of an enhanced sub-gradient technique. In order to further improve the performance of this technique, these two modules are executed in parallel, and the sequence gets repeated twice. Comprehensive experiments are carried out, demonstrating that the proposed technique outperforms better than the other available algorithms.

Huang *et al.* [88] investigated a sensing-based RA scenario in cognitive femtocell networks and an effective Distributed Imperfect-spectrum-sensing-based Resource Allocation (DIRA) algorithm. In addition, optimal allocation of power considering the practical spectrum sensing and interference uncertainty is carried out employing the newly introduced Chance-constrained Power Optimization (CPO) algorithm. Bernstein's approximation is carried out in order to have the chance constraint more tractable. The results of simulation show that the DIRA algorithm can yield substantial fairness amongst the femtocells and meanwhile, increase the overall data rate of the cognitive femtocell network.

Zhang *et al.* [89] highlighted on the RA issue in the UL transmission of an OFDMA based CR network. A new Particle Swarm Optimization (PSO) based joint uplink subchannel and power allocation algorithm is proposed for solving this resource allocation issue. The results of simulation exhibit the efficiency of the newly introduced algorithm.

Bedeer *et al.* [90] devised a Multi objective Optimization (MOOP) scheme for investigating the optimal link adaptation issue of OFDM-based CR networks, where SUs can have opportunistic access to the spectrum of PUs. The optimization issue enforces predetermined interference limits for the PUs, ensures the quality of service of SU in terms of a BER, and meets a transmit power budget and also a maximum number of assigned bits for each subcarrier. The results of simulation show the performance of the newly introduced algorithm and show the superiority of the MOOP scheme in comparison with single optimization techniques studied in the literature, with no added complexity. Moreover, the results indicate that the performance of the newly introduced algorithm nears to that of a thorough search for the discrete optimal allocations along with a considerably decreased computational effort.

Zhou *et al.* [91] examined the resource and pricing allocation techniques in the cross-tier cognitive femtocell networks, where the MCs and FCs are functioning over the same band of frequency. Dissimilar from the conventional underlay-based networks with just single price, in the newly introduced sensing-based networks, double prices are followed with respect to the vacant and busy states of the macrocell. The results of simulation reveal that the newly introduced mechanism can enhance the energy efficiency considerably in spectrum sharing femtocell networks.

Montazeri and Alavi [92] investigated the RA issue in a two-tier OFDMA based HetNets, where the FCs employing a closed access technique are facilitated with a CR function for identifying the radio environment such that they can share the subchannels with the macrocells without creating additional interference to the MUs comes under the coverage of the femtocells. The results of simulation indicate that proposed technique can enhance the throughput of the FUs with nearly no changes made in the infrastructure of the cellular networks.

Razaviyayn *et al.* [93] took a CR system into consideration with one PU and multiple SUs. In this Stackelberg game mechanism, PU (leader) declares the prices for the tones available such that a system utility is increased. The results indicate that this proposed scheme is polynomial time solvable under specific channel scenarios. The newly introduced technique is decomposable all across the tones and offers more power efficiency compared to the Iterative Water-Filling Algorithm.

Kang *et al.* [94] examined the price-based RA techniques for two-tier femtocell networks, where a central macrocell gets underlaid along with distributed femtocells, all working over the same frequency band. Numerical examples are provided in order confirm the studies presented. It is revealed that the newly introduced mechanisms are efficient in resource allocation as well as security of macrocell for the uplink as well as downlink transmissions in spectrum-sharing femtocell networks.

2.2 SUMMARY

In the existing literature several methods are explained based on the frequency resuse concept like FFR, SFR to resolve the co-tier co-channel interference problem. In this thesis an EFR is proposed to solve the co-tier co-channel interference problem. To solve the cross-tier interference problem several power allocation and resource allocation algorithms are addressed in the literature, here in this thesis by incorporating PUFB based cognitive spectrum sensing concept in the Femtocells cross-tier interference problem has been solved. Several optimization techniques are addressed in the literature for dynamic spectrum allocation, in this thesis a game theoretic approach is proposed with practical spectrum sensing considerations.

This chapter discusses the details about various resource allocation, spectrum sensing, dynamic spectrum sensing, power allocation, imperfect spectrum sensing, game theory techniques to reduce the interference in both femtocells and the cognitive femtocell networks along with macrocell.

CHAPTER 3

INTERFERENCE MANAGEMENT IN FEMTOCELL NETWORKS THROUGH EFFICIENT FREQUENCY REUSE

3.1 INTRODUCTION

In present days, Mobile network services turn out to be important for the whole world. Rising attractiveness of wireless systems has created an improved capacity demand. Novel multimedia services as well as greater data rate application need greater quality links as well as greater capacity. By means of bringing the transmitter as well as receiver nearer to one another, we can enhance the system capacity of a wireless links that create gains of greater quality links as well as additional spatial reuse. So as to improve indoor coverage, Home Base Stations called as Home eNodeBs (HeNBs) in LTE or Femtocell Access Points (FAPs) is an appropriate solution. FAPs are low-power base stations linked to the macrocell by means of utilizing IP-based wired backhaul (for instance Digital Subscriber Line (DSL)). Because of the dense deployment of femtocells, there exists more severe co-channel interference among the co-tier femtocells. There is a superior likelihood of existing robust co-channel interference amongst FCs as FAPs are arbitrarily set up by end users in a random manner. Therefore, it is vital to implement an effective interference mitigation technique among co-channel FAPs to reduce co-tier co-channel interference [26].

In this chapter, an Efficient Frequency Reuse (EFR) method is proposed for OFDMA based femtocell networks to reduce the co-channel interference among FAPs. Usually, adaptive resource allocation is more suits to network modifications, for instance unbalance traffic distribution as well as FAPs ON/OFF and therefore produces a greater gain when matched up with static ICIC [95]. With the intension of realizing the EFR technique, resource allocation for femtocells is considerably significant. There are many literatures addressing the stating Sub-Channel Allocation (SCA) dependent upon graph colouring.

The main goal of this research is to allot numerous SCs for every FAP provided the interference graph. In the Dynamic Frequency Reuse (DFR), initially, the central controller allots diverse SCs to FAPs dependent upon the interference graph and after that assigns numerous SCs idle by adjacent FAPs. Therefore, for improving the system capacity, FAPs could contain one or more SCs [96]. Collaborative SC allocation in Cognitive FCs dependent upon the cooperative game theory is conversed in present research [97]. In the current study, Coverage analysis of cognitive femtocells is conversed [98].

In the proposed EFR technique, the available SCs are split into Primary Sub Channels (PSCs) as well as Secondary Sub Channels (SSCs) with different power levels. PSCs are orthogonal to each other. A PSC Self-Configuration (PSC-SC) algorithm is presented dependent upon game theory and graph colouring technique. Here every FAP needs to get numerous PSCs, instead of getting a single PSC. The PSC-SC algorithm contains several benefits for instance fast convergence, less signalling overhead, greater spectrum utilization, less complexity, and good fairness. SSCs are allotted with less power in case of non-availability of PSCs. Interference Known Resource Allocation (IKRA) is implemented that executes in every FAP independently for enhancing intra-cell resource allocation.

3.2 FREQUENCY REUSE

In present years, mobile multimedia data traffic seen vast annual development rates [99-100] from 2G to present 4G with the more advanced features. In the direction of attaining the greater data rates in addition to improve the spectral efficiency, the Long Term Evolution (LTE) is developed by using a multicarrier modulation scheme called OFDM. At the present times, the insufficient of radio spectrum is an important issue, to address this problem; frequency reuse is selected as a suitable candidate to solve these issues. Figure 3.1 shows the basic frequency reuse model used in cellular networks. As a result that one proficient means of spectrum resource utilization is employing advanced frequency reuse techniques like Fractional Frequency Reuse (FFR) and variants of it. The resources like frequency as well as time are allotted to users in an orthogonal way. On the other hand, when the similar sub-carriers are utilized by diverse users amongst nearby cells mainly for cell edge users, the Co Channel Interference (CCI) problem would take place. Suitable Inter-Cell Interference Coordination (ICIC) method must be important in order to increase the capacity as well as throughput of the system [101-104]. Enhanced ICIC and Further enhance ICIC techniques are addressed in the release 8 and 9 of 3GPP LTE and LTE-A standards. These techniques are used to avoid the interference in co-channel macrocells. In this module an ICIC technique is proposed to address the co-channel interference issue in co-tier femtocells.

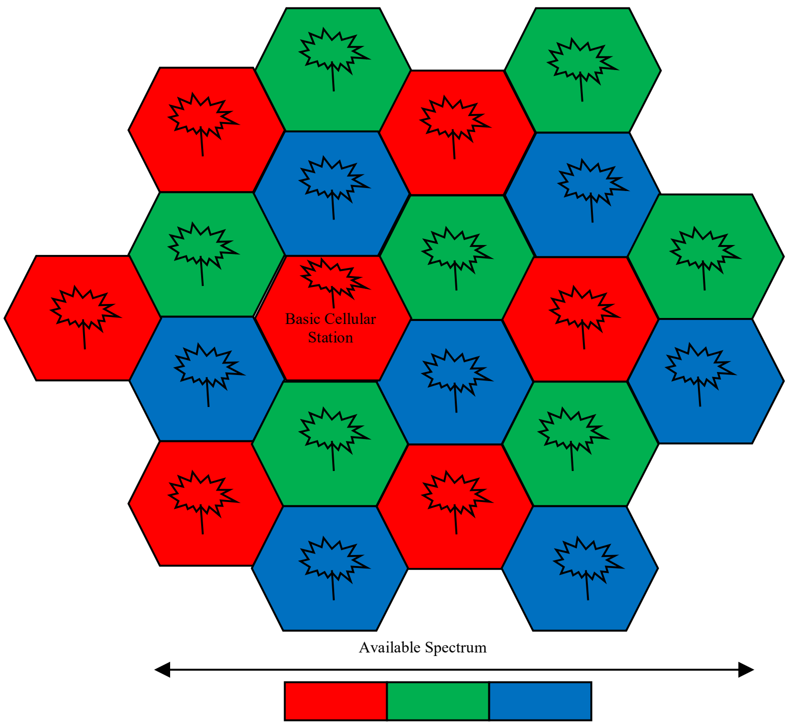


Figure 3.1 Basic Frequency reuse model

In recent times, for indoor coverage extension, LTE designed a femtocell. At the present time, the femtocell turns out to be widespread as a novel emerging cellular revolution. Essentially, femtocell is like as a Wi-Fi Access Point, it is known as Home Node B (HNB) or also called Home eNode B (HeNB) [105]. Figure 3.2 depicts the conception of FC networks in which underlay in the macrocell network. This underlay concept is known as HetNets containing macrocell as well as Low Power Nodes (LPNs). which contains three characteristics that make it simple and additionally supple to set up for instance the LPNs are small in size, and contain a low transmission power in addition it is cost efficient. The categories of LPNs set up in heterogeneous network are Picocell, Femtocell and Relay Station [106].

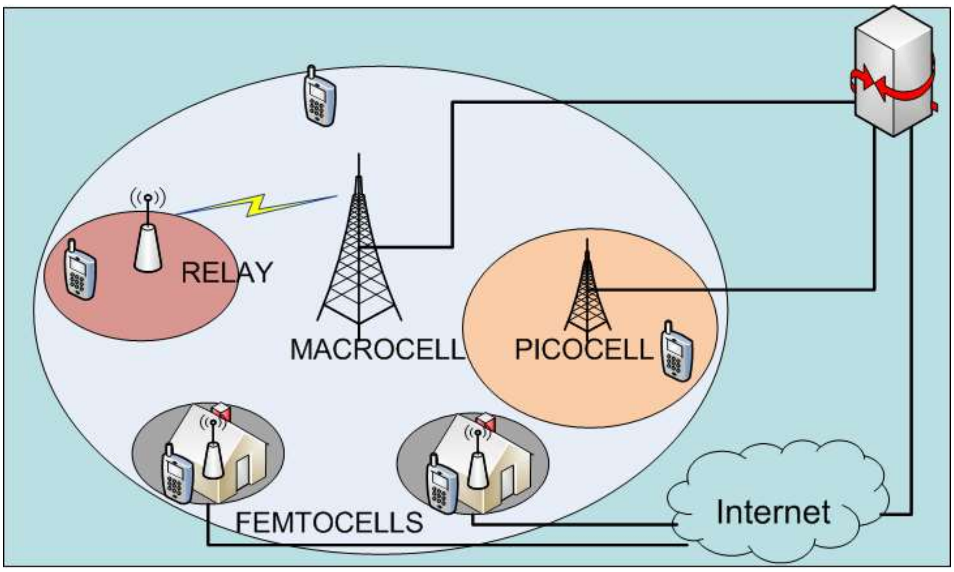


Figure 3.2 The Femtocell Deployment in HetNet

Effective frequency allocation for macrocell as well as femtocell networks is a main step on the way to effective network deployment. Co-channel allocation of spectrum resources results in higher Spectral Efficiency (SE) at a cost of QoS, when orthogonal channel allocation brings about a greater quality of service, and less interference at the cost of reduced spectral efficiency. Hybrid co-channel as well as orthogonal channel allocations is very competent frequency allocation techniques.

Numerous frequency allocation techniques were studied for MC networks. Raising the frequency reuse factor (for instance Reuse-3) could reduce interference from adjacent cells and improve the performance of cell-edge when matched up with Reuse1, at the cost of SE [107]. Soft Frequency Reuse (SFR) was presented in [108] like a combination of Frequency Reuse-1 and Reuse-3 techniques. The notion of FFR is utilized for the identical purpose, other deviations of FFR as Partial

Frequency Reuse (PFR), and Soft Fractional Frequency Reuse (SFFR) were presented for macrocell networks [109].

On the other hand, the FAPs are set up by end users in a random fashion creating a former frequency planning becomes infeasible. The above stated techniques need frequency planning; those could not be suitable for employing femtocell network. This research target is to develop an Efficient Frequency Reuse (EFR) method for femtocell networks to reduce the co-channel interference among the femtocells and to improve the performance of co-existence macro-femtocell networks.

3.3 SYSTEM MODEL

Whenever FAP is switched on it has to register to the corresponding macro eNodeB. It is done via the wired backhaul for instance Digital Subscriber Line (DSL) cable which provides information exchange such as the carrier frequency and the whole frequency band available to femtocells. After that every FAP utilizes this info in order to configure itself in addition carry out intra-cell resource allocation. Taking the characteristics of the femtocell network, the proposed method has the features such as distribution, adaption, scalability and low signalling overhead.

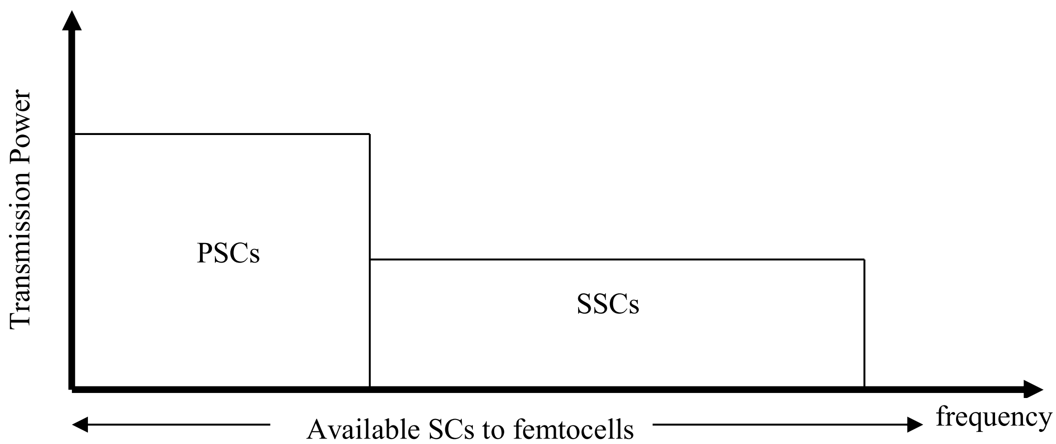


Figure 3.3 Scheme of proposed EFR

It is well known that SFR provide a simple and efficient method to mitigate inter-cell interference for cellular networks. As depicted in Figure 3.3, Motivated by the SFR technique, in the proposed EFR technique every Femtocell Access Points splits the whole SCs accessible to femtocell networks, denoted as A, into PSCs and SSCs, here collection of PSCs as well as SSCs of FAP i are correspondingly represented as A_{PSC}^{i} and A_{SSC}^{i}. Subsequently, also $A_{SSC}^{i} = A \backslash A_{PSC}^{i}$. and a transmit power ratio β is introduced, $P_{PSC}^{i} = \beta P_{SSC}^{i}$, where P_{PSC}^{i} and P_{SSC}^{i} are power masks on PSCs and SSCs, respectively.

Consider the system utilizes cell-specific orthogonal reference signals. As a result, the interference got from diverse Femtocell Access Points is segregated. When the interference produced by other Femtocell Access Points with P_{PSC}^{i} exceeds a predefined threshold θ, then the Femtocell Access Points is known as its neighbor Femtocell Access Points. This FAP should safeguard its users from the interference produced by its neighbor. Therefore, PSCs of neighbor Femtocell Access Points must be completely orthogonal to one another, denoted as

$$A_{PSC}^{i} \cap A_{PSC}^{j} = \emptyset, \forall j \in N_i \tag{3.1}$$

where, N_i represents the group of neighbor Femtocell Access Points of ith FAP. According to the above description seen that the proposed EFR Scheme is applied for femtocell networks can be viewed as the extension of SFR. In the regular cellular network, the frequency reuse factor is normally fixed, i.e. 3, that decides the frequency partition. On the other hand, the femtocell network typifies random deployment with the help of the end users when matched up with the regular cellular network. This will produce a superior challenge to frequency partition. The EFR scheme contains two algorithms, PSC-SC algorithm that allots sub channels with various power levels functioned as inter-cell PSC coordination as well as IKRA algorithm worked as intra-cell resource allocation, respectively.

3.3.1 Primary Sub-Channel Self- Configuration Algorithm

Dependent upon game theory, a PSC self-configuration (PSC-SC) algorithm functioned as ICIC is presented that gives a theoretical basis for femtocell. SCs are split into Primary SCs (PSCs) as well as secondary SCs (SSCs). PSCs amongst adjacent femtocells are orthogonal. Every FAP needs to get numerous PSCs, instead of just one PSC.

The main objective in these studies is to allot numerous SCs for every FAP provided the interference graph. Therefore, many versions of the original graph coloring technique are presented. Therefore, FAPs could have one or numerous SCs for the purpose of augmenting the system capacity. With the aim of increasing the spectrum utilization with a reasonable means, FAPs must be allotted numerous PSCs provided the interference graph. Before giving the near optimal number of PSCs allotted to every FAP, firstly introduce the subsequent notations [110].

- ***Subgraph induced by vertex*** *i. Consider* G_i*denote the subgraph induced by vertex ithat is represented like the graph contains vertex i in addition to its adjacent vertices.*
- ***Degree of vertex*** *i. Consider* d_i*denotes the amount of vertex i that is represented by means of the amount of adjacent vertices.*
- ***Clique number of vertex*** *i. Consider* c_i *denote the clique amount of vertex i. A clique in known as an undirected graph, which is a subset of the vertex set, wherein there is an edge connecting the two for every two vertices. A maximal clique is a clique, which could not be prolonged by adding an additional neighboring vertex. The amount of vertices in a maximum clique in subgraph induced by vertex i is known as the clique amount of vertex i.*
- ***Conflict-free PSC allocation****. the subsequent condition must be fulfilled by the PSC allocation profile of every FAP:*

$$\mu_i(A_i, A_{-i}) = 0 \tag{3.2}$$

subject to

$$\sum_{k=1}^{K} a_k^i = k_i, \forall i \in \{1, \dots, N\} \tag{3.3}$$

The near-optimal number of PSCs allocated to each FAP is given as

$$k_i = max\{\lfloor K/c_i \rfloor, 1\}, \forall i \tag{3.4}$$

where k_i represents target amount of PSCs allotted to FAP i, c_i is known as the highest clique number of G_i, $\lfloor . \rfloor$ is known as the floor function, K represents total number of SCs. The PSC-SC algorithm based on the protocol interference model and show that how the femtocell network reaches stabilization of each FAP selects its optimal strategy only according to strategies of its two-hop neighboring FAPs. The steps involved in the PSC-SC are as follows:

Neighbor table construction

As depicted in Table 3.1, every FAP builds its neighbor table, which encompasses the subsequent info regarding its adjacent FAPs, that is to say the identification (ID), collection of adjacent FAPs N_i, degree d_i, clique number c_i, and equivalent allotted PSC set A^i_{PSC}. FAP i must add FAP j into its neighbor set when the interference from FAP j surpasses the predefined threshold θ. Subsequently finding out the entire neighbors, every FAP must broadcast its neighbor set to its neighbors.

Table 3.1. Neighbor table

ID	Set of neighbors	Degree	Clique number	PSCs
i	N_i	d_i	c_i	$A^{(i)}_{psc}$
j	N_j	N_j	c_j	$A^{(j)}_{psc}$
…	…	…	…	…
…	…	…	…	…
…	…	…	…	…

Topology change

The network topology will be modified if a FAP is turned on/off. In every update interval, every FAP must verify the modification of the local topology. It must reset its approach to be the empty set and recalculates its degree d_i as well as clique number $c_i$when its local topology $N_i$is modified.

Updating sequence of neighboring FAPs

To control the strategy updating series of adjacent FAPs is a significant problem of the PSC-SC algorithm. The well-defined rules must assure that in every update interval, merely one adjacent FAP could bring up-to-date its strategy. Additional problem is how to decrease the conflict probability.

Regulate that FAPs who satisfy one of the following conditions (i)-(iii) wins opportunity to update their strategies.

- **i)** If the FAP contains the supreme clique number amongst residual neighbors, this FAP will get this chance to bring up-to-date its strategy in the present update interval.
- **ii)** The FAP with the highest degree would get this chance to bring up-to-date its strategy in the present update interval when numerous FAPs contain the identical highest clique number amongst residual neighbors.
- **iii)** The FAP with the highest ID would get this chance to bring up-to-date its strategy in the present update interval when numerous FAPs contain the similar highest clique number as well as degree.

3.3.2 Selection of Optimal Strategy

Conflict resolution cannot completely resolve conflicts due to the existence of conflict cycle. Hence regulate that the FAP containing conflicts must remain quiet in the subsequent update interval when it brought updated its strategy in the present update interval. In Figure 3.4, an instance of conflict resolution is depicted. Ideal strategy of FAP 2 is {1, 2, 3} or {4, 5, 6}. There is a conflict between FAP 2 and FAP 5, if FAP 2 chooses the strategy {1, 2, 3}. FAP 5 wins the chance to bring up-to-date its strategy with {4, 5, 6} since FAP 2 must remain quiet. Likewise, FAP 1 wins the chance to bring updated its strategy with {1, 2, 3} in the subsequent update interval. Like this the conflict amid the neighbors is solved.

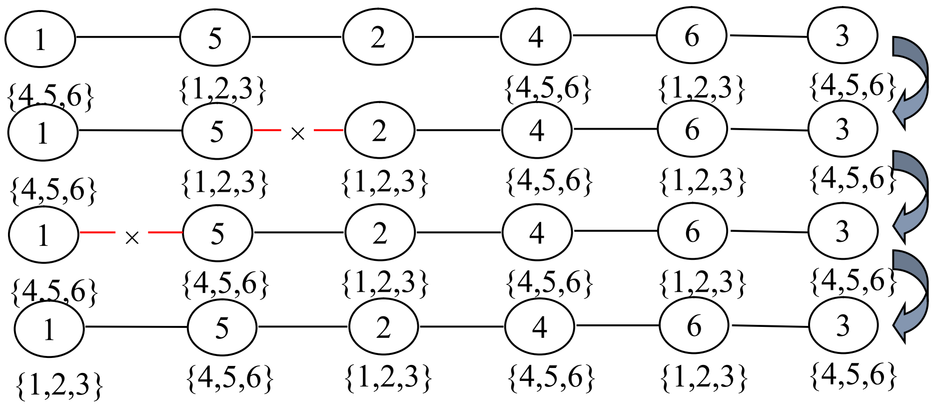


Figure 3.4 Conflict resolution with 6 SCs

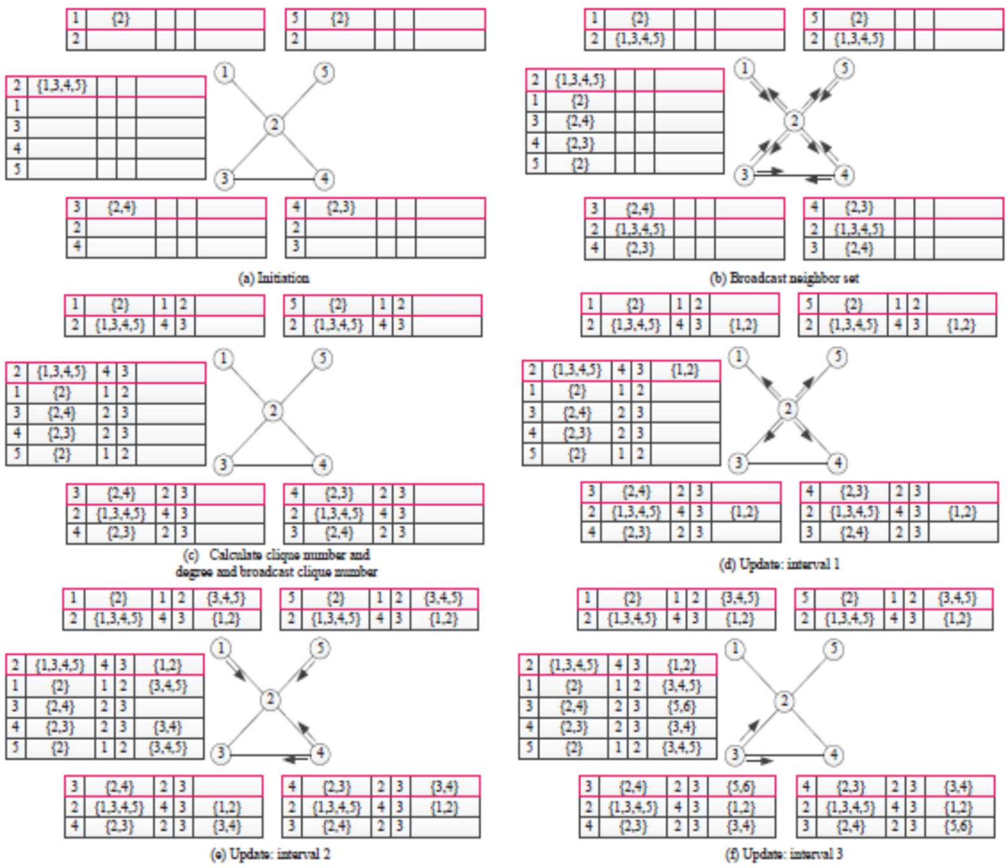


Figure 3.5 PSC-SC allocation with 6 SCs

In Figure 3.5, an instance of the PSC-SC process containing 6 SCs is depicted. Initially, every FAP finds its adjacent as well as broadcasts its neighbor set to each and every neighbors. In keeping with two-hop neighbor info, every FAP could compute the clique number as well as broadcast it to neighbors. As FAP 2 contains the highest degree amongst FAP 2, 3, 4 containing the similar clique number in update interval 1, it triumphs to bring up-to-date its strategy as well as broadcast the ideal strategy {1, 2} to the entire neighbors.

However, in update interval 2, as FAP 1 and FAP 5 are solitary nodes deprived of bringing up to date their strategies amongst their corresponding neighbor set, they get chances to bring update their techniques. Instead, as FAP 4 contains the greater ID compared to FAP 3, it could bring update its strategy. In update interval 3, FAP 2 and FAP 4 brought up to date their strategies, FAP 3 could bring update its strategy. After that the network attains stability in regard to PSC allocation.

3.3.3 Interference Known Resource Allocation Algorithm

An Interference Known Resource Allocation (IKRA) algorithm is implemented that runs independently in every FAP with the aim of enhancing the intra cell resource allocation. This method concentrates on the individual FAP so as to share resource amongst the Cell Edge User (CEU) as well as Cell Centre User (CCU). Take the frequency selective channel model as well as state the average channel gain in this manner

$$g_m^{(i,i)} = \frac{1}{K}\sum_{k=1}^{K} g_{m,k}^{(i,i)} \tag{3.5}$$

where, $g_{m,k}^{(i,i)}$ is known as the channel gain on SC k between FAP i as well as its user m. A channel quality indicator for every SC is,

$$\eta_{m,k}^{i} = \frac{g_{m,k}^{(i,i)}}{I_{m,k}^{F(i)} + I_{m,k}^{M(i)} + \sigma_0^2}, m \in F_i, k \in A \tag{3.6}$$

Where, F_i is known as the collection of active users related to i^{th} FAP. σ_0^2 denotes the thermal noise power over every SC. $I_{m,k}^{F(i)} and\ I_{m,k}^{M(i)}$ represent the interference from the macrocell as well as the femtocell, correspondingly. $I_{m,k}^{F(i)}$ is as follows,

$$I_{m,k}^{F(i)} = \sum_{j \in N_i} p_{m,k}^{j} \rho_{m,k}^{i} \, g_{m,k}^{(j,i)} \tag{3.7}$$

Where, $g_{m,k}^{(i,i)}$ is known as the channel gain on SC k amid user m of FAP i and FAP j. p_k^j is the allotted power on SC k of FAP j. When SC k is allotted to user m of FAP i, an indicator variable $\rho_{m,k}^{i}$ is represented as: $\rho_{m,k}^{i}$=1 and $\rho_{m,k}^{i}$=0, else. Therefore, every active user must be every so often quantify the interference on every SC as well as feed back to its related FAP. The feedback info is utilized to enhance resource allocation. The transmission modulation format as well as channel code rate is identified dependent upon the outcomes of SC as well as power allocation. Provided the highest transmit power, the attainable rate is computed as here B denotes the bandwidth for each SC. The function *f (.)* maps the SINR to the attained spectrum efficiency. After that the ensued rate of user m is in this manner,

$$R_m^i = \sum_{k=1}^{K} \rho_{m,k}^{i} r_{m,k}^{i} \tag{3.8}$$

The Cell-Edge User (CEU) experiences high pathloss and severe interference from neighboring femtocells. Therefore, the CEU contains a less SINR value matched up with the Cell-Center User (CCU). So, it is significant to alleviate interference for the CEU. Interference known resource allocation (IKRA) is proposed for solving resource allocation problem. The important notion of the research technique is that PSCs are allotted to CEUs containing highest precedence as well as CCUs unscrupulously access SSCs containing improved channel quality. Taking the pathloss compensation, the power allotted to SC k of user m is provided in this way

$$p_{m,k}^{i} = \begin{cases} min\{P_0 + \alpha PL_m^i, P_{psc}\}, k \in A_{psc}^i \\ min\{P_0 + \alpha PL_m^i, P_{ssc}\}, k \in A_{ssc}^i \end{cases} \tag{3.9}$$

Where P_0 is known as the target received signal power in dBm, as well as $\alpha(\leq 1)$ is represented as an adjusted factor, called pathloss compensation factor is chosen in keeping with the total power constraint. Provided the power mask P_{ssc}, the user could right to use this SSC just while the attained SINR is greater than one needed by the least MCS. Underneath the IKRA algorithm, the femtocell is likely to place its CEUs into PSCs. Every FAP will simply utilize its PSCs for transmissions in the low-load case, by taking the absolute priority of PSCs over SSCs. There exists no inter-cell interference as PSCs amongst adjacent femtocell are completely orthogonal. When a higher bandwidth is required the FAP can augment its capacity by opportunistically accessing the SSCs.

3.4 SIMULATION RESULTS

An OFDM based macro-femtocell scenario is considered for simulation. In the each macrocell, 100 femtocells are randomly deployed, the users are distributed in macro and femtocells are based on a uniform distribution. The simulations are carried out in MATLAB software. Simulation parameters used for simulation are listed in Table 3.2.In this part discussed about the results obtained for the presented interference limited efficient frequency reuse method for the femtocell networks. The FAPs are uniformly distributed within the coverage area of macrocell base station (MBS) containing the radius of 1000m. For all the simulation, set the density of FAPs and change the amount of FAPs. The performance metrics considered for simulation are spectrum efficiency, fairness, spectrum utilization, throughput and outage probabilities.

Table 3.2 Parameters and typical values used for simulation

Parameters	Values
Carrier Frequency	2GHz
Bandwidth	10 MHz
No. of Subchannels	100
Total Tx Power of MBSs	46 dBm
Total Tx Power of FAPs	23 dBm
Noise power density	-174 dBm/Hz
Power on PSCs	10 dBm
Interference Threshold	-110 dB
Minimum separation distance from UE to associated FAP	0.2 m
Path loss of indoor/outdoor wall	5/ 20 dB
Standard deviation for log normal shadowing for MCs/ FCs	4/8 dB
Number of FAPs	100
MBS Radius	1000 meters

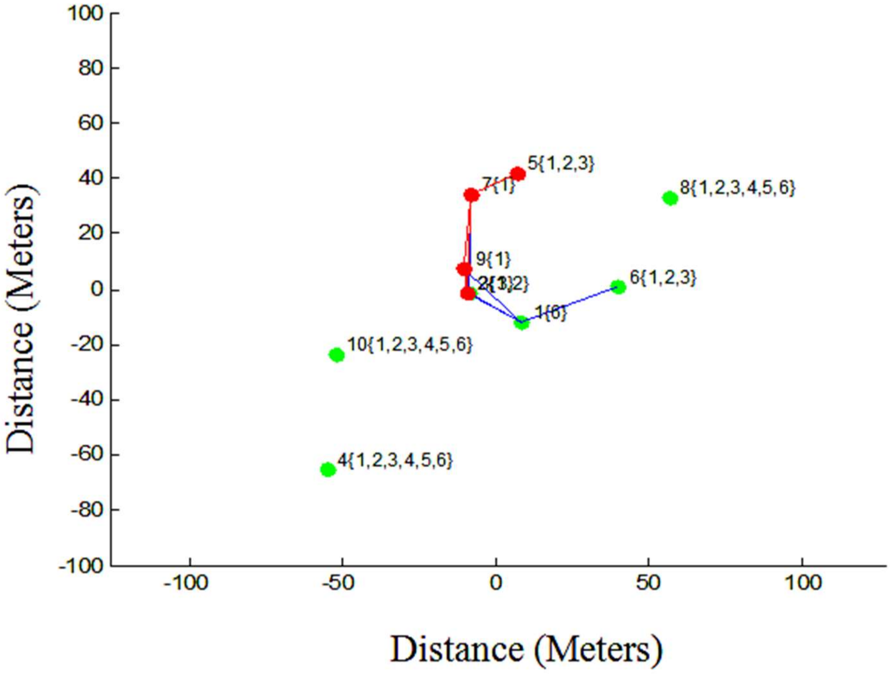


Figure 3.6 Interference Graph

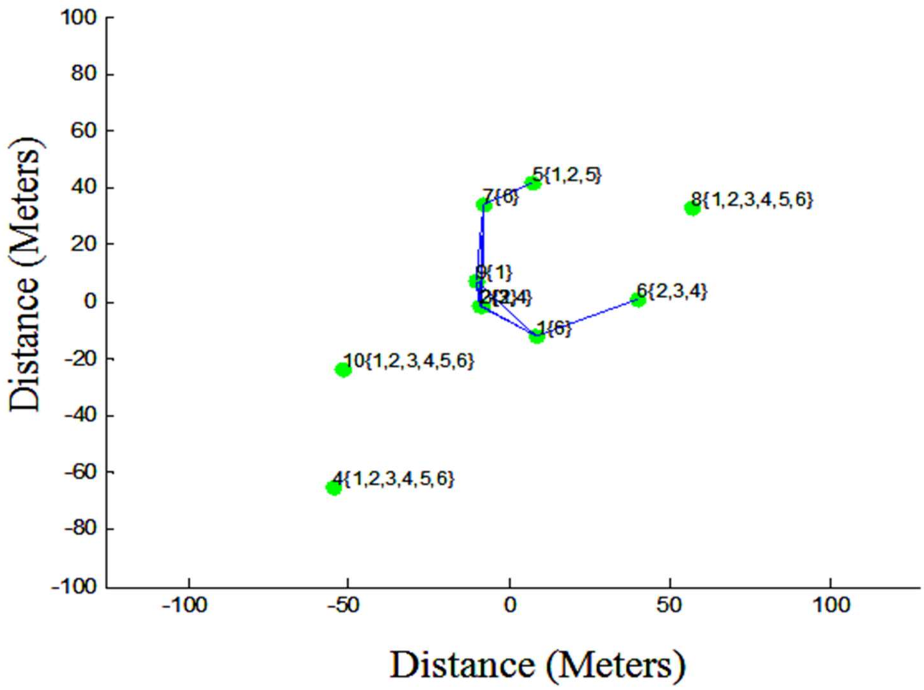


Figure 3.7 Conflict resolution

For explaining the conflict resolution process, here we considered an example with 10 FAPs and 6 subchannels. The FAPs are deployed based on the uniform distribution. When the subchannels are assigned to these FAPs there are is a chance of arising conflict among the neighbours is shown in the Figure 3.6. The conflict can be resolved based on the conflict resolution algorithm; the subchannel allocation after conflict resolution is shown in Figure 3.7. The FAP with conflict can obtain its optimal strategy during update interval. This conflict resolution is carried out by means of the presented PSC-SC algorithm.

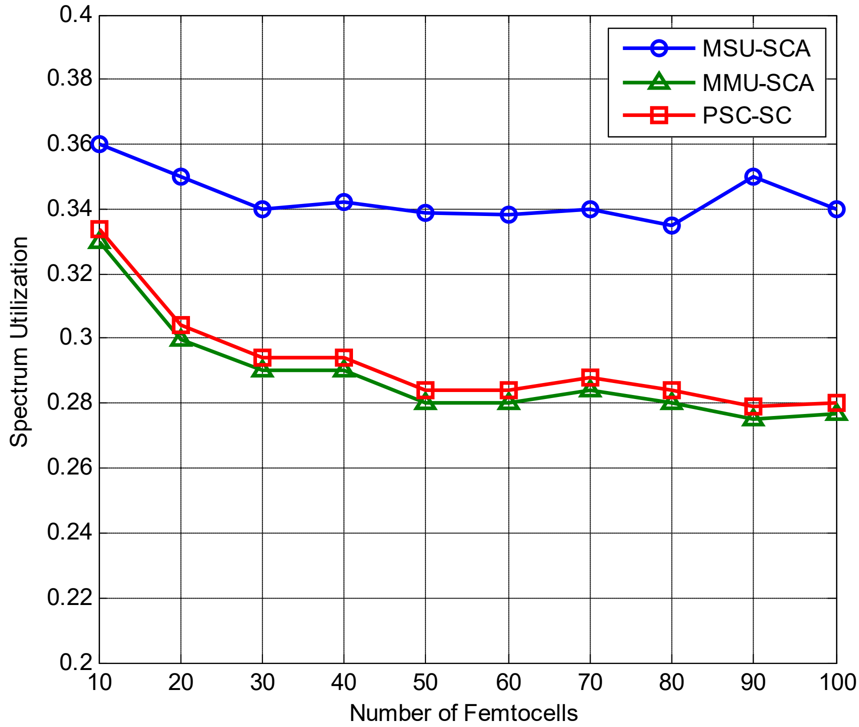


Figure 3.8 Spectrum Utilization with Increase in No. of FAPs

The above Figure 3.8 depicts the performance of Spectrum Utilization (SU) with the diverse number of FAPs with the similar density. The PSC-SC algorithm could attain up to 0.278 of spectrum utilization for 100 numbers of FAPs. In Table 3.3, the outcomes are discussed.

Table 3.3 Spectrum Utilization (SU) and Fairness Index for different number of FAPs

Parameter	MSU-SCA			MMU-SCA			PSC-SC		
	Number of FAPs								
	10	50	100	10	50	100	10	50	100
Spectrum Utilization	0.36	0.34	0.346	0.332	0.282	0.274	0.338	0.286	0.278
Fairness Index	0.55	0.55	0.55	0.8	0.81	0.82	0.75	0.746	0.740

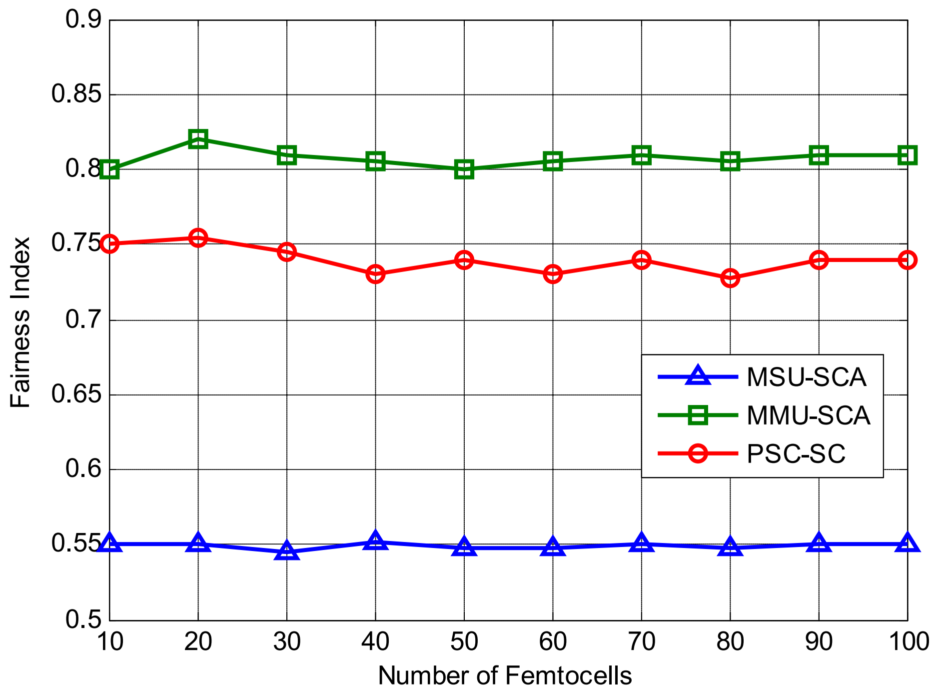


Figure 3.9 Fairness Index (FI) with Increase in No. of FAPs

The above Figure 3.9 depicts the performance of Fairness Index (FI) and the diverse amount of FAPs with the similar density. The PSC-SC algorithm could attain Fairness Index (FI) is approximately 0.740 for 100 number of FAPs. Suppose that, in every femtocell, two users are there. One is called CCU, who are arbitrarily distributed inside a zone with $0.2 < R < 10$, and next one is called CEU arbitrarily distributed inside a zone with 10 < R <20. The path loss models for femto-user as well as macro-user taking the wall penetration are correspondingly,

$$\text{PL (dB)} = 38.46 + 20log_{10}\text{R} + 0.7\text{R} + 5[R/10] \quad (3.10)$$

and

$$\text{PL (dB)} = 2.7 + 42.8log_{10}\text{R} + 20\ (14) \quad (3.11)$$

Here R is the distance between the transmitter and receiver.

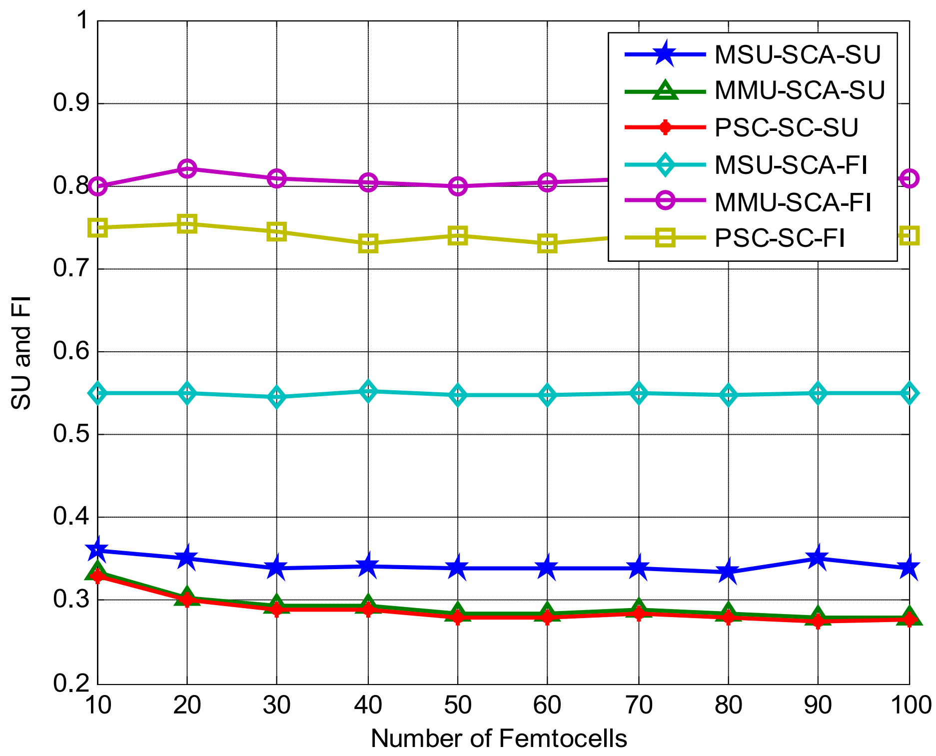


Figure 3.10 Trade-off between SU and FI with Increase in Number of FAPs

The above Figure 3.10 shows the tradeoff between SU as well as FI and the diverse amount of FAPs containing the similar density. The MMU-SCA algorithm gives higher fairness index but the spectrum utilization is less, whereas the MSU-SCA algorithm gives better spectrum utilization and lesser in terms of fairness index. The proposed PSC-SC algorithm is trade-off between the both, it gives optimal results in terms of spectrum utilization and fairness index which is indicated in Figure 3.10. It concludes that the proposed work performs better than the other two methods.

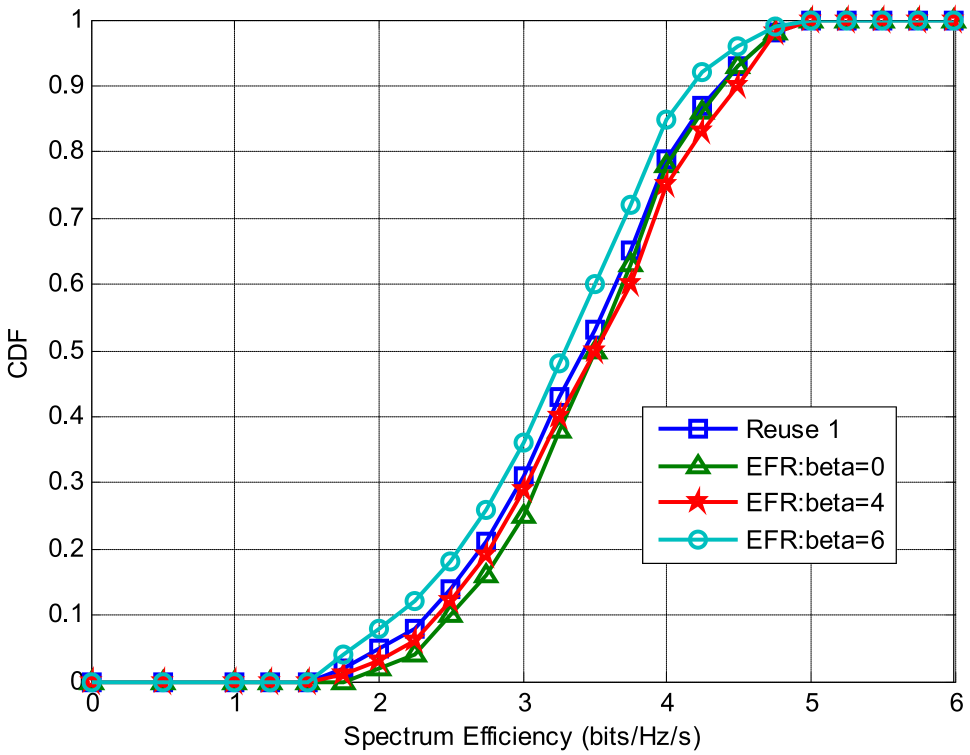


Figure 3.11 Cumulative Distribution Function (CDF) of Cell Edge User (CEU) with Change in Spectral Efficiency

The above Figure 3.11 shows the Cumulative Distribution Function (CDF) of CEUs with change in spectral efficiency. CDF defines a statistical distribution whose value at every possible outcome is the probability of getting that outcome or a lesser one. The proposed EFR scheme does superior when matched up with the Reuse 1 because of the enhancement of power allocation. Therefore, the attained gain of Reuse 1 is much lower than the one got by the EFR scheme in regard to spectrum efficiency of CEUs.

The Figure 3.12 shows the Cumulative Distribution Function (CDF) of spectrum efficiency of CCUs. The proposed EFR scheme is compared with the Reuse 1 which gives better performance. The key cause is that the interference undergone by CCUs is lower than the one obtained CEUs taking wall penetration.

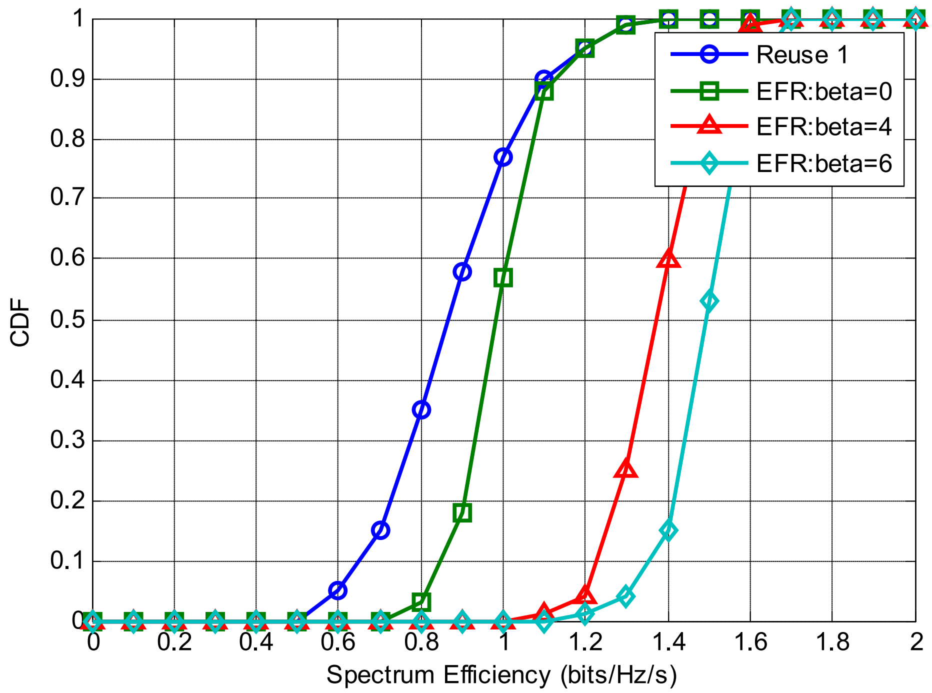


Figure 3.12 Cumulative Distribution Function (CDF) of Cell Center User (CCU) with Change in Spectral Efficiency

The Figure 3.13 depicts the amount of iterations with the diverse amount of FAPs with the same density. It concludes that the proposed work EFR takes only 16 iterations for 100 numbers of FAPs whereas other FFR and SFR takes 43 and 31 iterations. It concludes that the proposed EFR performs better than the other methods. These values are discussed in Table 3.4.

The Figure 3.14 shows the Macro user Throughput with the different number of femtocells. It concludes that the research work EFR performs quickly 9.7 Mbps to 100 numbers of FAPs whereas other FFR and SFR have provides 4.4 and 4.6 Mbps only. It concludes that the proposed EFR performs better than the other methods. These values are discussed in Table 3.4.

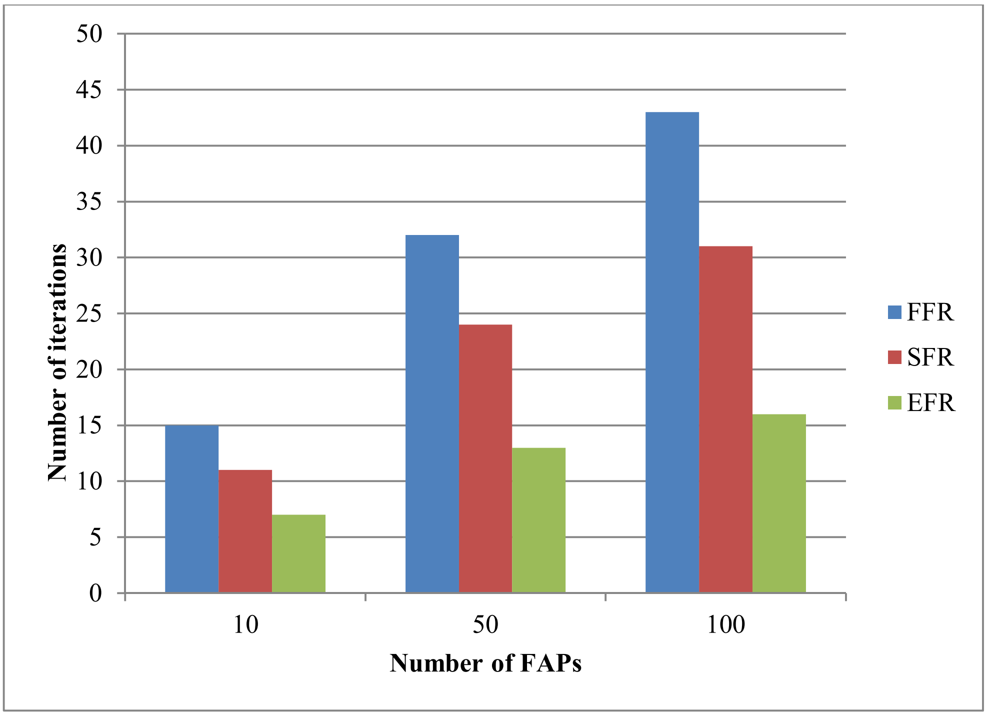


Figure 3.13 Number iterations with Increase in FAPs

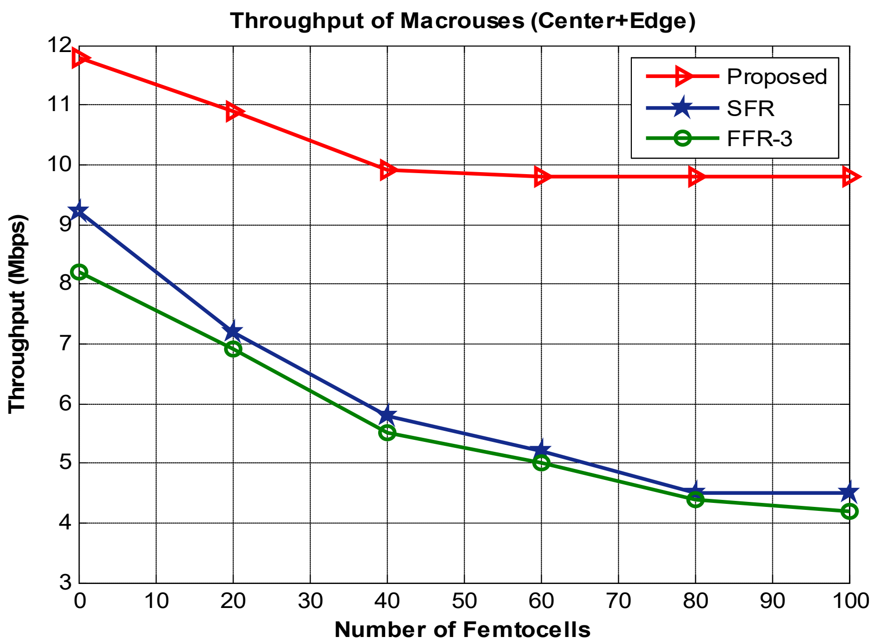


Figure 3.14 Macro (cell center + cell edge) users Throughput

The Figure 3.15 shows the Macro and Femto user Throughput variation with the different number of femtocells. It concludes that the research work EFR performs quickly 106 Mbps to 100 numbers of FAPs whereas other FFR and SFR have provides 78 and 89 Mbps only. It concludes that the proposed EFR performs better than the other methods. These values are discussed in Table 3.4.

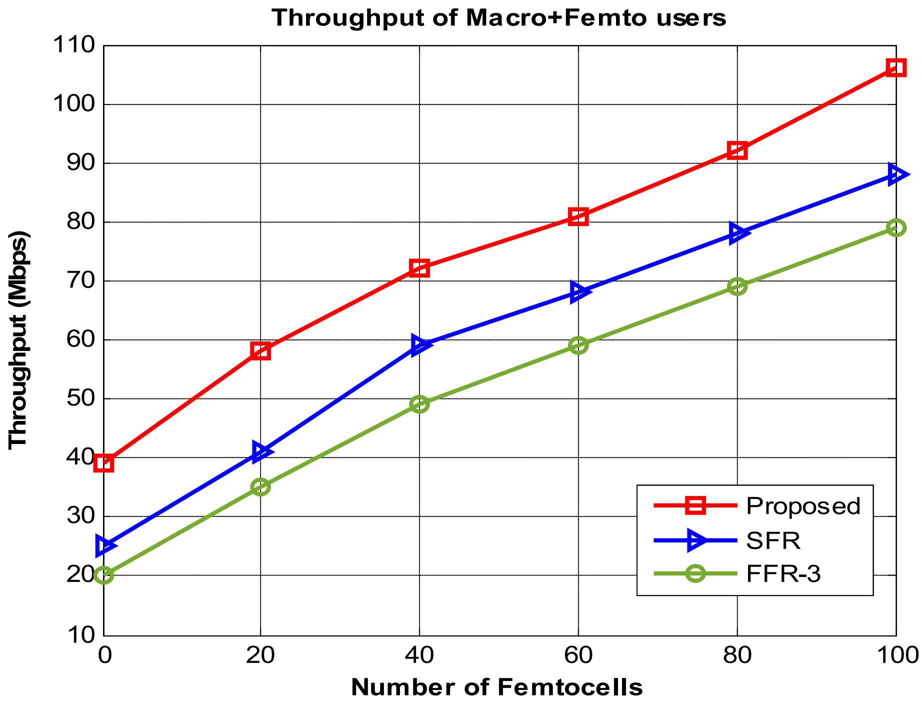


Figure 3.15. Throughput of Macro and Femto users

The Figure 3.16 depicts the outage likelihood of Macro users versus the different amount of femtocells. It concludes that the presented work EFR provides only 0.82 probability to 100 numbers of FAPs whereas other FFR and SFR provides 0.9 and 0.86 probability values. It concludes that the proposed EFR has lesser outage probability than other methods. These values are discussed in Table 3.4.

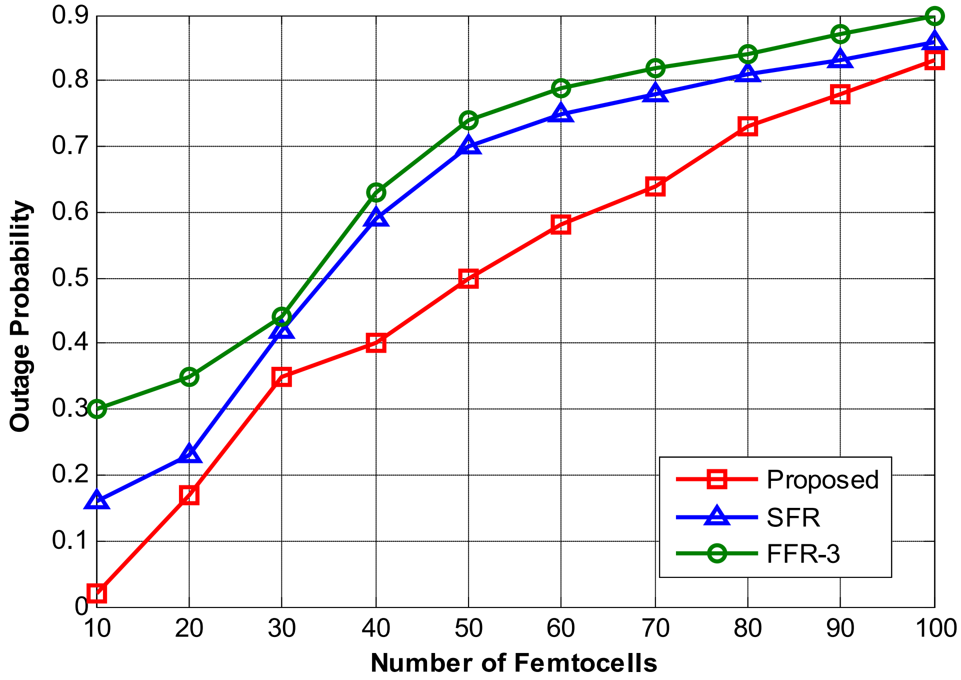


Figure 3.16 Outage Probability of the Macro users

Table 3.4 Performance comparison metrics vs. different number of FAPs

Parameter	**FFR**			**SFR**			**EFR**		
	Number of FAPs								
	10	**50**	**100**	**10**	**50**	**100**	**10**	**50**	**100**
Number of Iterations	15	32	43	11	24	31	**7**	**13**	**16**
Throughput of Macro users (in Mbps)	7.6	5.2	4.1	8.2	5.5	4.6	**11.3**	**9.8**	**9.7**
Throughput of Macro + Femto users (in Mbps)	25	52	78	31	62	89	**47**	**75**	**106**
Outage Probability of Macro user	0.3	0.72	0.9	0.16	0.7	0.86	**0.02**	**0.5**	**0.82**

3.5 SUMMARY

Interference Mitigation for femtocell networks can be done with the proposed EFR scheme due to its drastic reduction of complexity in the implementation and remarkable improvement in spectrum efficiency of CEUs. In EFR scheme, PSCs are being selected by each FAP by communicating with its neighbouring FAPs. The near-ideal amount of PSCs that are able to be allotted to every FAP is derived, with the intention of enhancing the spectrum utilization. Matched up with Reuse 1, the EFR scheme attained gain in regard to spectrum efficiency of CEUs containing a less influence on spectrum efficiency of CCUs.

CHAPTER 4

PARAUNITARY FILTER BANK BASED SPECTRUM SENSING TO AVOID INTERFERENCE IN MACRO-FEMTO CELLULAR NETWORKS

4.1 BACKGROUND KNOWLEDGE

In cellular wireless networks, the requirement for higher data rates and usage of less power is rising endlessly, whereas the ability given by the current macrocell networks is not fulfilling the demand. Investigations on wireless usage provides, above 50% of voice calls as well as 70% of the data traffic is generating from indoor users [111]. This experience stimulates the research and progress of FC networks, which demands every customer, to put in a low-cost, short-range and low-power home base station. Because of installation of huge femtocells the macrocell traffic will be offloaded, MC networks can concentrate their resources on the rest of the truly mobile users [11] [112].

While implementing the femtocell networks, issue occurs in sharing spectrum. The conventional spectrum allocation techniques for cellular networks are not suitable for these HetNets, because of the random deployment of femtocells [113]. Femtocells are operating in the same frequency band with the macrocell, with this the spectrum reuse efficiency will increases which in turn improve the capacity of the total network.

The extensive proliferation of wireless communications inevitably leads to the shortage of frequency spectra. On one side, wireless users find difficult to gain vacant frequency bands for communications. On other side, many frequency bands already allocated are unfortunately under-utilized and thereby resources are simply wasted. Even though all the radio spectrum is allocated to different users, services and applications, most of the time if you observe the spectrum, it shows that usage of the spectrum is actually quite low. The inefficient use of the spectrum necessitates a new communication technology, denoted as Cognitive Radio (CR). There are two types of users in CR technology called Primary User (PU) and Secondary User (SU). The one who require stable frequency spectra and have the rights of priority in using it for communications are known as PU or licensed users. Whereas, SU only needs to access spectra temporarily and can access the frequency spectra allotted to PU without causing interference [114]. Hence, the utilization of the spectrum is enhanced effectively. A CR supervises the utilization of spectrum activity of a primary user working in a provided licensed frequency band, and opportunistically makes use of it, when it is recognized as vacant. Hence, a key step in enabling CR is dependable and fast detection of an active primary user in a primary network. This functionality of CR is pointed to as Spectrum Sensing (SS).

4.2 COGNITIVE RADIO FEMTOCELL NETWORKS

Here, the CR technology was connected with the femtocell networks, a new paradigm takes place known as Cognitive femtocell. In which the cognitive femtocell finds the unused spectrum from the surrounding licensed systems for instance like macrocell and TV broadcast systems as shown in Figure 4.1. Femtocells users are limited in number and coverage is small these features makes the installation of CR concept into the femtocells. This is the main variation when compared with the cognitive radio macrocell networks, in which the channel availability might differ among the neighbour cells.

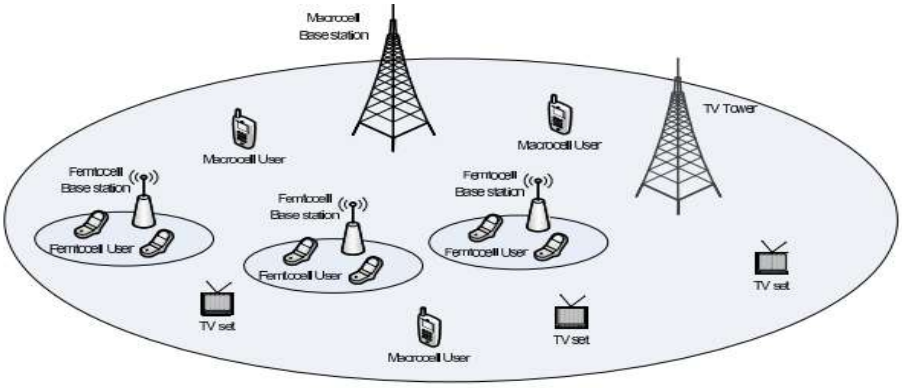


Figure 4.1 A Heterogeneous network consisting of co-existence of primary systems like TV and MCs with cognitive femtocells

The Figure 4.2 explains about the two-tier network consisting of macrocell with cognitive femtocells. Consider that a network consisting of one PU (macro user), one SU (femto user) and their corresponding Base Stations (BS).

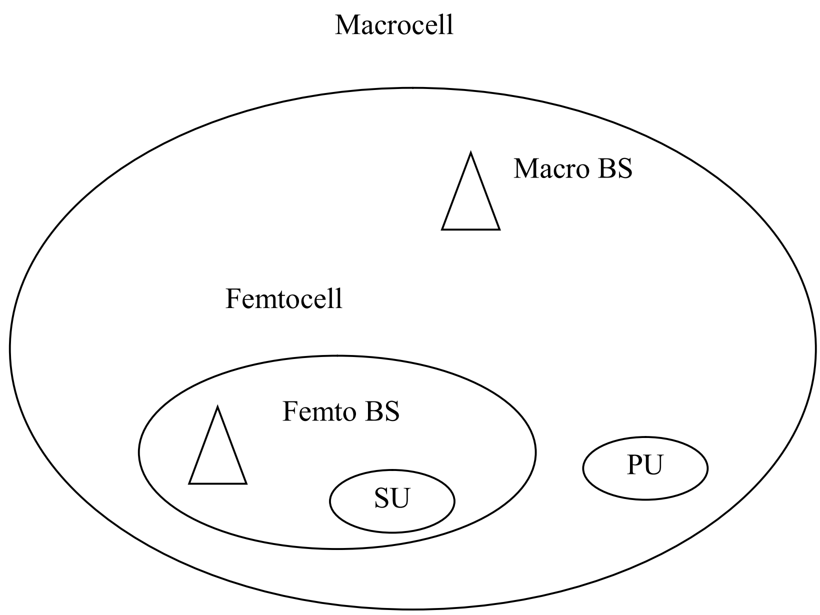


Figure 4.2 Example femtocell network with primary MU and secondary FUs

In cognitive femtocell, the SU does not contain any licensed spectrum of its own and it aims to broadcast the unscrupulously to the FBS over any vacant licensed spectrum. Similarly, the design of cooperative cognitive radio networks are visualized in [115]–[117]. This is modeled as a single server queuing system containing two classes of arrivals in which one class contains a strictly superior priority over the other class.

4.2.1 Spectrum Sensing Techniques

The main objective of Spectrum Sensing (SS) is to identify the existence of the idle channels from primary users. In literature, one could identify numerous kinds of spectrum sensing method which, generally, are segregated as Non-cooperative sensing, cooperative sensing, interference based sensing, spectral estimation and other sensing techniques. Spectrum sensing is executed in the time, frequency and spatial domain. This section gives an explanation of various spectrum sensing methods.

Figure 4.3 indicates the various kinds of spectrum sensing which exist in the physical layer. A CR can acquire required observations regarding the surrounding radio environment like existence of PUs and the look of white space through spectrum sensing.

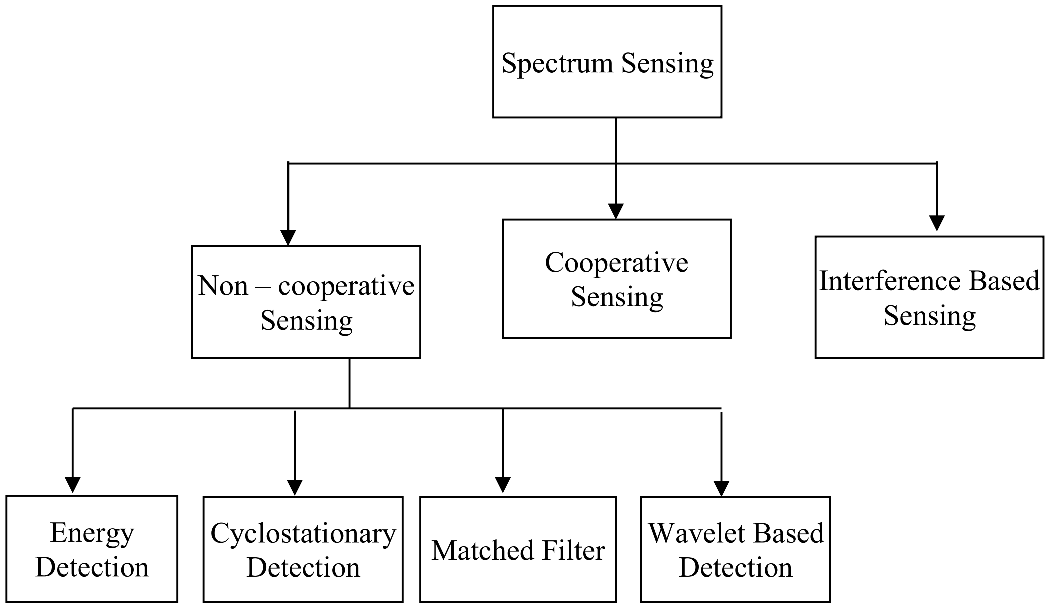


Figure 4.3 Different types of spectrum sensing in physical layer

In this module a novel spectrum sensing technique called Paraunitary Filter Bank (PUFB) based spectrum sensing is proposed and the results are compared with the conventional Energy Detection (ED) technique. PUFB method outperforms in terms of greater spectrum sensing capabilities like higher Probability of detection (P_d) and less Probability of false alarm (P_{fa}). This method is incorporated in the FAP to sense the surrounding macro spectrum to obtain the unoccupied channel information to assign it for the femto users. In this way the cross-tier interference between the macro-femto networks is going to reduce. Finally the performance of the system is tested for the three access techniques of the femtocell like closed, open and hybrid access modes.

The proposed PUFB spectrum sensing technique comes under the category of matched filter based detection.

Energy Detection (ED)

The ED is a non-coherent detection technique. Any prior knowledge of the PU signal is not necessary for this method to identify whether the channel is busy or not. When the PU information is not available, the energy detection [118] is the optimal method for spectrum sensing. In energy detection the output of the Band Pass Filter (BPF) is squared and associated over the sensing period. To recognize whether the primary user exists or not, the output of the integrator is compared with a threshold. Typically, energy detection based spectrum sensing performance deteriorates when the SNR reduces.

Matched Filter

To maximize the output SNR ratio for a provided input signal in the existence of additive Gaussian noise [119], a Matched Filter (MF) designed, which is a linear filter. Also in [120], the author demonstrated a matched filter based spectrum sensing for CR networks. Complete knowledge of the PU is required to sense the channel in the MF based spectrum sensing. In this technique the input signal is transmitted through a BPF, the output of the BPF is complicated with the match filter whose impulse response is same as that reference signal. The output of the matched filter is compared with a threshold value for identifying the presence of the PU.

Various methods were suggested to find the existence of PUs. In 5G, which is examined now, FBMC has increased to a high degree of interest as a potential candidate for 5G waveform. Here, FB technique for recognizing spectrum holes is examined in different multipath fading channels. In [121], an introduction to multicarrier modulations for transmission and detection is provided. In [122], the performance of ED method is examined by the author.

4.3 SYSTEM DESCRIPTION AND MODEL

A significant block in CR system is spectrum sensing block. The primary working of this block in every CR network is to monitor the PU movements and thus notify about the existence or absence of PU. In a CR system to recognize the

PU signal, the received signal obtained the receiver is provided by

$$y(t) \; = \; hs(t) + w(t) \tag{4.1}$$

where $y(t)$ the received signal at the receiver, h is is the impulse response of the channel, $s(t)$ is the transmitted signal and $w(t)$ is the AWGN noise. To apply signal processing techniques in spectrums sensing, consider that the signal in the frequency band with central frequency f_c and bandwidth W. The received signal is sampled at a frequency of f_s where $f_s > w$ and $T_s = 1/f_s$ is the sampling period. Therefore, the sampled received signal is represented as

$$y(n) = hs(n) + \; w(n) \tag{4.2}$$

Sensing problem can be minimized to a simple identification problem, formalized as a hypothesis test:

$$r(t) = \begin{cases} w(n); & under \;\; \mathrm{H}_0 \\ h * s(n) + w(n); & under \;\; \mathrm{H}_1 \end{cases} \tag{4.3}$$

H₀ and *H₁* are the hypotheses corresponding to the noise-only and signal with noise. The channel is free under the null hypothesis and busy under the alternate. A system model for interpreting spectrum sensing case in CR network is depicted in Figure 4.4. The modulation technique integrated in the primary transmitter is QAM modulation. The other modulation techniques are also probable for the execution. The system model can accommodate "*q*" number of CR's. Only spectrum sensing block of CR is given in the system model. The spectrum sensing technique addressed here is filter bank based spectrum sensing method over different multipath fading channels like AWGN, Rayleigh and Rician Fading Channels. The performance of FB method is examined by distinguishing the performance of ED method.

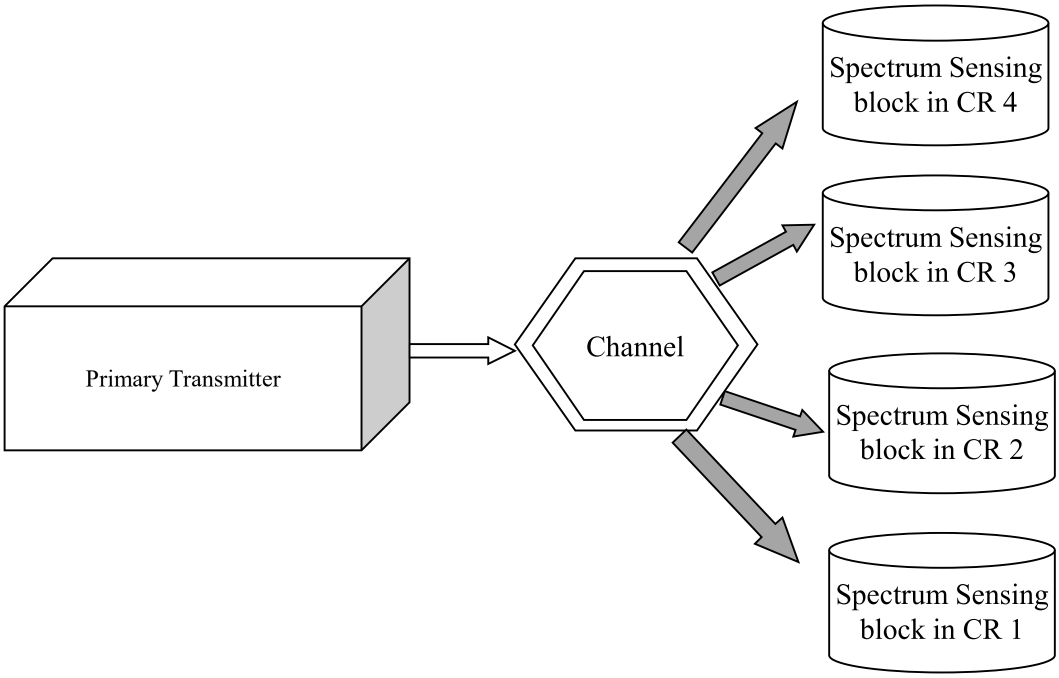


Figure 4.4 System Model

4.4 FILTER BANKS

The Filter Bank (FB) is an application of sampling rate conversion in multirate digital signal processing. An analysis and synthesis filter bank is nothing but a filter bank and it is an array of BPFs with either a common input or a summed output, respectively. Filter banks involves different sampling rates hence it noticed as a multirate system [123]. A typical M channel FB is provided in Figure 4.5. It consists of M analysis filter with different pass bands which decomposes the applied input signals into M sub-band signals. Each sub-band signal brings information of input signal in a specific frequency band.

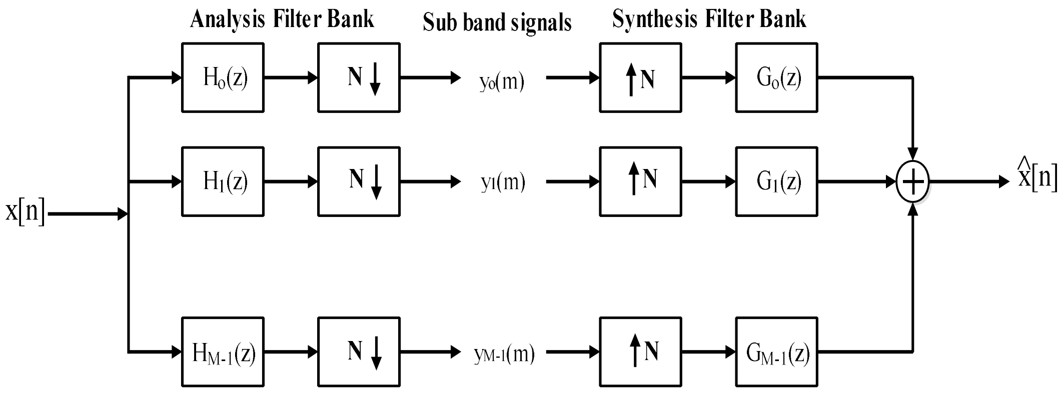


Figure 4.5 M-channel filter bank

Down-sampling process avoids duplicates in the M sub band signals. The up-sampling process allows recovering actual sampling rate. In the synthesis filter bank the M filters integrates the M sub-band signals into a reconstructed signal. The reconstructed signal endures three kinds of errors due to the reality that the analysis filters and synthesis filters are not perfect. Here we have aliasing distortion, amplitude distortion and phase distortion. The system is considered as a perfect re-construction multirate system, if the output is help-up and scaled replica of the input signal. The sub-band signal number should be same as the decimation or the interpolation factor (i.e. M = L), for a perfect re-construction multirate system. The synthesis filter bank is used as a filter bank at the transmitter end and analysis filter bank used at the receiver end, in digital communications. Hence, the analysis filter bank can be utilized for SS in a cognitive radio. A two channel FB is required for sensing a single channel. The signals in a two channel FB are incorporated as

$$Y_0(z^2) = \frac{1}{2}[H_0(z)X(z) + H_0(-z)X(-z)] \tag{4.8}$$

$$Y_1(z^2) = \frac{1}{2}[H_1(z)X(z) + H_1(-z)X(-z)] \tag{4.9}$$

$$\widehat{X}(z) = [Y_0(z^2)G_0(z) + Y_1(z^2)G_1(z) \tag{4.10}$$

The input-output relationship can be acquired by combining (4.8), (4.9) and (4.10) and is given by

$$Y(z) = \frac{1}{2}[H_0(z)G_0(z) + H_1(z)G_1(z)]X(z)$$

$$+\frac{1}{2}[H_0(-z)G_0(z) + H_1(-z)G_1(z)]X(-z) \tag{4.11}$$

The transmitted signal *X(z)* via the filter bank is described with the help of the first term and the second term, which demonstrates the aliasing component at the filter bank output. If the output is a delayed version of the input signal applied, then it is called as perfect reconstruction. In fact, the transfer function of the signal component, represented by *S(z)* and must fulfill

$$S(z) = H_0(z)G_0(z) + H_1(z)G_1(z) = 2z^{-q} \tag{4.12}$$

and the aliasing component transfer function *F(z)* must be zero.

$$F(z) = H_0(-z)G_0(z) + H_1(-z)G_1(z) = 0 \tag{4.13}$$

If both (4.12) and (4.13) are fulfilled, the output signal has no aliasing and amplitude distortion also vanishes.

4.4.1 Quadrature Mirror FBs

A Quadrature Mirror Filter (QMF) banks with two channels is utilized for dividing the signal into two or more sub-bands in the frequency domain. Thus, it assists in processing sub-band signal independently and it can accomplish maximum compression. It is feasible to re-build back the original signal from the subband signals at some point in the process. QMF banks recognizes its application in various signal processing areas like image compression, transmultiplexers utilized in FDM/TDM conversion, ECG signal compression, Antenna systems, subband coding of speech signal, biomedical signal processing, design of wavelet bases, equalization of wireless communication channels and many more. Practically the received signal can be explained by two processes:

- Changing of the broadcast signal
- Addition of noise

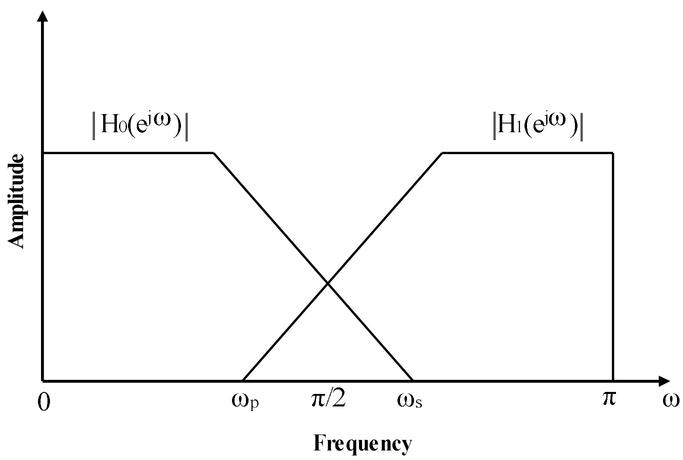


Figure 4.6 Frequency responses of analysis filters *H₀(z)* and *H₁(z)*

This is indicated in time domain mathematically as (4.1). The channel Impulse Response (IR) of the analysis filters used in QMF is shown in Figure 4.7. A graph among the ratio of received signal power to the transmitted signal with distance is sketched and shown in Figure 4.7 [124]. The plot can be broken into three major components [125]. They are

- Path Loss during propagation
- Shadowing
- Multipath fading

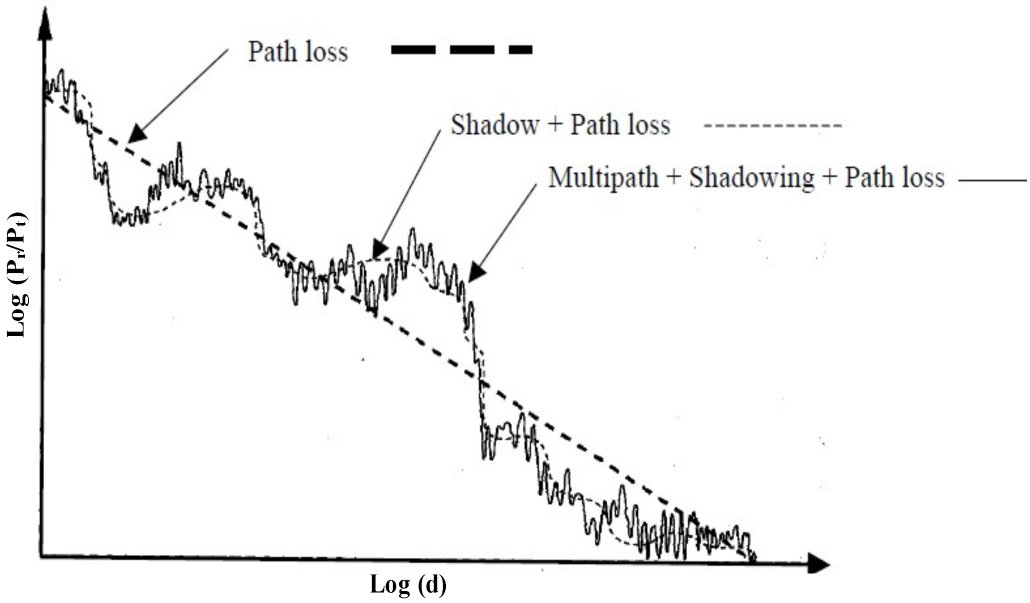


Figure 4.7 Three components of channel response

A channel impulse response can be linear/non-linear, time-variant/time-invariant and frequency flat/frequency selective. The additive noise can be Gaussian/Non-Gaussian, Noise correlated in time/frequency, noise correlated spatially and noise correlated across multiple users. The wireless channel environment can be modeled and divided as illustrated in Figure 4.8.

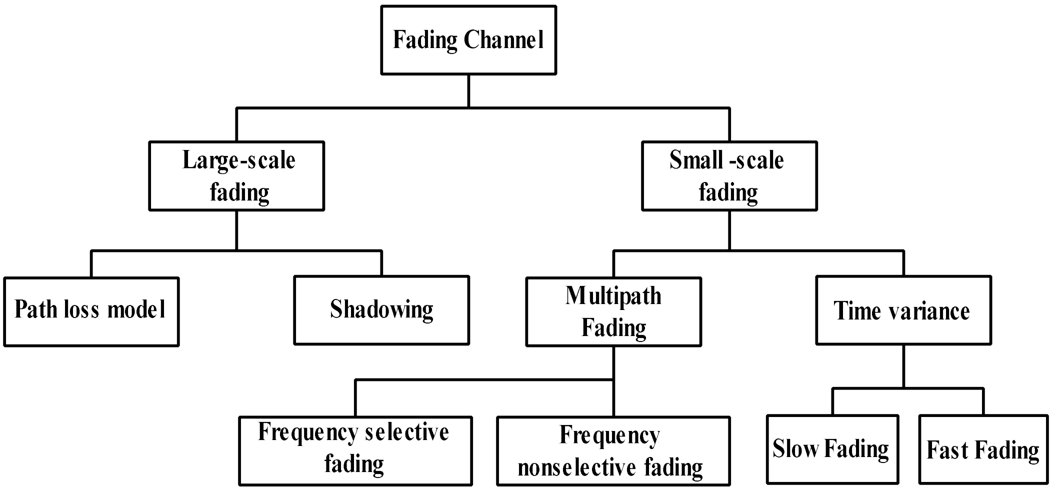


Figure 4.8 Radio Channel Model

4.5 CHANNEL MODELS

The character of a signal received can be acquired from the broadcasted signal if there appears a model for the medium among the transmitter and the receiver. In general, the prediction of the channel is performed with the help of three multipath channel models such as AWGN, Rayleigh and Rician channels [126].

4.5.1 AWGN Channel

This channel is the basic but immense model in which the communication gets weaken by the linear addition of white noise with a constant spectral density and a amplitude of the Gaussian distribution. The first component indicates the deterministic function of the transmitted signal, which is acquired in the noise absence. The second component is noise, independent of the transmitted signal and a quantity drawn from a Gaussian probability distribution with zero mean and some variance. The noise process is pointed as white Gaussian noise, if these noise samples are independent from one sample to another. The output signal can be assumed as Gaussian with mean $\mathrm{E}[y(n)] = \mathrm{E}[hs(n) + w(n)] = hs(n)$ and a variance $2\sigma_w^2$ for a provided gain of the channel h and signal to be identified [127]. The Figure 4.9 shows the model utilized for the simulation of QAM over AWGN channel.

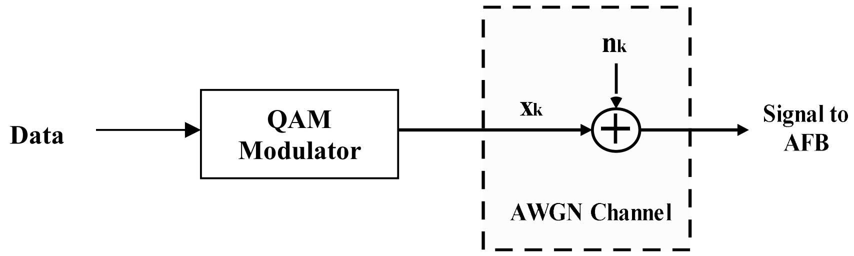


Figure 4.9 QAM Modulated signal through AWGN Channel

The receive SNR can then be provided as

$$\gamma_{AWGN} = \frac{|h|^2 \frac{1}{N}\sum_{n=1}^{N}|s(n)|^2}{2\sigma_w^2} \tag{4.20}$$

where N represents the total number of samples. The probability of detection, P_d is given by

$$P_d = Q_N\left(\sqrt{2N\gamma_{AWGN}}, \frac{\sqrt{\lambda}}{\sigma_w}\right) \tag{4.21}$$

where $Q_N(a,b) = \int_b^{\infty} x\left(\frac{x}{a}\right)^{N-1} e^{-\frac{x^2+a^2}{2}} I_{N-1}(ax)dx.$

The generalized Marcum-Q distribution function and λ is the predefined threshold. An approximate expression for probability of false alarm is provided by

$$Pf \approx Q\left(\frac{\lambda - N(2\sigma_w^2)}{\sqrt{N}(2\sigma_w^2)}\right) \tag{4.22}$$

where $Q(x) = \frac{1}{\sqrt{2\pi}}\int_x^{\infty} e^{-\frac{u^2}{2}}du$ is the Gaussian-Q function.

The probability of misdetection can be defined by

$$P_{md} = 1 - P_d \tag{4.23}$$

4.5.2 Rayleigh Multipath Fading Channel

Rayleigh model is considered as the famous among these models, that determines the NLOS propagation. This model demonstrates the statistical time varying behavior of the envelope of a received flat fading signal. Utilizing central limit theorem the time-variant IR of the channel can be designed as a complex-valued Gaussian process. As the impulse response is a zero mean complex-valued Gaussian random process, then the channel is conceived as a Rayleigh multipath fading channel. If there is no LOS signal, then Rayleigh fading is the optimal model for stochastic fading. The amplitude gain is compared by a Rayleigh distribution in Rayleigh fading. This model is suitable in cases where we have different scatters like heavily built up city centers with different buildings and other objects between the transmitter and receiver to attenuate, reflect, refract and diffract the signal. The model shown in Figure 4.10 is utilized for the simulation of QAM over Rayleigh Fading channel.

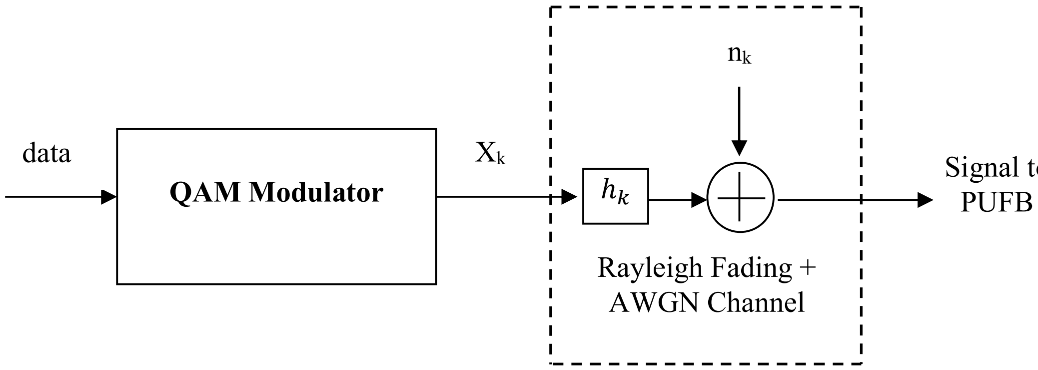


Figure 4.10 QAM Modulated signal through Rayleigh Fading Channel

A Rayleigh Fading model is build here by assuming only two multipath components *X(t)* and *Y(t).* The model is acquired from zero-mean complex Gaussian process of *X(t)* and *Y(t).* Rayleigh distributed process is obtained by adding the two Gaussian RV's and by conceiving the square root. The phase of those RV follows uniform distribution. The two Gaussian RV has zero mean and same variance and *X* and *Y* The complex Gaussian RV is defined as

$$Z = X + jY \tag{4.24}$$

The envelope of the complex RV is given by

$$R = \sqrt{X^2 + Y^2} \tag{4.25}$$

and the phase is given by

$$\phi = \tan^{-1}\left(\frac{Y}{X}\right) \tag{4.26}$$

The envelope of RV follows Rayleigh distribution and phase will be spreading a uniform manner. The Rayleigh distribution probability density function (pdf) is articulated by

$$f(r) = \frac{r}{\sigma^2}\exp\left(-\frac{r^2}{2\sigma^2}\right)u(r) \tag{4.27}$$

An expression for probability of detection in Rayleigh fading channel is acquired as

$$P_{dRay} = e^{-\frac{\kappa}{2}}\sum_{n=0}^{d-2}\frac{1}{n!}\left(\frac{\kappa}{2}\right)^n + \left(\frac{1+\bar{\gamma}}{\bar{\gamma}}\right)^{d-1}\left[e^{\left(-\frac{\kappa}{2(1+\bar{\gamma})}\right)} - e^{-\frac{\kappa}{2}}\sum_{n=0}^{d-2}\frac{1}{n!}\left(\frac{\kappa\bar{\gamma}}{2(1+\bar{\gamma})}\right)\right] \tag{4.28}$$

Nevertheless under any fading channel, the likelihood of false alarm remains same as provided by (4.22) since P_f is framed for the no transmission of signal scenario and is independent of SNR. The probability of misdetection P_{md} can be calculated utilizing (4.23).

4.5.3 Rician Fading Channel

Rician is the small scale fading envelope distribution, when we have a LOS component. This component is because of to line-of-sight propagation path. The random multipath components reaching at various paths super impose on a stationary dominant signal. Multipath fading model can be built with the help of using tapped-delay line filter. The gain incorporated with every tap is distinguished by a Rician Distribution and the maximum Doppler frequency. The model shown in Figure 4.11 is utilized for the simulation of QAM over Rician Fading channel.

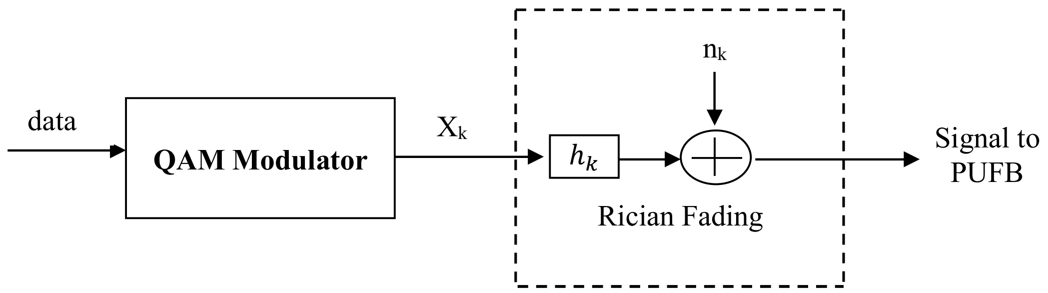


Figure 4.11 QAM Modulated signal through Rician Fading Channel

The complex Gaussian RV is determined in (4.24). The envelope and phase of Z is determined in (4.25) and (4.26) correspondingly. With the help of polar coordinate, a unique solution to these equations for X and Y in terms of R and θ can be specified as follows:

$$X = R\cos\theta, \qquad Y = R\sin\theta \tag{4.29}$$

Making use of Jacobian method, the probability density function for R and θ can be acquired as

$$f_{R,\theta}(r,\theta) = \frac{r}{2\pi\sigma^2}\exp\left(-\frac{r^2+s^2}{2\sigma^2}\right)\exp\left(-r\frac{m_1\cos\theta + m_2\sin\theta}{\sigma^2}\right)u(r), \theta \in [-\pi,\pi] \tag{4.30}$$

The parameter s is defined as the non-centrality parameter of the faded envelope and provided by

$$s = \sqrt{m_1^2 + m_2^2} \tag{4.31}$$

A measure of the power in the faded envelope produced by means of X and Y is termed as Rice factor K. It is articulated as

$$K = \frac{m_1^2 + m_2^2}{2\sigma^2} = \frac{s^2}{2\sigma^2} \tag{4.32}$$

The parameter K is nothing but the ratio of the energy in the LOS path to energy in the scattered paths; if the K means is high, then channel will be more deterministic. Integrating equation (4.30) over $\theta \in [-\pi, \pi]$, the probability density function of Rician distribution is acquired and is as provided by

$$f_R(r) = \frac{r}{\sigma^2} \exp\left(-\frac{r^2 + s^2}{2\sigma^2} \right) I_0 \exp\left(\frac{rs}{\sigma^2} \right) u(r) \tag{4.33}$$

where $I_0(x)$ is modified zeroth order of the first kind Bessel function provided by

$$I_0(x) = \frac{1}{2\pi} \int_0^{2\pi} e^{-x\cos\theta} d\theta$$

A special case: when there was no leading LOS component, (K =0), the Rician faded envelope in (4.33) will reduce to Rayleigh faded envelope as in (4.27). A closed form expression for detection probability in Rician fading channel can be articulated as

$$P_{dRic} = Q\left(\sqrt{\frac{2K\gamma}{k+1+\gamma}}, \sqrt{\frac{\lambda(K+1)}{k+1+\gamma}} \right) \tag{4.34}$$

where K is the Rician factor, selected as K = 2, 4 and 6. K is the Predefined threshold and γ is the SNR

4.6 SPECTRUM SENSING BASED ON FILTER BANKS

The Analysis Filter Bank (PUFB) behaves as a filter bank at the receiver, in a filter bank transceiver [128]. So, it helps in sensing white spaces when a cognitive radio is considered with the filter bank transceiver. The incoming signal is divided into sub-bands in the analysis filter bank side; whereas in the case of the synthesis filters sub-bands are combined in to single signal. When the signal is divided into M sub-bands, it is appropriate to function every sub-band separately [120]. A Quadrature Mirror Filter (QMF) banks were utilized very often, in most of the signal processing applications. In the case of spectrum sensing for single user cases, a two channel QMF will be a suitable one. AFB, PUFB methods are comes under the category of FB method.

4.6.1 Parameters for Design

The primary parameters for design of filter bank detector were nothing but a threshold and number of samples. The execution of detector also works according to the SNR and noise variance. Nevertheless, developers have less control over these parameters, as it works according to the behavior of wireless channel.

Threshold

In filter bank detector, a predefined threshold λ is required to recognize presence of a user. The performance metrics P_d, P_f and P_{md} is determined, based on this threshold. According to the target value of performance metric of interest, the working threshold can be calculated. The P_f and P_d decreases (or increases) when the threshold increases (or decreases). Hence, the common practice of setting the threshold for known *N* and σ_w is by fixing a constant false alarm probability P_f, eg., $P_f \leq 0.1$. The chosen threshold based on P_f is given by

$$\lambda = (Q^{-1}(P_f)/\sqrt{N}) + 1 \tag{4.35}$$

The selection of threshold can be considered as an optimization problem to stabilize the two conflicting objectives-maximize P_d and minimize P_f.

Number of Samples

So, to accomplish the demanded required detection and false probabilities, another significant parameter is assumed while designing the number of samples. For a provided P_f and P_d, the minimum number of samples required is expressed in terms of SNR as

$$N = \left[Q^{-1}(P_f) - Q^{-1}(P_d)\sqrt{2\gamma+1} \right]^2 \gamma^{-2} \qquad (4.36)$$

Signal can be perfectly identified even at low SNR regions by increasing the value N when the noise power is perfectly known. This happens due to the monotonically decreasing property of function $Q^{-1}(.)$. Nevertheless, chosen N is also optimization issues among the considered number of samples at low SNR region simultaneously have low sensing time.

4.6.2 Filter Bank Detector

The block diagram of Analysis Filter Bank (AFB) based spectrum sensing is shown in Figure 4.12a. where $S[n]$ is the transmitted signal of the primary user. $S_1[n]$ is the signal received by the secondary user which is divided into two sub-bands with the help of the analysis filters $H_0(z)$ and $H_1(z)$. These are the low pass and high pass filters having equal pass bands. The filtered signals $S_2[n]$, $S_3[n]$ are down sampled to reduce the sample rate by an integer factor of N. Then the total energy of the down sampled sub band signals $U_0[n]$ and $U_1[n]$ were calculated by using (4.37) and (4.38).

$$m_1^{1} = \sum_{n=1}^{N/2} \left| U_0[n] \right|^2 \qquad (4.37)$$

$$m_1^{2} = \sum_{N/2}^{N} \left| U_1[n] \right|^2 \qquad (4.38)$$

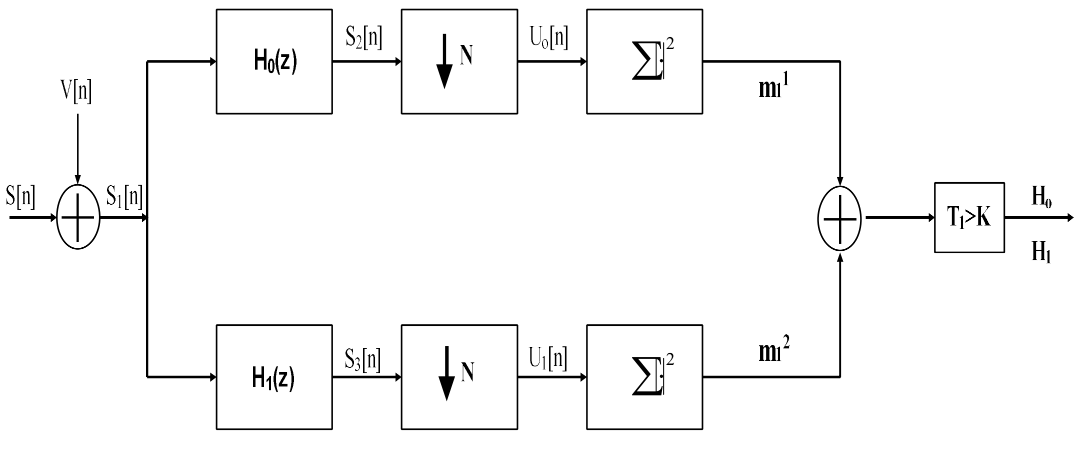


Figure 4.12 (a) AFB based spectrum sensing Block diagram

At last, the test statistics were computed by including the energy of the sub-band signals [129].

$$T_l = m_l^1 + m_l^2 \tag{4.39}$$

The value $T_l$is then compared with the pre-defined threshold determined by utilizing the equation (4.35) to recognize the presence of a user in the channel.

4.6.3 Spectrum Sensing based on Paraunitary Filter Bank Method

A novel spectrum sensing technique based Paraunitary filter bank is proposed in this part. It is considered as a Perfect Reconstruction (PR) filter bank in which physical matrix *E(Z),* which devises an look in polyphase execution of filter bank structure, and it fulfils a special property called as lossless or paraunitary property [130]. Paraunitary filters are practically realizable filters because of the special properties like causality and lossless. Let a *N*- channel filter bank be given by,

$$H(z) = \begin{bmatrix} H_1(z) \\ \vdots \\ \vdots \\ H_n(z) \end{bmatrix} \tag{4.40}$$

then it is said to be an paraunitary filter bank, it must satisfies the following relation,

$$\widetilde{H(z)}H(z) = dI \tag{4.41}$$

whenever *E(z)* is parunitary it often articulate by axiom that, "Analysis filter bank forms a paraunitary set", or "Analysis filter bank is paraunitary" or "Paraunitary QMF" [123].

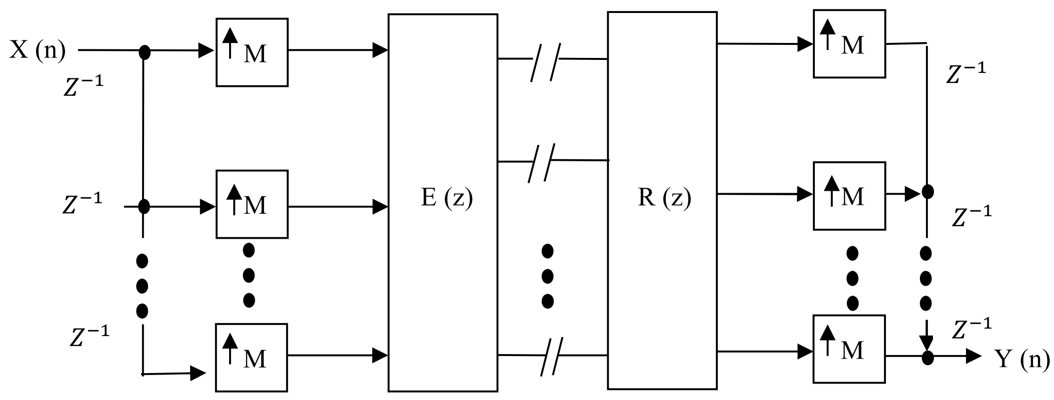


Figure 4.12 (b) Block diagram of PUFB based spectrum sensing

The paraunitary property is stated by,

$$\widetilde{E(z)}E(z) = dI \quad (4.42)$$

That means

$$E^{-1}(z) = \frac{E(z)}{d} \text{ for all Z} \quad (4.43)$$

In PUFB approach, to classify the incoming input signal into various sub-bands of preferred frequencies digital filter banks have been used. The response of amplitudes of FIR filter, the analysis and synthesis filters in paraunitary filter banks are the same. The signals reached after receiving, divided into dissimilar sub-bands, in the digital filter banks, and then they were coded and conveyed. The process of division of signal is executed by analysis part and is clearly shown in Figure 4.12(b).

4.6.4 Interference Mitigation in Macro-Femto Cellular Networks based on Paraunitary Filter Bank Method

The femtocells are designed for indoor applications with some restricted spectrum, in an overlaid macro-femto cellular network. Indoor coverage is conventionally accomplished through macrocell signaling. Because of the higher demand of data, the technology is moving towards the higher carrier frequencies. At higher frequencies the path losses becomes more and indoor coverage becomes a serious problem. Operators put an attempt to preserve an acceptable level of "economic" indoor coverage, which is, fulfilling indoor user, therefore generating revenue, without great investment in the development of macrocells. Since these are operating in the licensed band with same frequencies of macrocell there is a chance for huge co-channel interference between the macro and femtocells. To target this issue, spectrum sensing is incorporated in the femtocell have been developed called as cognitive femtocell, By applying spectrum sensing, femtocell identifies the free channels in the surrounding macrocell region and allocates it to the corresponding femto users to reduce interference caused to the primary macro user. By sensing the channel before using, secondary femtocell can reduce the maximum transmit power. Since, the interference caused to macro user can be reduced. The femto cellular setup varies from the conventional macrocell setup in two important aspects:

1. Network size, and

2. Random deployment

The sensing duration is very less in case of PUFBMC algorithm. Within the sensing duration complete channel state information has to be captured. Hence it plays a significant role.

4.7 SIMULATION RESULTS

The simulations were carried out in MATLAB software. A graphical chart in signal estimation theory termed as Receiver Operating Characteristic (ROC) curve is used, which explains the performance of a binary classifier system as its threshold differs. ROC curve is nothing but the curve drawn between the probability of detection (P_d) and the probability of false alarm (P_f), at various SNR values. It gives better tools for computing the performance of the spectrum sensing method. The simulation parameters used for the implementation of PUFB based spectrum sensing method to avoid interference in macro- femto cellular are shown in Table 4.1.

Table 4.1 Parameters and typical values used for simulation of PUFB Method

Parameters	Values
Carrier frequency	2 GHz
Bandwidth of the system	10 MHz
Modulation technique	64-QAM
No. of bits/symbol	5
Symbol period	0.5 μsec
Sensing duration	10 μsec
No. of FCs per MC	100
No. of active users per FC	4
No. of users per MC	2,000
Maximum transmit power of MC	46 dBm
Maximum transmit power of FC	15 dBm

4.7.1 Energy Detection

The performance of filter bank method is validated by comparing it's functionality with an existing technique named energy detection method. Energy detection method is simple and more commonly used technique for spectrum sensing in CR. Initially, energy detection method was simulated over three different channels for different SNR values. Figure 4.13 explains the probability of false alarm versus probability of detection for SNR= -1dB, -5dB and -10dB under AWGN channel. At lower SNR region the detection probability lowers as indicated in Figure 4.13.

The likelihood of false alarm probability versus probability of detection in Rayleigh fading channel for SNR=-1dB,-5dB and -10dB is charted in Figure 4.14. Because of several phenomena like reflection, absorption, attenuation, dispersion, diffraction and refraction, the detection probability in Rayleigh fading channel is lowered when compared in AWGN channel. The detection probability still decreases at low SNR regions.

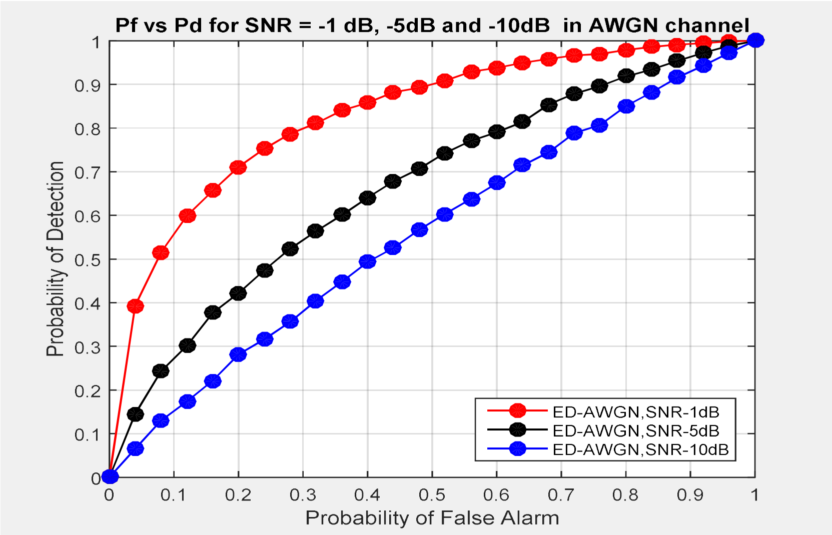


Figure 4.13 ROC curve for SNR=-1dB,-5dB and -10dB over AWGN channel

In Rician fading channel, probability of detection slightly improves when compared to Rayleigh fading because of the presence of strong dominant LoS component. The variation of P_d with respect to P_f for SNR=-1dB, -5dB and -10dB in Rician fading channel is depicted in Figure 4.15.

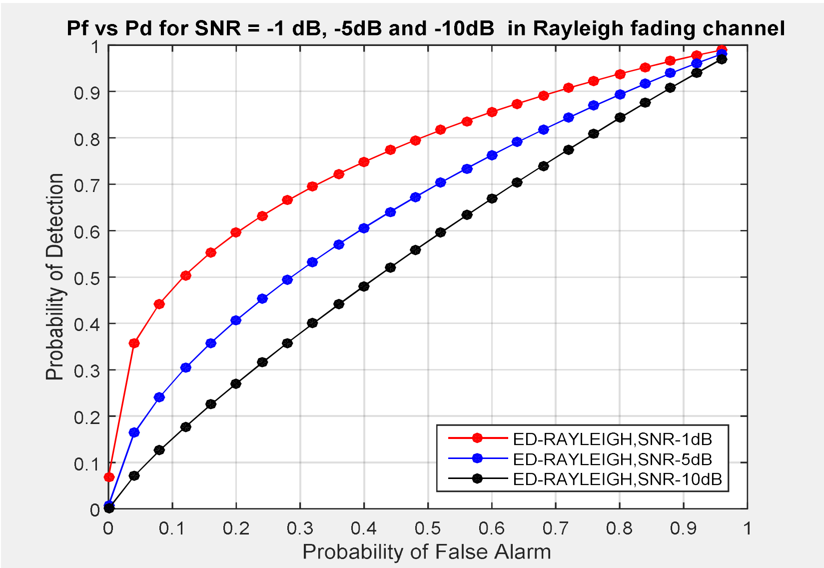


Figure 4.14 ROC curve for SNR=-1dB,-5dB and -10dB over Rayleigh channel

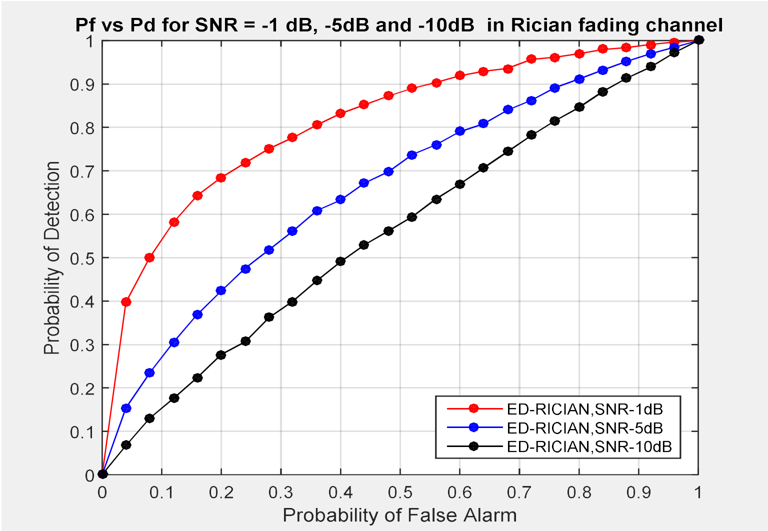


Figure 4.15 ROC curve for SNR=-1dB,-5dB and -10dB over Rician fading channel

From the above analysis a relative ROC curve is explained the detection capabilities of energy detection method over three different multipath fading channels. Figure 4.16 visualizes comparative ROC curve for SNR =-1dB for energy detection method. From the Figure 4.16 it is clear that the performance is better in AWGN channel, then in Rician channel and least in Rayleigh channel.

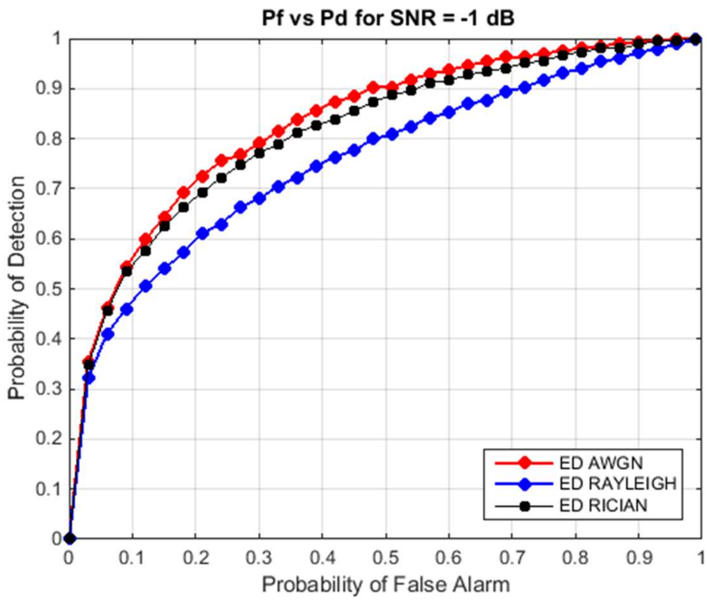


Figure 4.16 Comparative ROC curve for SNR = 1dB over AWGN, Rayleigh and Rician fading Channel

Figure 4.17 depicts a plot between SNR and likelihood of detection for various probability of false alarm. False alarm probabilities considered for sketching are 0.1, 0.2, 0.3 and 0.4. A false alarm in the context of CR networks yields unnoticed spectrum holes. Hence, a large P_f donates to pitiable spectrum usage by CR. As SNR value increases the probability of detection increases. However, when false alarm probability increases, the detection probability decreases. Maximum allowable limit to false alarm probability is upto 0.3. IEEE has allotted standard for the implementation of CR by incorporating IEEE 802.22 standard. IEEE 802.22 WRAN does not recommend a particular spectrum sensing technique. Therefore, the designers are free to choose any spectrum sensing techniques.

At low SNR region the energy detection method performs poorly. In order to increase the sensing performance only option is to increase the number of samples. Figure 4.18 shows the variation between SNR and detection probability for different number of samples. For the simulation the number of samples considered are 10, 50, 500 and 1000**.** From the plot it is understood that at low SNR, the detection probability is less for little number of samples. The detection probability increases even at low SNR region for a large number of samples.

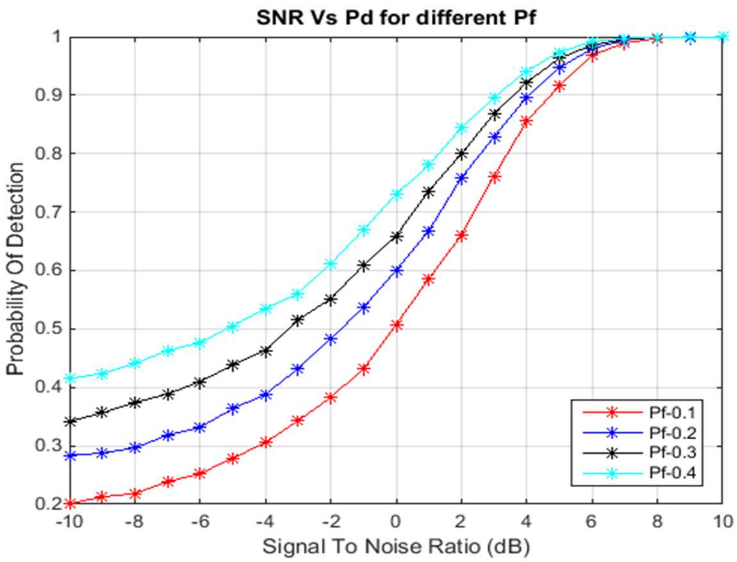


Figure 4.17 SNR versus probability of detection for different probability of false alarms

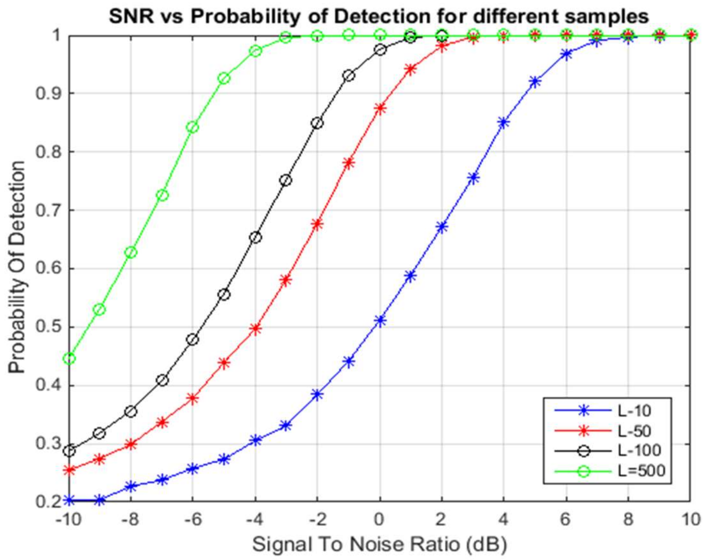


Figure 4.18 SNR versus detection probability for different number of samples

But at the same time, attention has to pay on sensing time as it increases when the number of samples is more. Therefore, a tradeoff should be there between sensing time and the number of samples. This is an optimization problem between sensing duration and number of samples.

4.7.2 Filter Bank Method

An array of BPFs is utilized to recognize the presence or absence of spectrum hole. The parameter values for simulating PUFB based spectrum sensing are indicated in Table 4.2. Similar to energy detection method, the performance of PUFB method in multipath fading channel is analyzed. Figure 4.19 explains the probability of false alarm versus probability of detection for SNR = -1dB, -5dB and -10dB under AWGN channel. The probability of false alarm versus probability of detection in Rayleigh fading channel for SNR=-1dB,-5dB and -10dB is pictured in Figure 4.20.

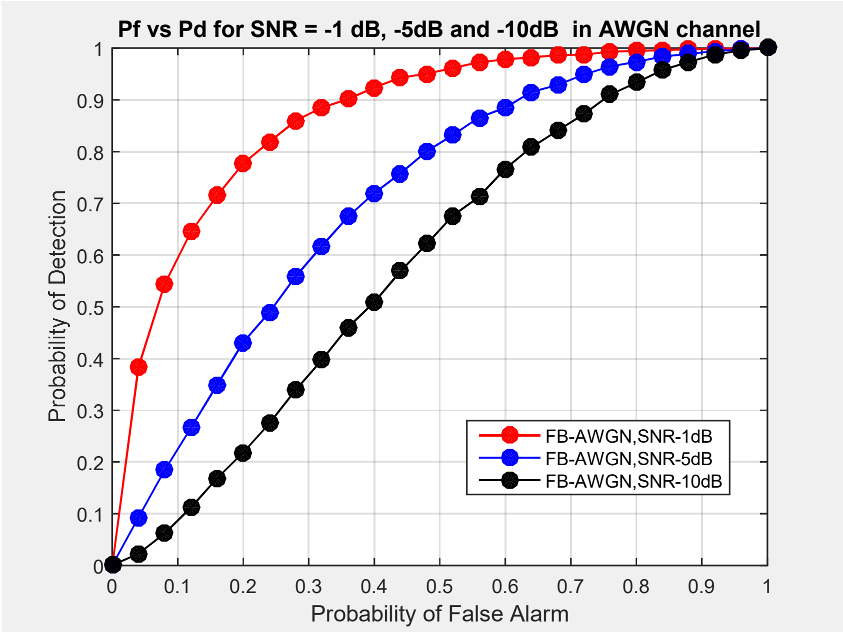


Figure 4.19 ROC curve for SNR=-1dB,-5dB and -10dB over AWGN channel

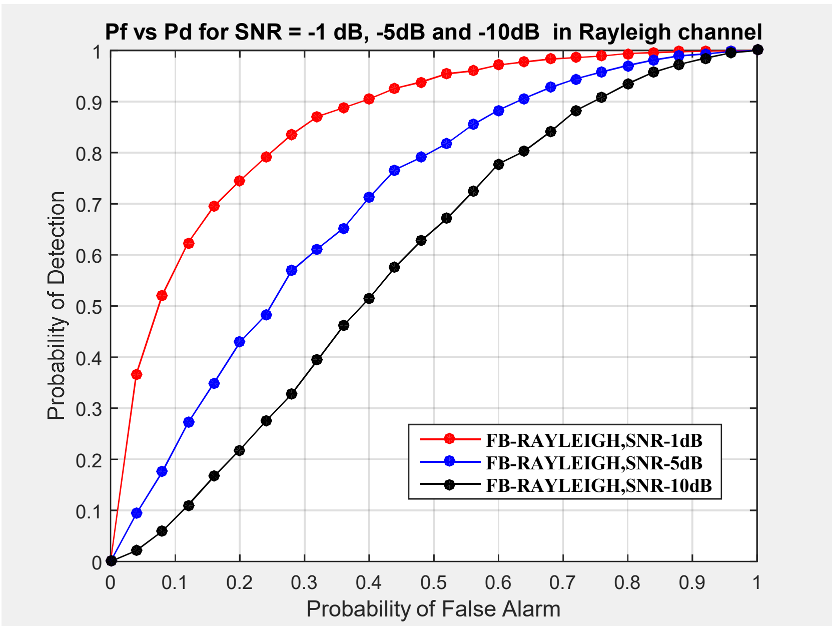


Figure 4.20 ROC curve for SNR=-1dB,-5dB and -10dB over Rayleigh channel

Due to LoS component in the received signal, the detection probability will be improved in Rician fading channel. The variation of P_d with respect to P_f for SNR=-1dB, -5dB and -10dB in Rician fading channel is depicted in Figure 4.21.

Figure 4.22 visualizes a relative ROC curve for SNR = 1dB with respect of PUFB method. From the figure it is understood that the performance is better in AWGN channel, then in Rician channel and least in Rayleigh channel.

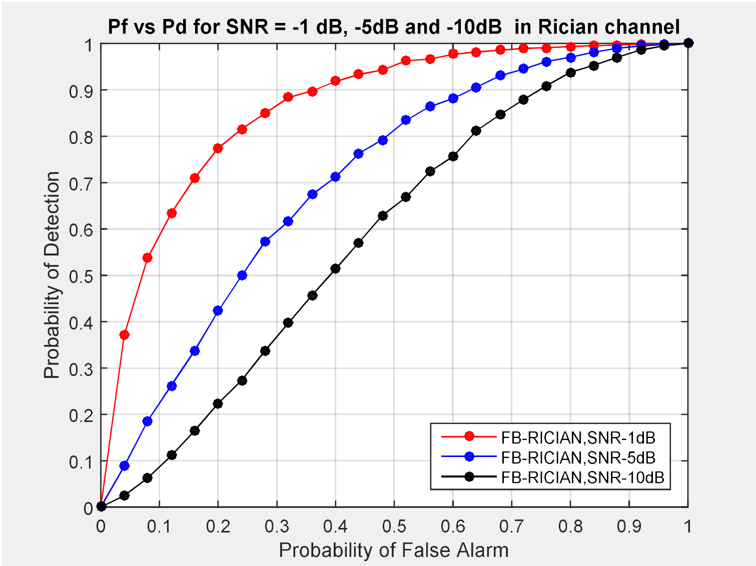


Figure 4.21 ROC curve for SNR=-1dB,-5dB and -10dB over Rician channel

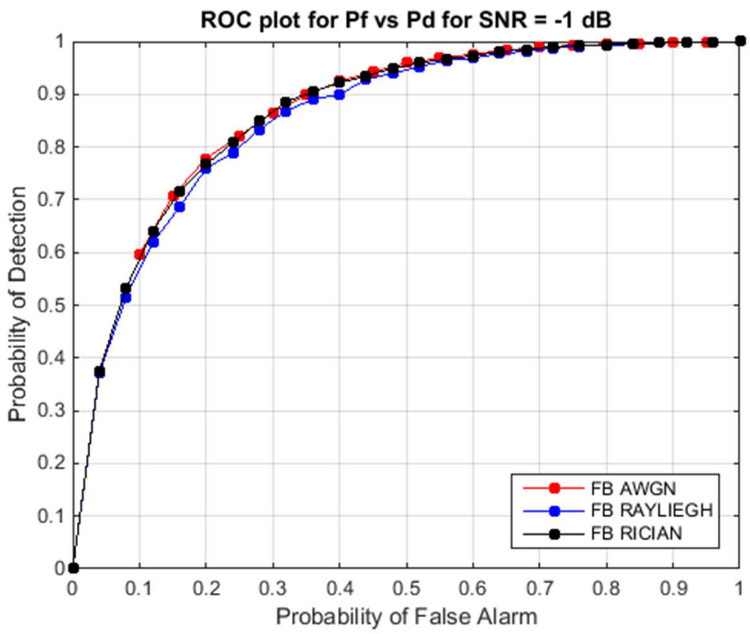


Figure 4.22 Comparative ROC curve for SNR = 1dB over AWGN, Rayleigh and Rician fading Channel

Figure 4.23 depicts a plot between SNR and P_d for various false alarm probabilities. The detection probability is increased as PUFB method is employed when compared to energy detection method. For P_f = 0.3 and SNR = -5dB, a detection probability of 0.5 is attained. Increasing false alarm probability can increase detection probability. But a large P_f contributes to miserable spectrum usage by CR.

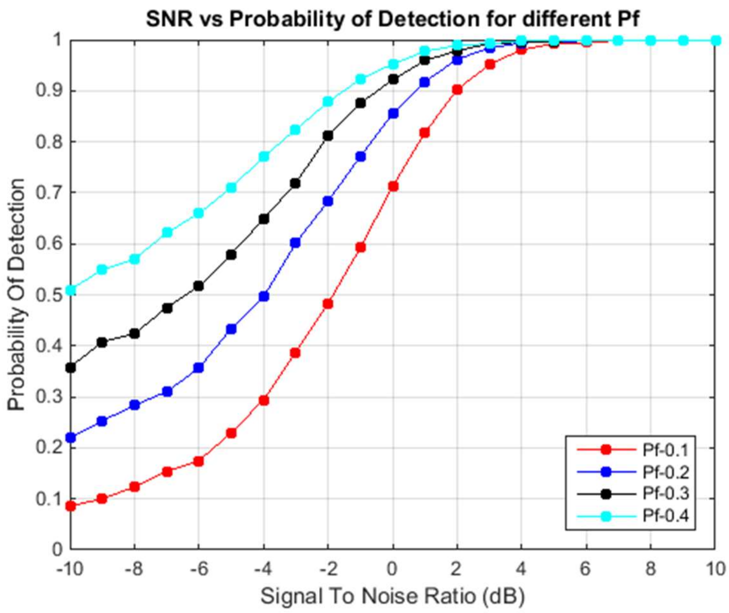


Figure 4.23 SNR versus detection probability for different false alarm probability

In order to enhance the sensing performance of PUFB method even at low SNR region is by raising the number of samples. The plot among the P_f and P_d for different number of samples at SNR = -10dB is displayed in Figure 4.24. The samples taken for simulation purpose are 10, 100, 500 and 1000. The detection probability increases even at low SNR region for a large number of samples.

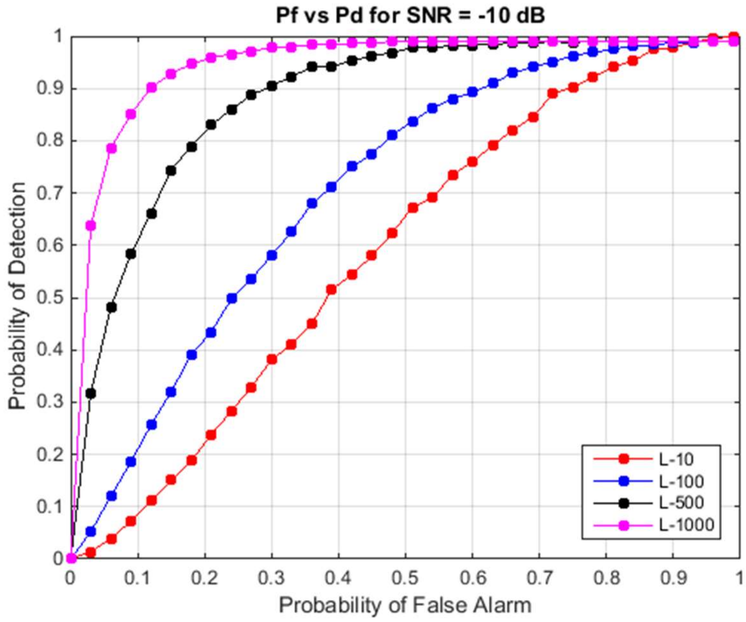


Figure 4.24 False alarm probability versus detection probability for different no. of samples

The plot among false alarm probability and detection probability for different number of samples is displayed in Figure 4.24. However, large number of samples will lead to increase in sensing time. Similar to energy detection method, a tradeoff should be there between sensing time and number of samples in PUFB method. But it is clear PUFB method is having better detection probability when distinguished to energy detection method.

4.7.3 Performance Comparison between ED Method and PUFB Estimator

The energy detection method and PUFB method are analyzed over an AWGN channel, Rayleigh channel and Rician channels. The likelihood of P_d for various values of signal to noise ratio and P_f is charted for energy detector and PUFB spectrum sensing as shown in Table 4.2. The ROC curve for ED, AFB and PUFB method over an AWGN channel at SNR = 1dB is shown in Figure 4.25. From the figure it is understood that the curve navigates towards the left upper when distinguished with the ED, which reports that PUFB method performs better when compared with the energy detection and AFB methods. For P_f in the range 0.1 to 0.3, a maximum detection probability of 87% is accomplished in the case of filter bank method. When P_f = 0.1, the detection probability obtained is approximately 58% in the case of filter bank method. This is somewhat better when distinguished to energy detection method as in IEEE 802.22 maximum permitted P_f is 0.1.

Table 4.2 Performance Comparison between ED and PUFB Estimator

P_f	Energy Detection Method					PUFB Method				
	P_d					P_d				
	SNR (1 dB)	SNR (-1 dB)	SNR (-2 dB)	SNR (-3 dB)	SNR (-5 dB)	SNR (1 dB)	SNR (-1 dB)	SNR (-2 dB)	SNR (-3 dB)	SNR (-5 dB)
0.1	0.59	0.45	0.39	0.34	0.26	0.82	0.6	0.49	0.39	0.27
0.2	0.68	0.54	0.48	0.42	0.37	0.91	0.79	0.69	0.61	0.43
0.3	0.74	0.6	0.57	0.51	0.43	0.95	0.88	0.81	0.72	0.59
0.4	0.79	0.68	0.62	0.57	0.5	0.98	0.93	0.88	0.82	0.71

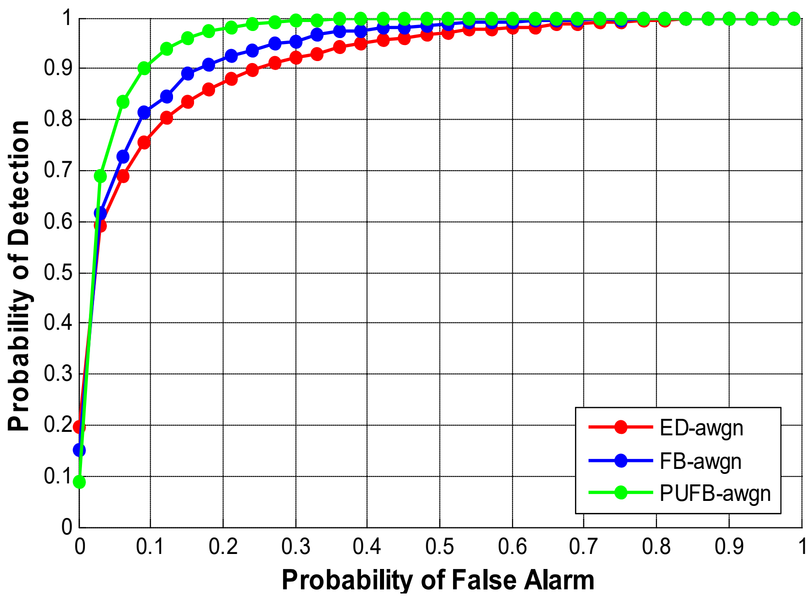


Figure 4.25 Comparative ROC curve for ED, AFB and PUFB Spectrum sensing methods over an AWGN channel

Relative ROC curve for ED and PUFB method over a Rayleigh channel at SNR = 1dB is given in Figure 4.26. Maximum detection probability achieved is 84%, when P_f is in between 0.1 and 0.3. At P_f = 0.1, the detection probability is

56% in the case of filter bank method when compared to 47% in the case of energy detection method. This shows that PUFB method is performing better than ED method in Rayleigh channel.

Relative ROC curve for ED and PUFB method over a Rician channel at SNR = 1dB is given in Figure 4.27. The probability of detection is 57% at P_f = 0.1 in the case of filter bank method. A percentage increase of approximately 8% is observed in detection probability in case of filter bank method when compared energy detection method at P_f = 0.1. When P_f = 0.3, this becomes approximately 12%.

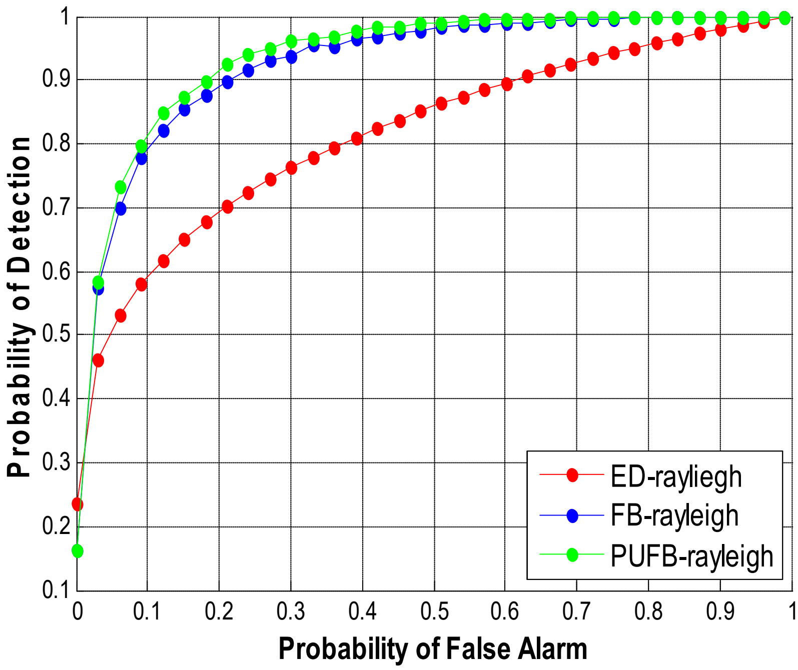


Figure 4.26 Comparative ROC curve for ED, AFB and PUFB spectrum sensing methods over a Rayleigh channel

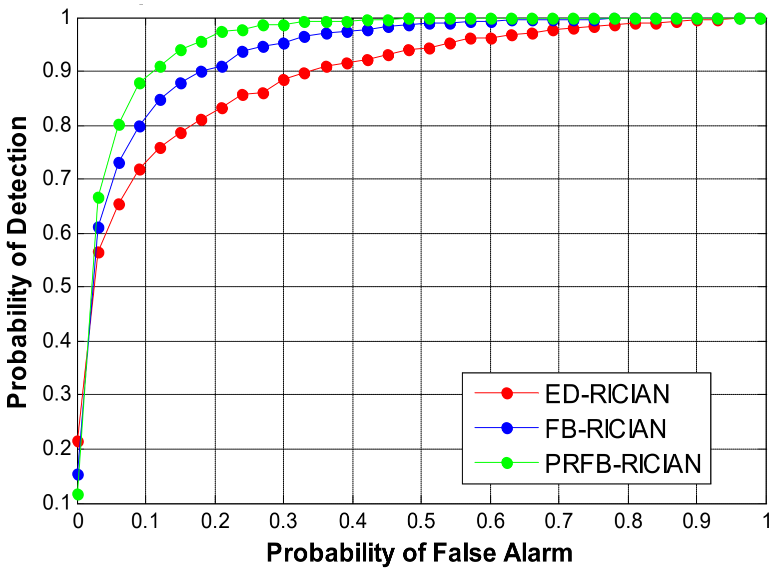


Figure 4.27 Comparative ROC curve for energy detector, AFB and PUFB method over a Rician channel

From the Figure 4.25-4.27 it is understood that the curve navigates towards the left upper when distinguished to energy detector in entire channels, which reports that PUFB method performs better when compared with the ED, AFB method over multipath fading channels. PUFB method performs better in AWGN channel, then in Rician fading channel and then in Rayleigh fading channel.

In Figure 4.28, a relative ROC curve among PUFB method and ED method for various numbe of samples (L =100, 500 and 1000) at SNR = -10 dB is provided. When the number of samples is maximized, the performance of PUFB method is better when compared with the energy detection method. Nevertheless, the sensing time maximizes with rise in number of samples. For a good spectrum sensing method, the P_d should be higher for low values of P_f and with the lower number of samples. Hence a tradeoff among P_f and number of samples should be considered into account while enforcing the technique.

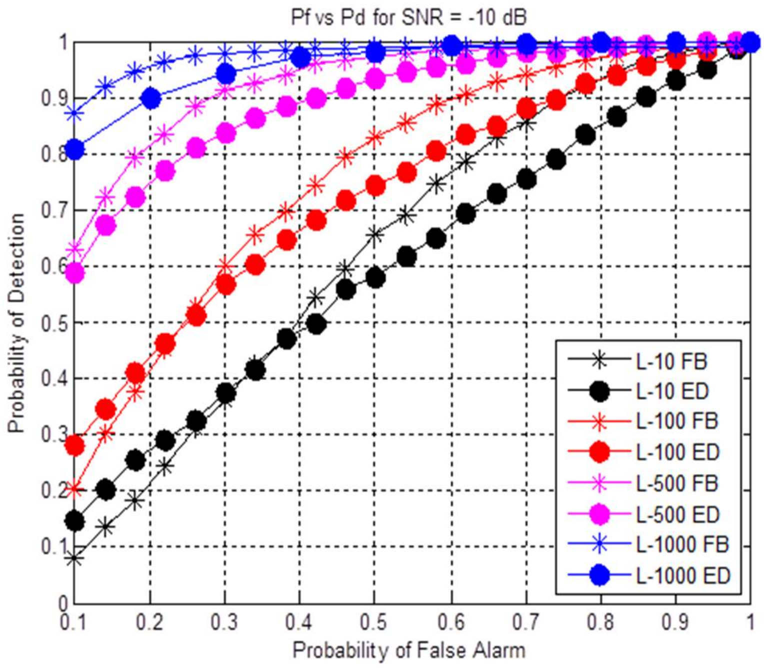
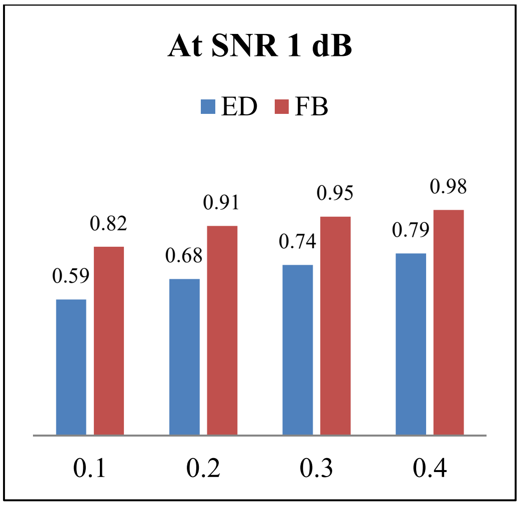
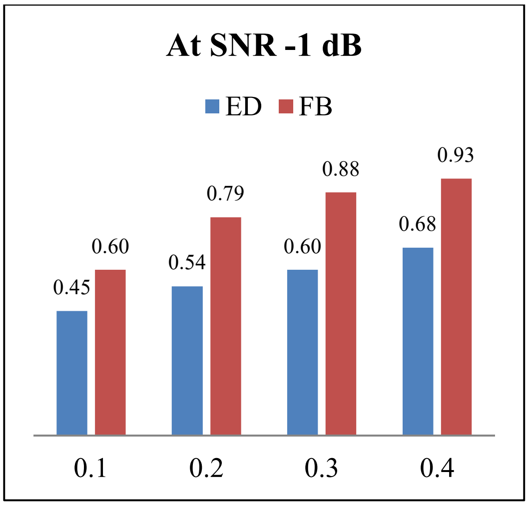


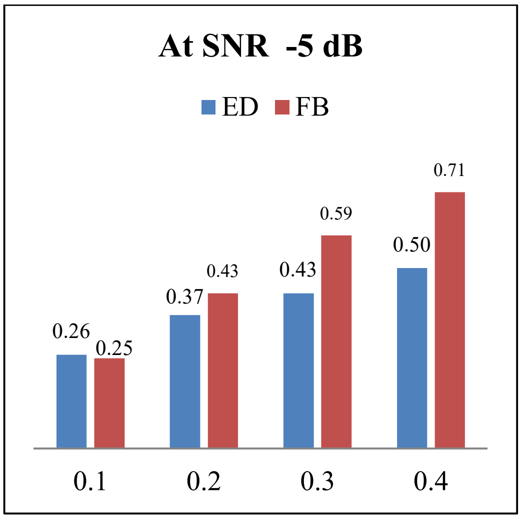
Figure 4.28 Comparative ROC curve for different number of samples at SNR = -10 dB

To get an inference from the analysis, a bar chart is sketched in Figure 4.29 to observe the performance of PUFB method when distinguished with the ED method under AWGN channel, Rayleigh channel and Rician channel correspondingly. The bar chart represents that the PUFB based spectrum sensing is showing enhanced output. From the figure it is understood that at SNR = 1 dB and P_f = 0.2 there is a rise of 12.8% in P_d in favor of PUFB based method when distinguished with the ED method. A percentage increase of 16.2% in P_d is accomplished at SNR = -1 dB and P_f = 0.2 with respect to PUFB based method when distinguished to ED method. At SNR = -5 dB and P_f = 0.3 the percentage increase in detection probability becomes 37.2%.





(a) **(b)**



(c)

Figure 4.29 Performance of PUFB in Rayleigh channel at (a) SNR = 1 dB, (b) SNR = -1 dB and (c) SNR = -5 dB

It is noticed in Rayleigh fading channel that the PUFB method gives better results than the ED method for various values of SNR as illustrated in Figure 4.29. For instance, at SNR = -5 dB and P_f = 0.3 there is an increase of 15.7% in probability of detection in the case of PUFB method when distinguished with the ED energy detection method. At SNR = -1 dB and P_f = 0.2, an increase of 28.3% in probability of detection is acquired.

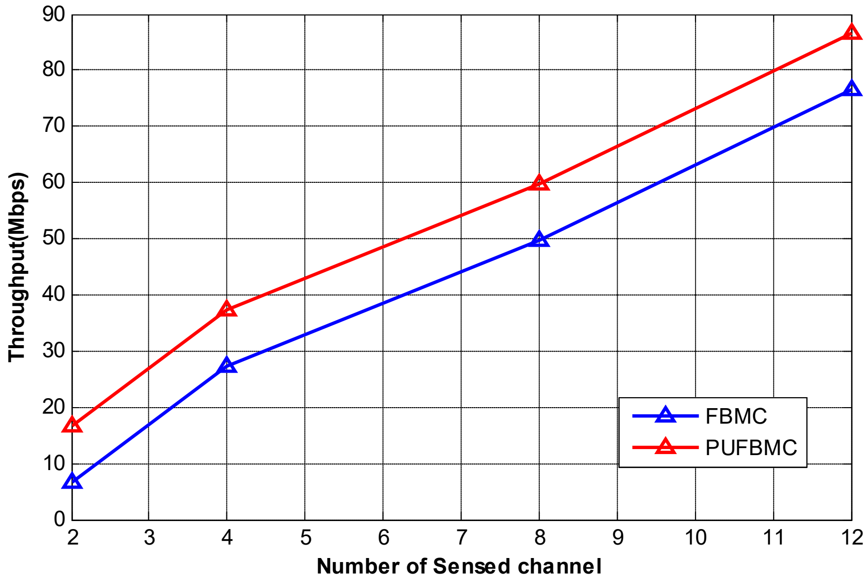


Figure 4.30 Increase in Throughput with the No. of Sensed Channel

As the number of sensed channels increases the throughput of the system is also increases, it is shown in the Figure 4.30 and listed in Table 4.3. The results of PUFBMC are compared with ED, FBMC (AFB). Because of the practically realizable filters, the proposed PUFBMC is showing increase in throughput as the number sensing channels increases.

Table 4.3 Throughput with the No. of Sensed Channel

Parameter	**ED**			**FBMC (AFB)**			**PUFBMC**		
	Number of Sensed Channels								
	2	**6**	**12**	**2**	**6**	**12**	**2**	**6**	**12**
Throughput (in Mbps)	5	25	50	8	39	76	**19**	**49**	**87**

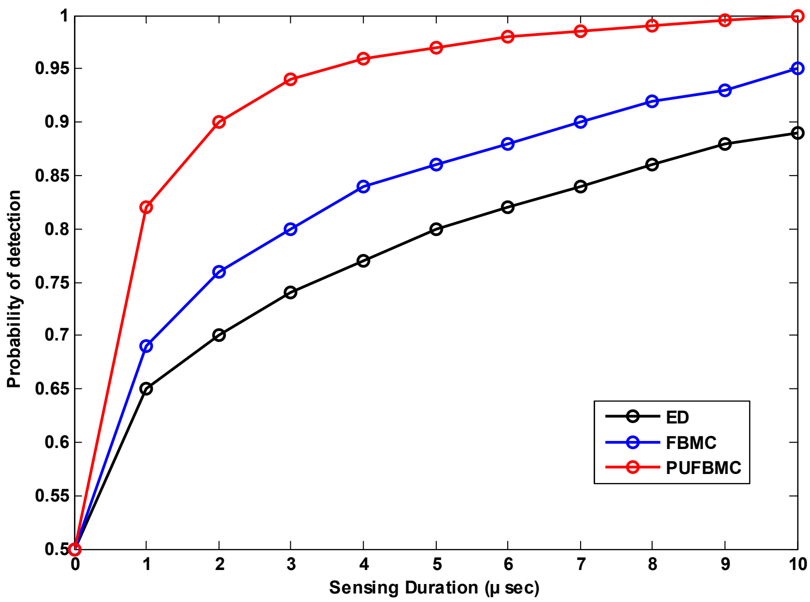


Figure 4.31 Comparison between ED, FBMC and PUFBMC over different sensing durations at SNR=3dB

Figure 4.31 shows the sensing capabilities of the proposed PUFBMC with conventional ED and FBMC (AFB) under different sensing durations. As the sensing duration increases the detection capabilities also increases which is shown in Figure 4.36 and is tabulated in Table 4.4 at SNR=3dB. It is observed that the proposed PUFBMC method outperforms better and produces higher probability detection of 1.0 for 10 microseconds.

Table 4.4 Comparison between ED, FBMC and PUFBMC over different sensing durations at SNR=3dB

Parameter	ED			FBMC			PUFBMC		
	Sensing Duration (in µs)								
	1	5	10	1	5	10	1	5	10
Probability of detection (P_d) at SNR=3dB	0.65	0.77	0.87	0.68	0.85	0.94	**0.82**	**0.96**	**1.0**

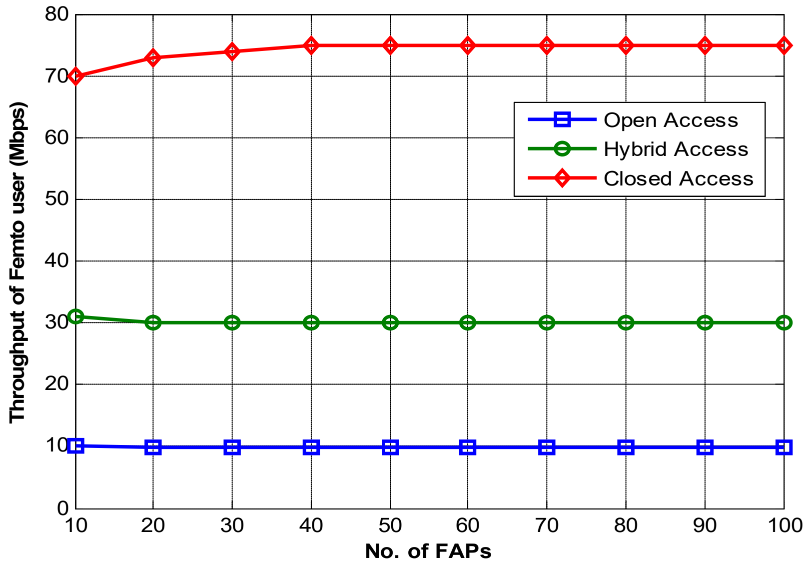


Figure 4.32 Femto user Throughput with the No. of FAP's for different Access Mechanisms

Figure 4.32 shows the Femtocell user throughput comparison with increase in number of FAPs over the three different access schemes such as open, closed and hybrid access. Table 4.5 tabulated the values corresponding to Femto user throughput, Interference factor of MUs, Sum throughput of Macro and Femtocell as the number of FAPs increases. From Figure 4.32 it is clear that the Femtocell throughput is good in closed access because of only registered users can get the service and then hybrid access and last in open access because of access given to nearby MUs.

Table 4.5 Throughput for different Access Mechanisms

Parameter	Open Access			Closed Access			Hybrid Access		
	Number of FAPs								
	10	**50**	**100**	**10**	**50**	**100**	**10**	**50**	**100**
Throughput of Femto user (Mbps)	10	10	10	70	75	75	**31**	**30**	**30**
Interference factor of Macro Users	0.79	0.25	0.1	0.91	0.97	1.0	**0.89**	**0.35**	**0.21**
Sum throughput of Macro+Femto (Mbps)	20	60	110	5	5	5	**10**	**51**	**99**

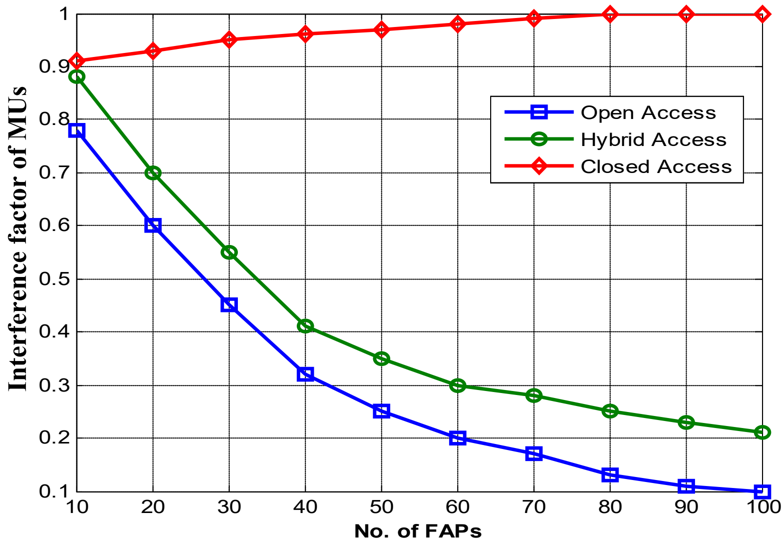


Figure 4.33 Interference factor of MUs with the No. of FAP's for different Access Mechanisms

Figure 4.33 shows the variation of inference factor of MUs from the FAPs with the increase in number of FAPs over three closed, open and hybrid access schemes. The corresponding values are tabulated in Table 4.5. From the Figure 4.33 it is clear that as the number of FAPs increases the interference factor of MUs increases in closed access because of limited service for the registered users. The MUs nearer to FAP affected by severe interference. In case of open and hybrid access the interference factor reducing as the number of FAPs increases because of the serving of nearby MUs by the FAP.

Figure 4.34 shows the macro and femto user sum throughput comparison with the increase in number of FAPs for three different access such as open, hybrid and closed access. The corresponding values are listed in Table 4.5. From the Figure 4.34 it is clear that the overall sum throughput of macro and femto cellular network increases in open access and then in hybrid access and least in closed access because of the interference caused to the MUs nearer to the FAPs.

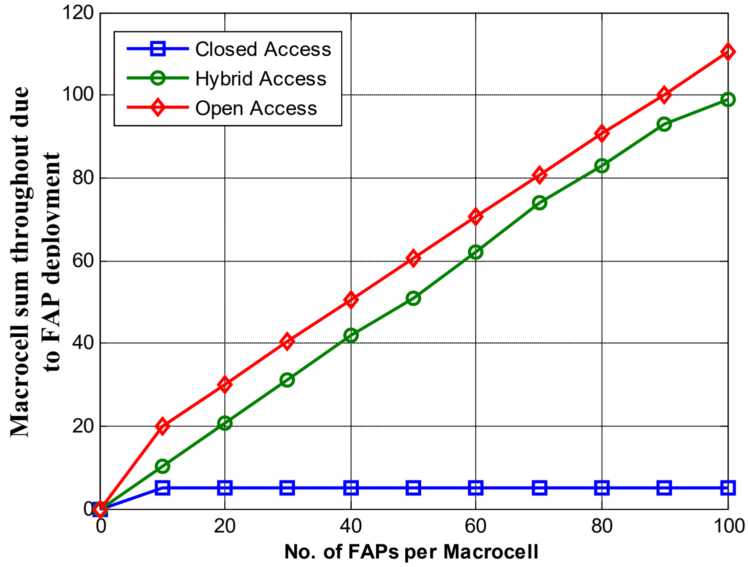


Figure 4.34 Macro user sum Throughput with the No. of FAP's for different Access Mechanisms

Closed Access: With the increase in number of FAPs, the Femto user throughput increases but interference factor caused for MUs is also increases, and the overall macro and femto throughput is low because of service given for only registered femto users.

Open Access: With the increase in FAPs, Femto user throughput is decreasing, interference factor of MUs is also decreasing and overall sum throughput of the system is high because of the service is common for both registered FAP uses and MUs.

Hybrid Access: With the increase in FAPs, Femto user Throughput and interference caused to MUs both are optimum. The overall macro and femto sum throughput is moderate because of limited access for nearby MUs along with registered FUs.

Hence, from Table 4.5 it is clear that the open access is the better choice, but the FAP owners are not ready to share their access with the MUs. Since, hybrid access is giving the optimal results which is the suitable solution for real time FAP installations.

4.8 SUMMARY

In this chapter, to address the co-channel interference between the macro–femto cellular networks, a Paraunitary Filter Bank Multi Carrieer based spectrum sensing (PUFBMC) scheme has been proposed. The suggested PUFBMC scheme effectively analyses the existence of a co-channel macrocell user on the channel. When identifying the presence of a co-channel macro user, the suggested scheme instantaneously conditions the maximum transmit power of the interfering femtocell user. The performance illustrates even at low SNRs also it is giving better sensing results, on the application of this technique to macro-femto cellular the system performance is increased. It is giving better throughput and capacity of the network. The analysis carried out for the three access modes of the femtocell networks, hybrid access is giving the optimal results and it suitable for real time environments.

CHAPTER 5

DYNAMIC SPECTRUM ALLOCATION IN HYBRID ACCESS COGNITIVE FEMTOCELL NETWORKS BY USING GAME THEORETIC APPROACH

5.1 INTRODUCTION

Because of the dense deployment of unplanned closed access FCs over limited resource may induce two types of interference namely Co-tier Co-channel Interference (CTCCI) and Cross-tier Co-channel Interference (XTCCI). The Efficient frequency reuse and PUFB based spectrum sensing algorithms are proposed in the previous modules addressed co-tier and cross-tier interferences in macro-femto cellular networks. Because of the deployment of the closed access FAPs, the MU in the coverage region of the FAP is suffering with severe downlink interference. In order to address this challenge, from the previous module results hybrid access is selected as the suitable solution. On the other hand in normal hybrid access the QoS of the registered femto users is less compared with the closed access because of sharing the resources with the nearby MUs. In order to address this issue, in this module an incentive mechanism is proposed for hybrid access cognitive femtocell networks, wherein network service provider as well as the femtocell will gets the benefits by means of using a Price bargaining and Stackelberg game.

5.2 DYNAMIC SPECTRUM ALLOCATION

Dynamic Allocation of Spectrum to a Secondary User (SU) should prevent the interference produced to the Primary User (PU). It is to allot the needed bandwidth to every SU with the intension that interference is reduced and spectrum utilization is increased. In this model, market based methods were extensively studied as they give incentives for PUs. It is attained by means of opportunity identification [131], which gives the info regarding the available spectrum bands.

The idea of dynamic spectrum access is the finding of spectrum holes (a frequency band that is free enough to be utilized) or white spaces and utilizes them for the purpose of communication [132]. Dynamic spectrum access is the dynamic application of cognitive radios. The PU bands are opportunistically used by the SU networks with the intension that the interference produced to the PUs is negligible. Figure 5.1 shows the Dynamic Spectrum Access (DSA) in which multiple PUs as well as SUs is coexisting [138].

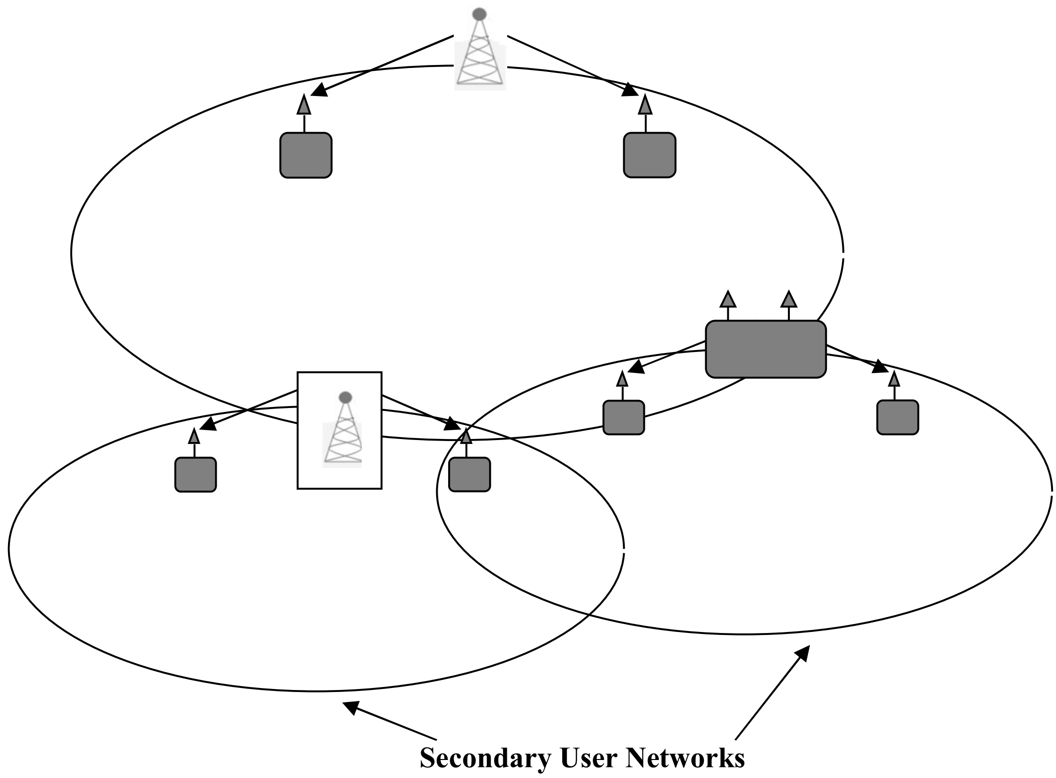


Figure 5.1 Coexistence of multiple primary and secondary user networks

This is a method through which a radio system adapts to available spectrum holes with limited spectrum usage rights dynamically, with respect to varying conditions as well as goals: the produced interference variations the radio's state in environmental restraints [133]. The foremost job of DSA is to overwhelm two kinds of interference: i) harmless interference, which is produced by device malfunctioning and ii) harmful interference, which is created by malicious user [134].

The three foremost functions in Dynamic Spectrum Access are as follows [138]:

i) Spectrum awareness,

ii) Cognitive processing and

iii) Spectrum access

Spectrum awareness creates awareness regarding the Radio Frequency environment while spectrum access gives the means to utilize the existing spectrum opportunities for the purpose of reuse resourcefully. Cognitive processing is the intelligent and decision making function, which does numerous subtasks such as efficient sensing, learning of the radio environment and access policies that controls interference for coexistence of the SU networks with the PU networks.

On the other hand, the present methods contain some drawbacks. Consider auction game, Present works uphold on-demand auctions in which a SU could demand for bandwidth as per its traffic demands. On the other hand, the time overhead in the auction, comprising bidding time, market setup time and pricing clearing time, hampers the timely fulfillment of SU traffic demands that frequently alter in a small time scale, for instance, in multimedia communications. Furthermore, auction loses its values and turn out to be less effective while there are just a small number of bidders. Pricing techniques might experience low signaling overhead as SUs are not engaged in identifying prices. Though, a centralized server is required to manage SUs admission control, to compute the prices, in addition to charge the SUs. So they are hard to be used in a situation where in SUs are in an ad-hoc fashion.

Open spectrum concentrates on regulating the conduct of secondary users when maintaining the system transparent to primaries. Increasing spectrum utilization is the main objective of dynamic spectrum systems; a good allocation method is required to give fairness crosswise users. A user occupying the spectrum without coordinating with others could produce harmful interference with its surrounding neighbors, and as a result decreasing available spectrum. Provided a fixed topology, previous methods could proficiently allot spectrum to users by means of decreasing the issue to an alternate of the graph coloring issue [135].

A conflict free spectrum assignment is got for the provided topology. Generally, a topology-optimized allocation technique starts with no former info, and allots every user an optimal assignment. On the other hand, users are continuously moving and the network topology varies in case of a mobile network. By making use of this global optimization method, the network requires to totally reallocate spectrum assignments for each and every users subsequent to each change, bringing about greater computational as well as communication overhead. This expensive operation must be repeated often for keeping the spectrum utilization as well as fairness. In this research, take a distributed method to allocate spectrum, which begins from the prior spectrum assignment, and performs a limited number of computations to adapt to new topology changes.

Propose a local bargaining method in which the users affected by the mobility event self-organize into bargaining groups and adapt their spectrum assignment to approximate a novel optimal conflict free assignment.

The key idea of this research work is three fold:

Local Bargaining Strategy: Propose a local bargaining structure, as well as two bargaining techniques: one-to-one fairness bargaining as well as feed poverty bargaining for enhancing fairness based system utility.

Bound of Local Bargaining Performance: Derive on a theoretical lower bound on the amount of channels are every user could obtain from bargaining, which is called Poverty Line. The fairness level imposed by the presented bargaining techniques is replicated by the bound, and could act like a super vision for bargaining. As well draw on an upper bound on the performance variance among the local bargaining as well as the global optimal solution denoted as price of anarchy.

Simulation of Efficiency and Complexity: In order to measure the performance of local bargaining, carryout widespread simulations. Outcomes denote the presented bargaining does alike to the graph coloring solution [135] on the other hand with meaningfully decreased complexity of the algorithm. As well confirm the accuracy of the poverty line in addition to the efficiency of poverty guided bargaining.

A dynamic spectrum allocation technique is presented with the aim of assuring QoS to the FUs in the hybrid access cognitive femtocells, for the purpose of encouraging service provider as well as FAP. In order to serve the MUs, the service provider allots a portion of the spectrum resource to the FAP to offshoot the FAP. In this presented technique, the service provider keeps a portion of sub channels with the intention of assuring the performance of MUs. Then, the FAP obtains numerous resources of spectrum for enhancing the FUs performance. Besides, so as to increase the femtocell network utility when assuring the throughput of the served MUs, the resource allocation amid the MBS and FAP is modeled as a price bargaining dependent upon the stackelberg game so as to provide the optimum solution. In the upcoming sections are matched the outcomes with the conventional dynamic resource allocation method. The outcomes prove that in the presented technique the service provider as well as FAP will obtain the gains

5.3 OVERVIEW OF THE SYSTEM

Figure 5.2 shows the authors consideration of centralized OFDMA-based two-tier network structural design containing a macro BS in addition to some FAPs, involving the deployment of FAPs with the help of the indoor users as well as linked to the macro BS with the help of the wired backhaul, for instance cable in addition to fiber. When matched up with Wi-Fi and FAPs, the FAPs function on the licensed cellular spectrum as well as utilize the cellular standard for easy integration with the cellular network. In addition, in this module, the similar spectrum overlay model similar to the representation in [136] and [97] are used. In case of the Spectrum-Overlay-Based Cognitive Femtocells, the FAPs perform with CR technology have the ability to rapidly identify the used channels by the macrocell as well as the adjacent femtocells in addition take up the spectrum holes of the licensed cellular spectrum with the intension of evading cross-tier as well as intra-tier interference to the macrocell and adjacent femtocells [136]. In this proposed system, Perfect spectrum sensing is inherent for the tractability of analysis.

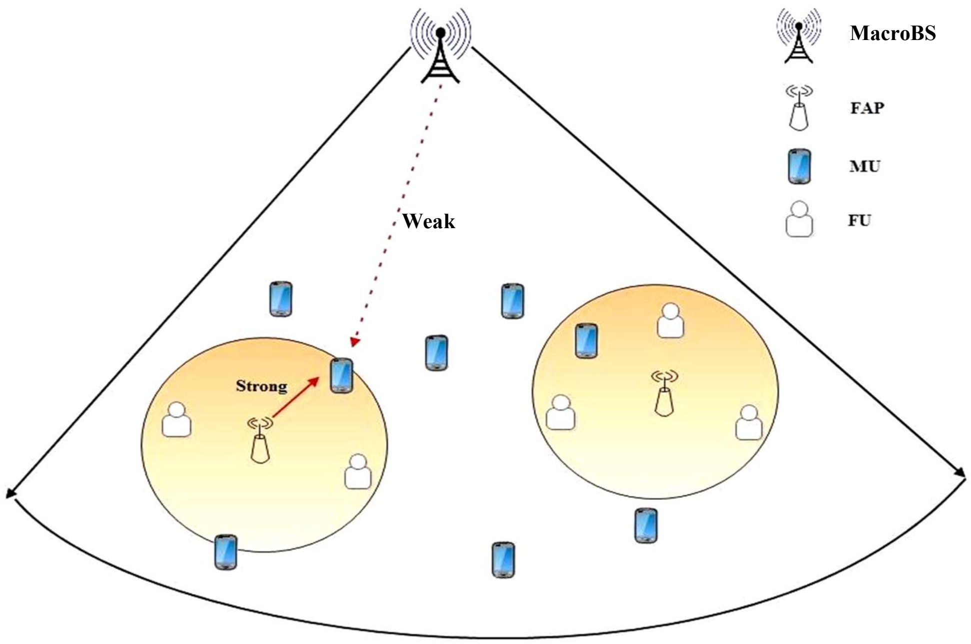


Figure 5.2 Interference Scenario

The OFDMA-based downlink broadcast is considered in the given network scenario. An all-inclusive of M MUs as well as N FUs in a femtocell are there. Consider in a cognitive femtocell, the group of the MUs as well as the group of the FUs are presented by $\Phi = \{1, 2, . . . , M\}$ as well as $\Omega = \{1, 2, . . . , N\}$, correspondingly. The index of a MU is denoted by $m \in \Phi$, and the index of an FU is represented by $n \in \Omega$. $\Psi = \{1, 2, . . ., M + N\}$denotes the group of indoor end users, who encompasses MUs as well as FUs, and every indoor end users is indexed by j, where $j \in \Psi$. By means of utilizing OFDMA technique, the indoor end users interconnect with the FAP allocation, where in successive subcarriers are packed into a sub channel. B is known as the bandwidth of each sub channel, when each sub channel is indexed by i. The FAP sets the group of available sub channels by means of spectrum sensing in every slot, in addition, k is represented as the amount of the accessible sub channels through spectrum sensing.

5.3.1 Price Bargaining based Dynamic Spectrum Allocation

With the aim of stimulating the wireless operator as well as the FAP in order to adopt hybrid access in the cognitive femtocell network, a dynamic spectrum allocation technique is presented. As per Figure 5.2, the Signal-to-Noise Ratio (SNR) of the link amid the MU as well as the FAP is greater than that of the link amid the MU as well as the macro BS rising from the less wall penetration, minimum transmission distance, and shadowing effects. Indoor communications takes less sub channels when matched up with the outdoor communications for achieving the same QoS as of the MU. This inspection has influenced the inspiration for a dynamic spectrum allocation technique in order to stimulate the wireless operator as well as the FAP with the aim of adopting hybrid access in the cognitive femtocell.

In order to stimulate the FAP so as to serve the MU, the research technique involves the allocation of a portion of spectrum resource to the FAP. The wireless operator as well as the femtocell could take advantage of the proposed technique. As a result of the availability of more number of available sub channels, the FAP offer an improved service to the FUs. In addition, by means of saving a part of the spectrum, the macro B will enhance its spectrum efficiency. An equivalent protocol is designed for enabling implementation of the dynamic spectrum allocation technique. Details of the protocol are provided along these lines.

1. **Step 1**: The m^{th} MU goes into the region covered by FAP and begins a data broadcast call through the control channel: the FAP gets the request then conveys it to the macro BS.

2. **Step 2**: The macro BS computes the amount of sub channels $q_m$that the m^{th} MU needs on the basis of the m^{th} MU's necessity D_m and the resource allowance technique of the macro BS.

3. **Step 3**: In order to serve the m^{th} MU, the macro BS negotiates with the FAP for offering stimulation. The macro BS alerts the FAP its neediness to allot c_m sub channels that are the portion of q_m sub channels to the FAP when the FAP canfulfill the m^{th} MU's need. Call the sub channels

that the macro BS allots to the FAP negotiation channels. Consider that c_m= [αq_m], here α is a convenient system parameter of the macro BS. [y] gets the nearby integer not more than or equal to y.

4. **Step 4**: In keeping with the profit of the femtocell, the FAP chooses whether to serve the m^{th} MU or not. The FAP chooses to serve the m^{th} MU, when the FAP identifies that the network utility of the femtocell as containing the capability to rise by *X* percent while it serves the m^{th} MU,. *X* is a controllable system parameter of the FAP. If not, the FAP does not serve the m^{th} MU, as well as the macro BS requires allocation of numerous sub channels to the FAP in order to stimulate it to serve the m^{th} MU. Consider the process of the proposed techniques well as spectrum sensing is carried out with the help of the femtocell concurrently as the negotiation of the protocol is carried out on the wired backhaul amid the macro BS as well as the FAP.

So, the equivalent resource allocation technique of the FAP is formulated as

$$max \sum_{n \in \Omega} U_n(\lambda_n) \tag{5.1}$$

$$\text{s.t.} \sum_{j \in \Psi} \mu_{i,j} \leq 1 \quad \forall i \in \gamma \tag{5.2}$$

$$\sum_{i \in \gamma} \sum_{j \in \Psi} p_{i,j} \leq P_{FAP}\, \lambda_m \geq D_m \tag{5.3}$$

where γ = *{*1*,* 2*, . . . ,* k + c*}*, and *c* represents the overall amount of negotiation channels in the presented technique, i.e.,

$$c = \sum_{m \in \Phi} c_m \tag{5.4}$$

Un (·) is called the utility function. It is a concave as well as increasing function of data rates replicate user satisfaction [8] and is represented in this way:

$$U_n(\lambda_n) = \begin{cases} k_1\left(1 - e^{-k_2\lambda n}\right) if \lambda_n \geq 0 \\ -\infty if \lambda_n < 0 \end{cases} \qquad (5.5)$$

where $\lambda_n$is the achievable rate of the *n*th FU, $\lambda_j = \sum_{i\in\gamma} \mu_{i,j} \,.\, R_{i,j}$, and $R_{i,j}$ is the practicable rate of the j^{th} user on subchannel *i*, that is computed by $R_{i,j}$= *B* log2(1 + $SNR_{i,j}$). k_1 denotes the utility function's upper limit, the value of k_2 is selected to let utility equivalent to 0.9$k_1$while the user attains the target rate *t*. provided *t*, k_2 = ln (0.1)/ − *t*. According to Figure 5.3, the sample of the utility function in which *t* = 15 Mb/s, k_1 = 1/3, and $k_2 = 7.675 \times 10^{-8}$. U_n (·) is an increasing function. While the achievable rate is lesser than the target rate *t* = 15 Mb/s, the utility rises fast. As the utility rises gradually while the attainable rate surpasses the target rate, allocation of numerous resources to the end users, which fulfill the target rate would make very small involvement to the utility function, and it could assure the fairness amongst the users.

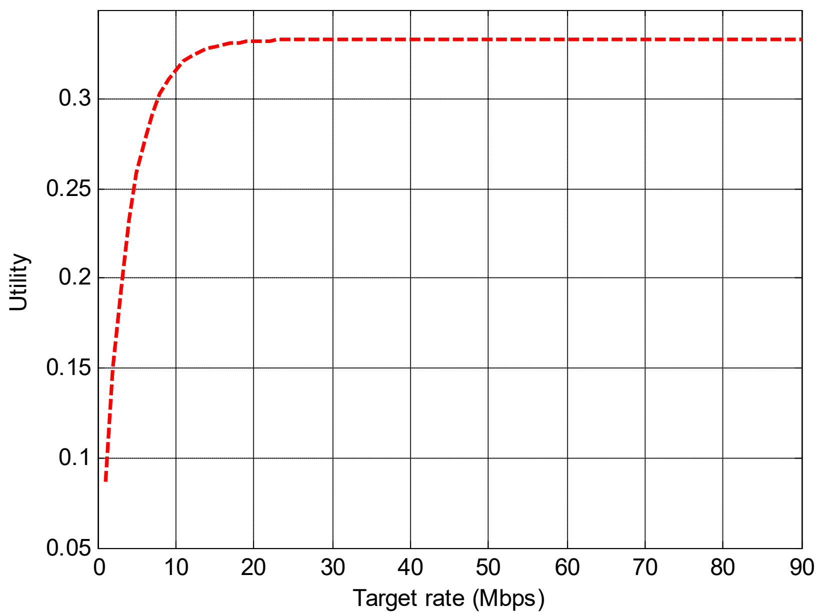


Figure 5.3 Utility function

The constraint in (5.2) denotes that each sub channel can be allocated to only one user. Equation (5.3) indicates the power constraint of the FAP, and (5.4) means that the FAP should guarantee the requirement of the served MUs if it makes a deal with the macro BS.

5.3.2 Stackelberg Game Formulation

In the below framework the entire terminals in the infrastructure are armed with a single signal antenna and all the channels are considered to be block-fading. It means the channels may subject to move from one block to another but remains constant during each transmission block. According to the Stackelberg game, by means of pricing the interference presented from FUEs transmission powers, the MBS as the leader must safeguard itself. Therefore, by selling the interference quota to FUEs, develop a technique to attain revenue. The revenue of the MBS is as follows

$$U_{MBS}(c,p) = \sum_{i=1}^{N} c_i \, p_i g_{0,i} \tag{5.6}$$

where c_i denotes the interference price of ith FUE. The existence of some relationships between p_i and c_i is observed. This presents the willingness of i^{th} FUE with the aim of buying the interference quota in price set by the MBS. Considering the interference threshold Q, the optimization problem at the MBS's side is as follows

$$max_{c_i \geq 0} U_{MBS}(c,p) = \sum_{i=1}^{N} c_i \, p_i g_{0,i} s.t. \sum_{i=1}^{N} p_i \, g_{0,i} \leq Q \tag{5.7}$$

In this work, a profit function as well as a cost function to, correspondingly, denote the fulfillment of the FUE with the QoS as well as the cost incurred. The revenue of i^{th} FUE is given as equation

$$U_i(p_i, p_{-i}) = \lambda_i \log(1 + \gamma_i) - c_i p_i g_{0,i} \tag{5.8}$$

Here, λ_i is known as the utility gain for each unit transmission rate of i^{th} FUE, p_{-i} is called the vector of power allocation for all FUEs excluding i^{th} FUE, that is to say, $p_{-i} = [p_1, \ldots, p_{i-1}, p_{i+1}, \ldots, p_N]^T$. It is noticed from (5.4) that when i^{th} FUE raises its transmission power, the transmission rate as well rises for this reason achieves the profit. On the other hand, with the rise in the transmission power, the FUE produces more interference to the MBS. Consequently there is an essential to buy more interference quota from the MBS those results in cost calculation. So the FUEs must choose the ideal power allocation techniques so as to increase their own utilities. Mathematically, the optimization problem uniting with the interference constraint is formulated as

$$max_{p_i \geq 0} U_i(p_i, p_{-i}) = \lambda_i \log(1 + \gamma_i) - c_i p_i g_{0,i} \quad (5.9)$$

$$\sum_{i=1}^{N} p_i \, g_{0,i} \leq Q \quad (5.10)$$

$$p_i \geq 0, \forall i \in \{1,2, \ldots\ldots, N\} \quad (5.11)$$

Stackelberg game is a kind of strategic game, which involves a leader in addition to numerous followers contending for specific resources. The leader makes the first move, after that the followers fine-tune their equivalent actions. In this work, so as to attain the maximum revenue, the MBS prices the interference from the FUEs. After that FUEs regulate their own transmission powers to maximize their individual utilities on the basis of the interference prices. The target set by the authors is to identify the SE point, specifically; the MBS in addition to all FUEs contain no motivations to diverge it, resulting in the Karush–Kuhn–Tucker (KKT) conditions

$$p_i \perp \left(-\frac{\lambda_i}{\delta_i + \sum_{j=1}^{N} \alpha_{ij} p_j} + c_i g_{0,i}\right) \quad (5.12)$$

$$\text{s.t.} \quad p_i \geq 0 \quad (5.13)$$

$$-\frac{\lambda_i}{\delta_i + \sum_{j=1}^{N} \alpha_{ij} p_j} + c_i g_{0,i} \geq 0 \quad (5.14)$$

Here the notation a $\perp$ b denotes the complementarily condition of a and b, called, ab = 0. Observe that $c_i > 0$ and $\delta_i > 0$ multiply by a non-negative scalar

$$\frac{\delta_i + \sum_{j=1}^{N} \alpha_{ij} p_j}{c_i g_{0,i}} \quad (5.15)$$

Then, it is defined as

$$p_i \perp \left(-\frac{v_i}{c_i} + \delta_i + \sum_{j=1}^{N} \alpha_{ij} p_j \right), \forall i \in \{1,2, \ldots\ldots, N\} \quad (5.16)$$

where $v_i = \lambda_i/g_{0,i}$. Taking the restraints stated in the aforesaid description, formula is corresponding to

$$p_i = \left[\frac{v_i}{c_i} - \delta_i - \sum_{j \neq i, j=1}^{N} \alpha_{ij} p_j \right]^+ , \quad \forall i \in \{1,2, \ldots\ldots, N\} \quad (5.17)$$

Here $[p_i]^+ = max\{p_i, 0\}$.

Stackelberg equilibrium

Let $c*$ and $p*$ be a solution obtained by solving the above equation. A strategy $(c*, p*)$ is called a SE strategy, if for any (c, p), the MBS achieves

$$U_{MBS}(c^*, p^*) \geq U_{MBS}(c, p) \quad (5.18)$$

Moreover, the i^{th} FUE achieve

$$U_i({p_i}^*, {p_{-i}}^*) \geq U_i(p_i, p_{-i}) \forall i \quad (5.19)$$

Generally, it is possible to obtain the SE for the Stackelberg game by identifying its sub game NE. with FUEs competing in a severe non-cooperative game. NE is the point in which no player could separately raise his own utility while any other players do not alter their strategies, due to the sacrifice of the related FUEs utility made by the adjustment of the strategy. As a result each rational FUE contains no readiness to alter the strategy separately in the NE point. In this presented method, must get the finest responses of both sides in order to get the best possible solutions.

5.4 SIMULATION RESULTS AND DISCUSSIONS

An OFDMA based Macro-Femto scenario is considered for simulation. The femtocell equipped with CR to sense the surrounding channels to reduce the cross-tier interference. All the femtocells are randomly deployed and users are distributed randomly in the network. The simulations are carried out based on the MATLAB software. Simulations are conducted to estimate and calculate the performance of the proposed game theory method. The path loss factors of wireless subchannels between indoor end users as well as the FAP are modeled dependent upon the ITU model

$$h_j = 10^{-3.7} r^{-3} 10^{-1.83\omega^{\left(\frac{\omega+2}{\omega+1}-0.46\right)}} 10^{-S/10} \tag{5.20}$$

Here *r* (in meters) is known as the transmission range, *S* is called the lognormal shadowing factor with the standard deviation 6 dB, as well as ω is known as the floors in the path and is set to be 2 in the simulations. The details of the simulation parameters used, were given in the below table.

Table 5.1 Parameters and typical values used for simulation

Parameters	Values
Carrier frequency	2 GHz
Bandwidth	10 MHz
Modulation technique	64-QAM
Number of bits/symbol	5
Period of the symbol	0.4 μs
Number of FCs per MC	100
Number of active users per FC	4
Number of users per MC	2,000
MC maximum transmit power	46 dBm
FC maximum transmit power	15 dBm
White noise power density	−174 dBm/Hz
BER	10^{-6}
Subcarrier per resource block	12

The network performance metrics namely network throughput and network service be employed to estimate the concert of the femtocell.

1. **Network Throughout:** The sum throughout of all the femtocells FUs residing in the femtocell network.

2. **Network Utility:** Utility is the quality or state of being useful. Hence Network service is the sum of all the utilities in the femtocell.

3. **Achievable Rate:** The extent of rate achieved by the end users as compared to the target rate, measured in Mbps.

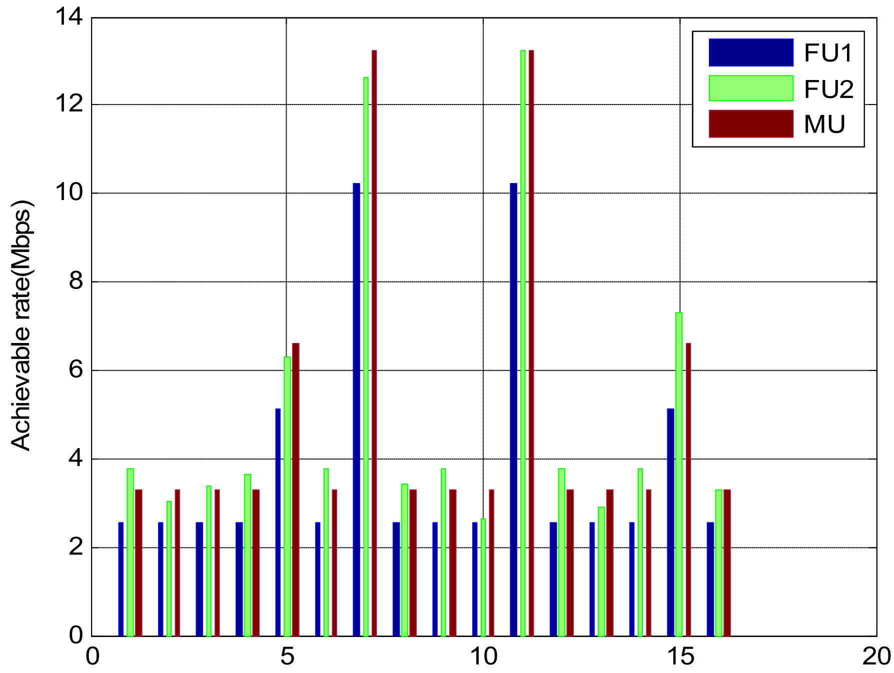


Figure 5.4 Feasible rates of each end user with the proposed Stackelberg game technique

To evaluate the performance of the proposed Price Bargaining Method (PBG), the simulation results were compared with the Dynamic Spectrum Allocation (DSA) method. Figure 5.4 shows the feasible rates of each end user i.e. Macro and Femto users compared with the existing and proposed techniques.

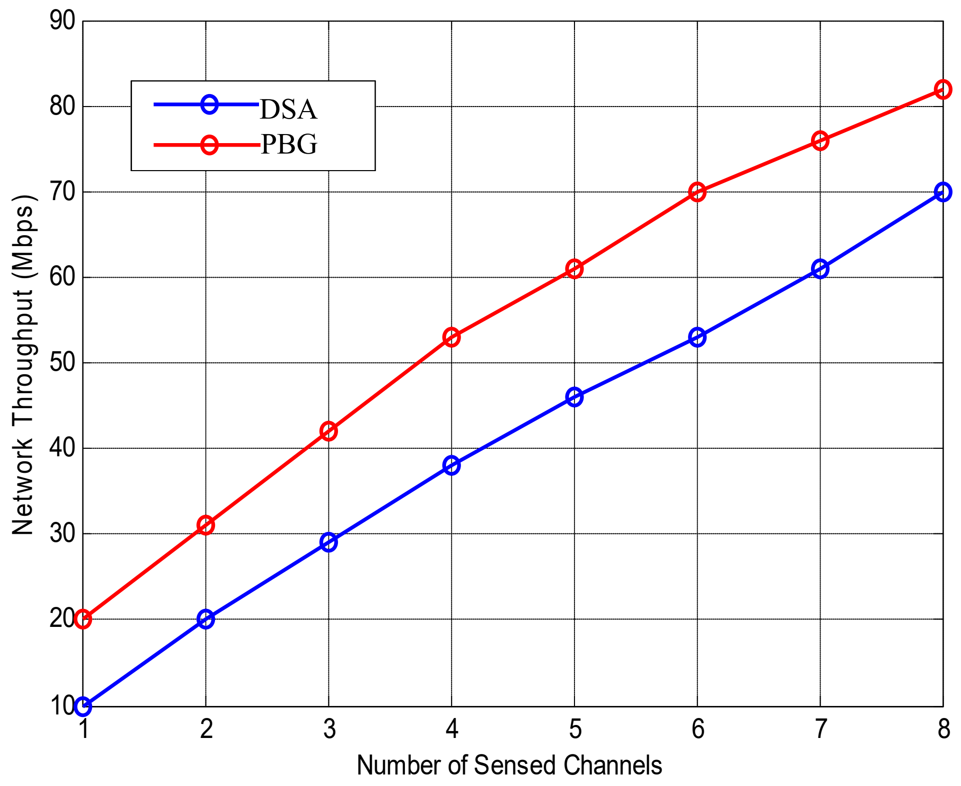


Figure 5.5 Network throughput with different number of sensed channel

In the Figure 5.5, Network Throughput with the amount of sensed channels is shown. The proposed PBG provides higher network throughput of 76 Mbps, whereas the DSA provides lesser network throughput of 61Mbps for an amount of 7 sensed channels. The results depicts that compared with the dynamic spectrum allocation method proposed Stackelberg game based resource allocation provides improved throughput and are discussed in Table 5.2.

Table 5.2 Network throughput with different number of sensed channel

Parameter	**DSA**			**PBG**		
	Number of Sensed Channels					
	1	**5**	**7**	**1**	**5**	**7**
Network Throughput (in Mbps)	10	46	61	**20**	**61**	**76**

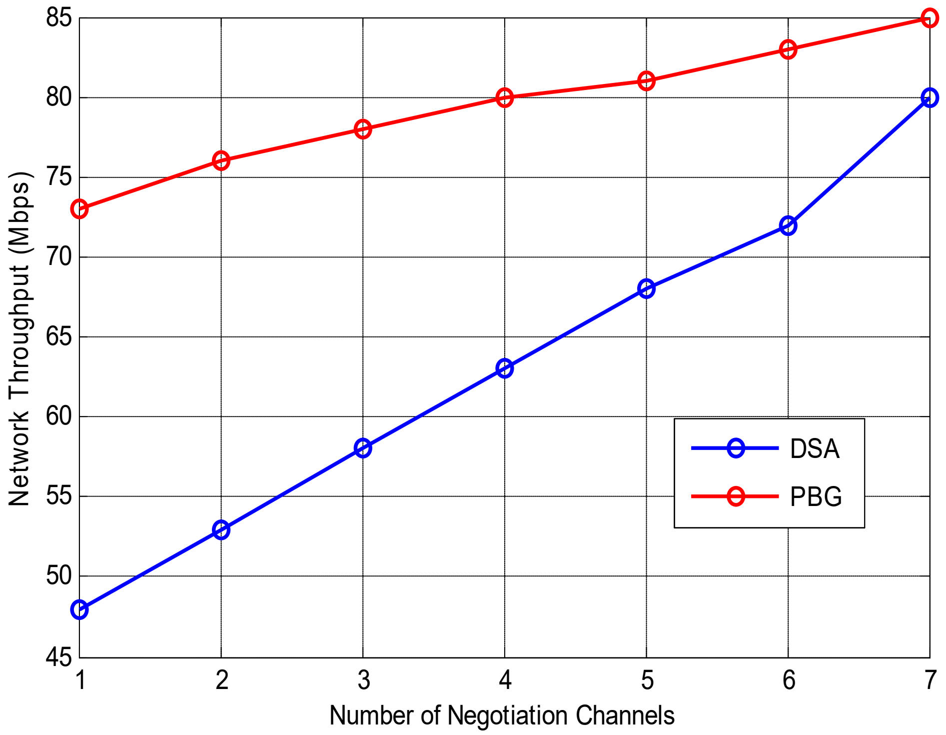


Figure 5.6 Network throughput with different number of negotiation channels

Network throughput varies with the number of negotiation channels as shown in Figure 5.6. As the number of negotiation channels increases, the throughput of the network will also increase. In Dynamic spectrum allocation method the negotiation channels is decided based on the target rate. It is modeled as a dual decomposition problem. Whereas in the proposed method the negotiation process between macro base station and FAP is modeled as a price bargaining game. The result shows that the price bargaining game (PBG) provides better throughput when compared with the dynamic spectrum allocation. When the number of negotiation channels increases, the Femtocell throughput will also increase, hence there is an increase in overall network throughput of the system. The proposed PBG provides higher network throughput of 85 Mbps, whereas the DSA provides lesser network throughput of 80 Mbps for 7 number of sensed channels.

Table 5.3 Network throughput vs. different number of negotiation channels

Parameter	DSA			PBG		
	Number of negotiation Channels					
	1	5	7	1	5	7
Network Throughput (in Mbps)	46	67	80	**73**	**80**	**85**

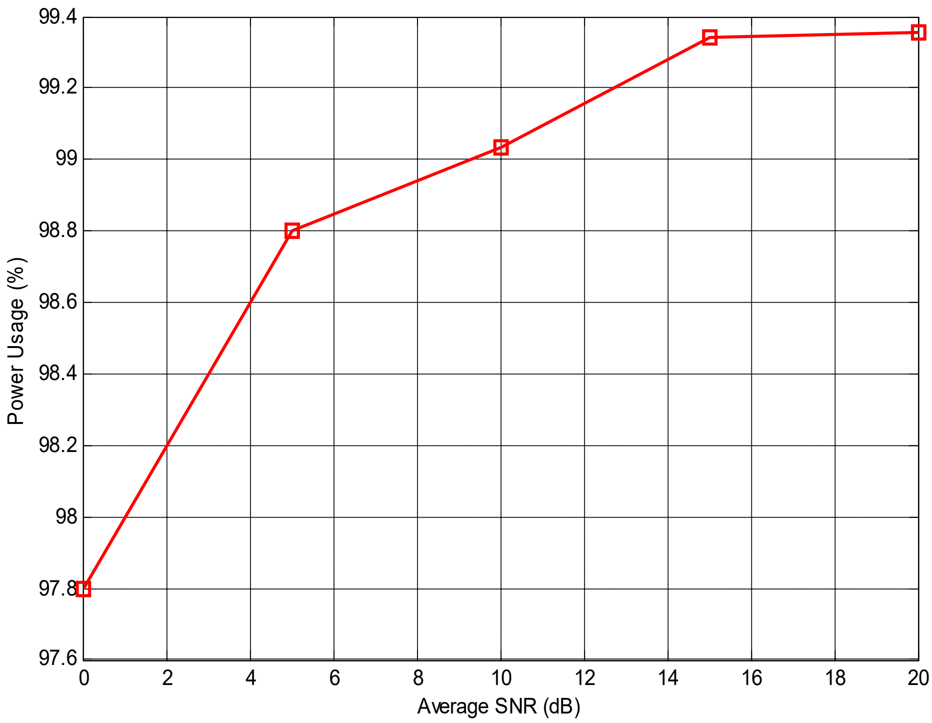


Figure 5.7 Power usage of end users with different levels of SNR

The power usage of the end user with different Signal to Noise Ratio (SNR) is shown in the Figure 5.7 for the proposed Stackelberg game based method.

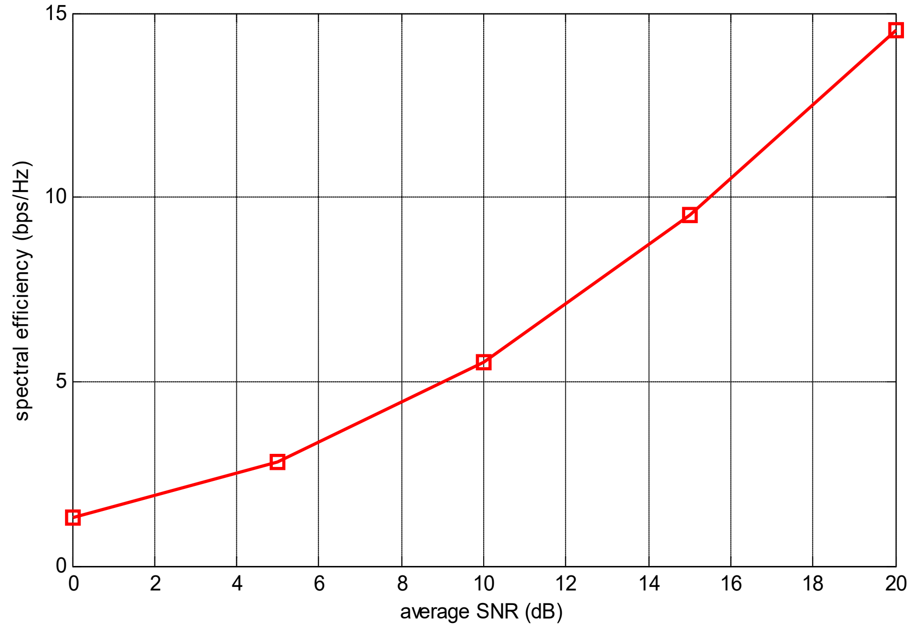


Figure 5.8 Spectral Efficiency versus Average SNR

The spectrum efficiency of the system with average SNR is shown in Figure 5.8. As the number of Femtocells increases, the frequency reuse factor will increase and results in improved spectrum efficiency and the capacity of the system.

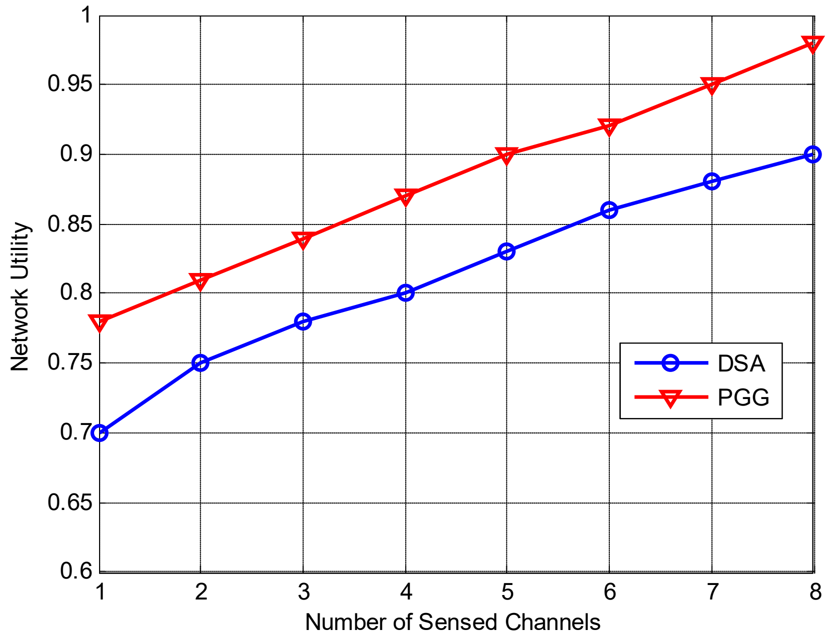


Figure 5.9 Network utility versus number of sensed channels

Figure 5.9 shows the equal increase in the methods of network utilities with increase in the quantity of sensed channels are discussed in table 5.4. The proposed PBG provides higher network utility results of 0.95, whereas the DSA provides lesser network throughput results of 0.88 for number of sensed channels (7).

Table 5.4 Network utility with different number of sensed channels

Parameter	DSA			PBG		
	Number of Sensed Channels					
	1	5	7	1	5	7
Network utility	0.7	0.83	0.88	**0.78**	**0.9**	**0.95**

Table 5.5 Network utility vs. different number of negotiation channels

Parameter	DSA			PBG		
	Number of negotiation Channels					
	1	5	7	1	5	7
Network utility	0.8	0.88	0.92	**0.9**	**0.96**	**0.97**

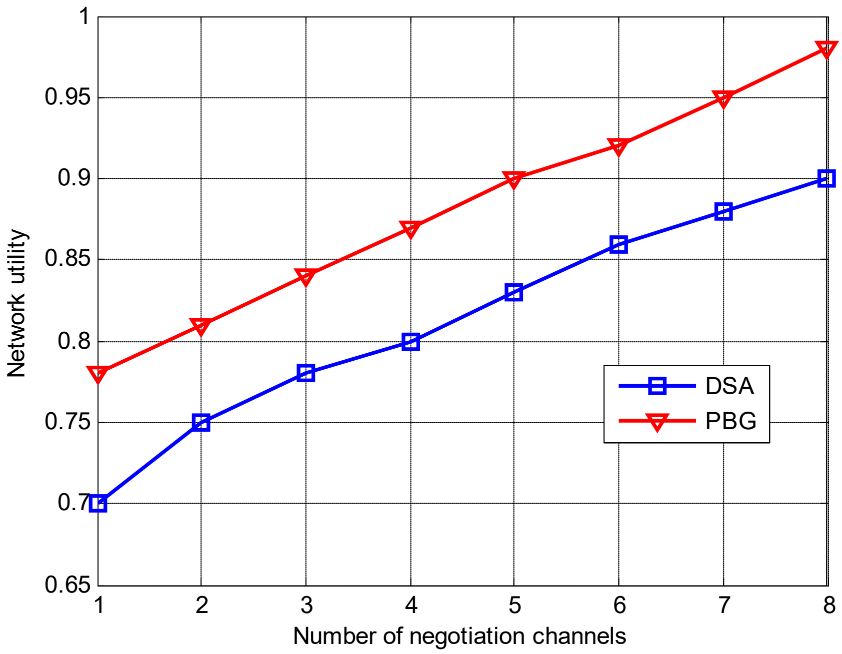


Figure 5.10 Network utility versus number of negotiation channels

Figure 5.10 shows that, as the number of negotiation channels increases the network throughput will increases, which is more in proposed method discussed in Table 5.5. Based on the results obtained, it is concluded that the overall performance of the Price Bargaining method including Network throughput, Network utility is much better compared to DSA-HA. The proposed PBG provides higher network utility results of 0.97, whereas the DSA provides lesser network throughput results of 0.92 for 7 number of sensed channels.

5.5 SUMMARY

In this module a Price-bargaining and Stackelberg game theoretic approach are proposed for hybrid access cognitive femtocell networks with perfect spectrum sensing. In which both network service provider and the FC will get the benefits in terms of Network utility and throughput. In the proposed method, the macro BS reserves a portion of spectrum for guaranteeing the performance of the MUs, and the FAP gets more subchannels to improve the performance of the FUs. The corresponding resource allocation strategies were modeled as a price bargaining game, and the Stackelberg game has been employed to obtain the optimal solution. Simulation results proved that both the network service provider and the femtocell could benefit from the proposed method.

CHAPTER 6

DYNAMIC ALLOCATION OF SPECTRUM IN HYBRID ACCESS COGNITIVE FEMTOCELL NETWORKS WITH PRACTICAL SPECTRUM SENSING

6.1 INTRODUCTION

In wireless communications, CR enabled femtocell is considered to be the hopeful method to solve the problems in FC networks. In the previous module, the dynamic allocation of spectrum for cognitive femtocell networks in hybrid access with perfect spectrum sensing is modeled by means of a game theoretic method. In case of practical environments spectrum sensing errors are inevitable. This module presented a RA technique for OFDMA based cognitive femtocells with practical spectrum sensing. The objective is to increase the total capacity of all FUs under provided QoS and co-tier and cross-tier interference restraints with inadequate channel sensing. In order to obtain the fairness amongst Femto Users, the minimum and maximum numbers of subchannels taken by each user is regarded. Initially, the subchannel along with power allocation problem is modeled as the price bargaining and Stackelberg game models.

On the other hand, perfect SS is hard to attain in practical cognitive wireless environments. Spectrum sensing errors are unavoidable, a very limited literature is available for a joint sub-channel as well as power allocation for cognitive femtocells by taking co-tier and cross-tier interference limits, fairness, in addition to practical spectrum sensing (spectrum sensing with sensing errors) was not finely examined.

In this chapter, a joint subchannel as well as power allocation in OFDMA based cognitive FCs under QoS requirement, fairness of FU constraints and co-tier and cross-tier interference limits with practical spectrum sensing. This is a novel attempt by mutually considering the sub-channel occupation fairness, capacity-maximization, spectrum sensing errors, co-tier as well as cross-tier interference mitigation, and QoS of user requirements in the formulation of OFDMA based cognitive femtocell optimization framework.

Downlink power and sub-channel allocation issue is expressed in cognitive femtocells like a price bargaining as well as Stackelberg game problem. Co-tier and cross-tier interference limits are utilized for protecting principal macrocell as well as nearby femtocells. A minimum QoS requirement is used to give consistent transmission for all cognitive FUs. Fairness in regard to minimal as well as maximal subchannel occupation is taken for every FU, in which SS errors coming because of the misdetection or false alarm are considered. The femtocell is facilitated with cognitive abilities, and therefore a cognitive femtocell must not have an impact on the process of primary macrocells. So, co-tier as well as cross-tier interference temperatures are taken, with the intention of alleviating the interference from adjacent femtocells.

6.2 IMPERFECT SPECTRUM SENSING

In case of OFDMA cognitive femtocell, because of channel fading conditions in addition to the renowned hidden terminal problem, SS is typically defective as well as enforces interference on the primary macrocell network. Paying multiple cognitive users, precisely by exploiting the accessible spatial diversity, brings about cooperative spectrum a sensing approach that enhances the detection reliability. On the other hand, because of imperfect spectrum sensing, interference happens to the primary as well as the secondary cognitive network, which is functioning on the similar frequency bands. Here, as soon as the SS has determined that the PU is off, the primary band is allotted to the cognitive BS containing the finest channel gain for a downlink data transmission with the cognitive users.

Perfect sensing is presumed and so the capacity of the secondary network based upon the channels SNRs as well as the transmission parameters since the secondary users transfers their data in absolute nonexistence of the PU. When the movement of the PU is sensed incorrectly, the likelihood of misdetection as well as false alarm disturbs the secondary network since their transmission might undergo collision with the primary network transmission and albeit collision never occurred the channels, SINR will reduce because of the interference from the primary or secondary users.

6.3 SYSTEM MODEL

An OFDMA downlink of a network encompassing one primary macrocell as well as K co-channel cognitive femtocells is taken that are setup arbitrarily in the coverage zone of a macrocell. Consider M and F represents the amount of active MUs inside the primary macrocell as well as FUs in every cognitive FC, correspondingly. The OFDMA system contains a total bandwidth of B_w that it is splitted into N_{total} subchannels. The model of the channel for every subchannel comprises path loss as well as frequency-flat Rayleigh fading. The FUs resourcefully gain access to the spectrum licensed to the primary MCs through cognitive FBS, as depicted in Figure 6.1.

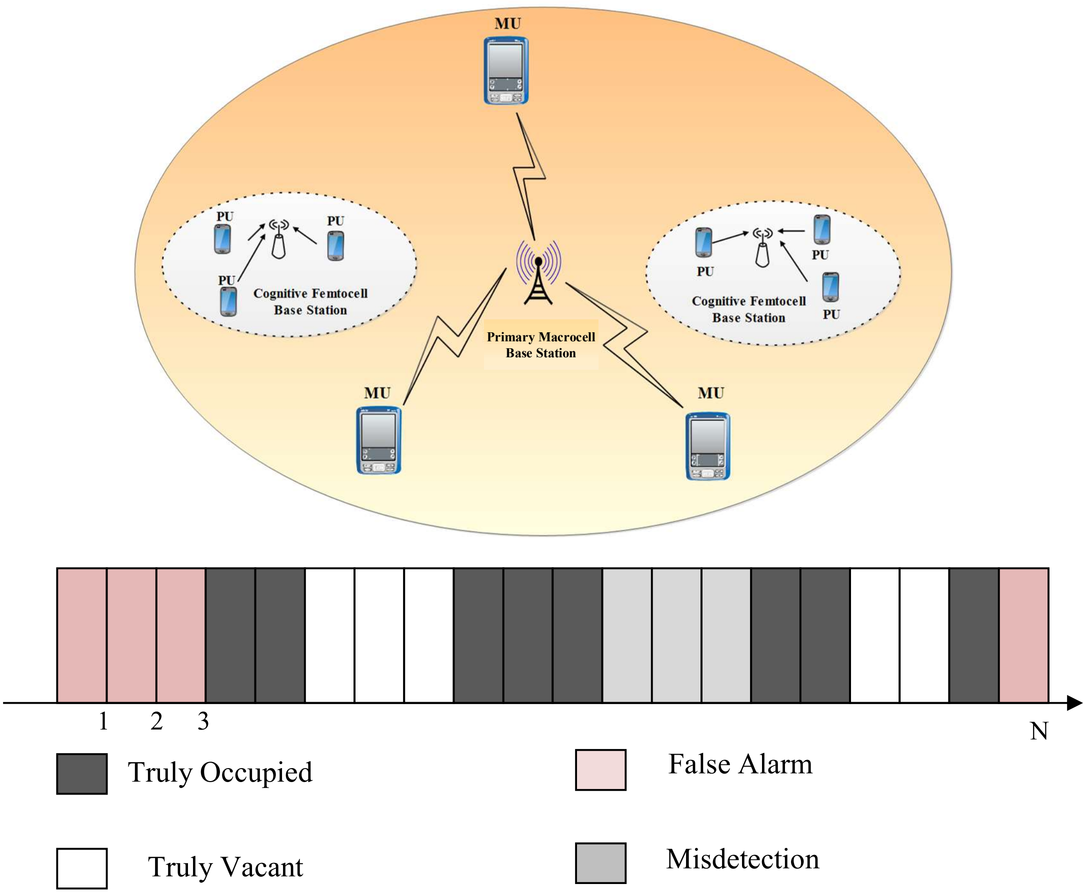


Figure 6.1 A cognitive macro-femto network model

In every time interval, the secondary femtocell network could sense N_{total} subchannels and speculatively gain access to idle channels by Para unitary Filter Bank (PUFB) based sensing of the spectrum. In a Spectrum Sensing period, the cognitive FC network senses N_{total} subchannels licensed to the primary MC network as well as identifies existing vacant or idle subchannels that are represented by N = 1, 2, ...,N. During the course of this research presume that a cognitive FBS contains perfect Channel State Information (CSI) amid FBS and cognitive FUs or primary MUs. So, the overall capacity of the cognitive FC networks by utilizing presented resource allocation methods will act as an upper bound of the attainable capacity with channel sensing errors in practical situations.

The received SINR $l_{k,i,n}^{F}$ at the k^{th} ($k \in \{1, \dots .K\}$) Cognitive FBS from its FU i (i$\in \{1, \dots .N\}$) sub channel is as follows

$$l_{k,i,n}^{F} = \frac{p_{k,i,n}^{F} h_{k,k,i,n}^{FF}}{\sum_{j=1,j\neq k}^{K} \sum_{v=1}^{F} p_{j,v,n}^{F} h_{k,j,v,n}^{FF} + p_{w,n}^{M} h_{k,w,n}^{FM} + \sigma^2} \tag{6.1}$$

Here $p_{k,i,n}^{F}$ is the transmit power of i[th] FU on subchannel n in cognitive FC k. $h_{k,j,v,n}^{FF}$ and $h_{k,w,n}^{FM}$ are the corresponding channel gains on subchannel n from FU v in cognitive FC j and from MU w to FBS k, correspondingly. w is called a particular MU utilizing subchannel n; $p_{w,n}^{M}$ is the transmit power of MU w on subchannel n; and $\sigma^2$is known as the noise power of the Additive White Gaussian Noise (AWGN) . The capacity of the system based on Shannon's capacity is as follows

$$R_{k,i,n}^{F} = log_2(1 + l_{k,i,n}^{F}) \tag{6.2}$$

6.4 FRAMEWORK WITH PRACTICAL SPECTRUM SENSING

In this module, a cooperative spectrum sensing technique is used, where in every cognitive FU senses subchannels and transmits the sensing outcomes to a cognitive FBS. Based on this, the cognitive FBS makes a decision that whether subchannel is free or used. In cognitive HetNets comprising cognitive FC networks as well as primary MC networks, practical spectrum sensing of cognitive FBS typically produces strong co-channel interference to primary MBS because of misdetection and false alarm, and therefore reduces the performance of the cognitive heterogeneous macro femto networks. As it is the cognitive FBS that identifies when a subchannel is taken by primary MBS or not, therefore there are four possible diverse cases that are stated along these lines.

- Case 1: Subchannel ‘s’ is free in a primary MC network, and it is determined by the cognitive FBS as free;
- Case 2: Subchannel ‘s’ is free in primary MC network, but it is determined by the cognitive FBS as occupied;
- Case 3: Subchannel ‘s’ is occupied in primary MC network, and it is determined by the cognitive FBS as free;
- Case 4: Subchannel ‘s’ is occupied in primary MC network, and it is determined by the cognitive FBS as occupied.

Algorithm 6.1: Joint Power and Sub channel allocation Algorithm

1. Cognitive FAP set: k={1,2….K}; Cognitive FU set per FC: u={1,2….F}
2. Allocate the equal amount power to each subchannel
3. Repeat
4. Cognitive FBS k measures sub-channel gains and interference limits
5. for each FAP do
6. subchannel set: N={1,2….N};
7. set $N_i=0$;
8. Subchannel allocation for obtaining user fairness
9. Subchannel allocation for getting capacity enhancement
10. Each FBS j $(j \neq k)$ measures the sub-channel gains and feedback to FBS k
11. Allocation of power
12. Primary MBS updates and transmits the updated value to all FBS via backhaul
13. Until convergence.

The problem formulation is alike to that in the former module, by containing less user data rate need, co and cross-tier interference limits, subchannel assignment fairness, and practical spectrum sensing**.** The subchannel allocation amid the macro as well as femtocell networks is modeled as the price bargaining game as well as the power allocation is dependent upon the stackelberg model in which macro cell as well as femtocell will gain the profits with an incentive technique.

6.5 SIMULATION RESULTS

In this section, the proposed joint power and subchannel allocation with practical spectrum sensing is studied through simulations and compared with perfect spectrum sensing algorithm. Performances are examined using MATLAB tool. The parameters used for simulation are listed in Table 6.1. Cognitive FCs and MUs are randomly distributed in the coverage area of a macrocell. The fading channel gains are modeled as i.i.d. exponential random variables with a mean of unity. The false alarm probability q_s^f, misdetection q_s^m and primary MU's occupation q_s^p are uniformly distributed over [0.04,0.1], [0.02,0.05], and [0,1], respectively.

Table 6.1 Simulation Parameters

Parameter	Values
Carrier frequency	2 GHz
Bandwidth	10 MHz
Modulation technique	64-QAM
Macrocell , Femtocell radius	500 m, 10m
Symbol period	0.4 µs
Access mode	Hybrid
No. of FCs per MC	100
No. of active users per FC	4
No. of users per MC	2,000
Maximum transmit power of macro users	23 dBm
Maximum transmit power of FC	15 dBm
Noise power	−174 dBm/Hz
BER	10^{-6}
Log-normal shadowing factor between MBS and Users	8 dB
Log-normal shadowing factor between FBS and users	10 dB

The Figure 6.2 shows the average cross-tier interference caused to the MU on each subchannel when the maximum transmit power of the each FU is increasing. The results are compared with the perfect spectrum sensing case. With a transmit power of 20 dBm, The femto user will cause a cross-tier interference of -103dBm in case of perfect spectrum sensing and -105.4dBm in case of imperfect spectrum sensing are discussed in Table 6.2.

Table 6.2 Average cross-tier interference to macro cells

Parameter	**Perfect Spectrum Sensing**			**Imperfect or Practical Spectrum Sensing**		
	Each FU Transmit power (dBm)					
	20	**23**	**30**	**20**	**23**	**30**
Average cross-tier interference caused to primary MC on each subchannel (dBm)	-103	-99.5	-94	-105.4	-103	-99.9

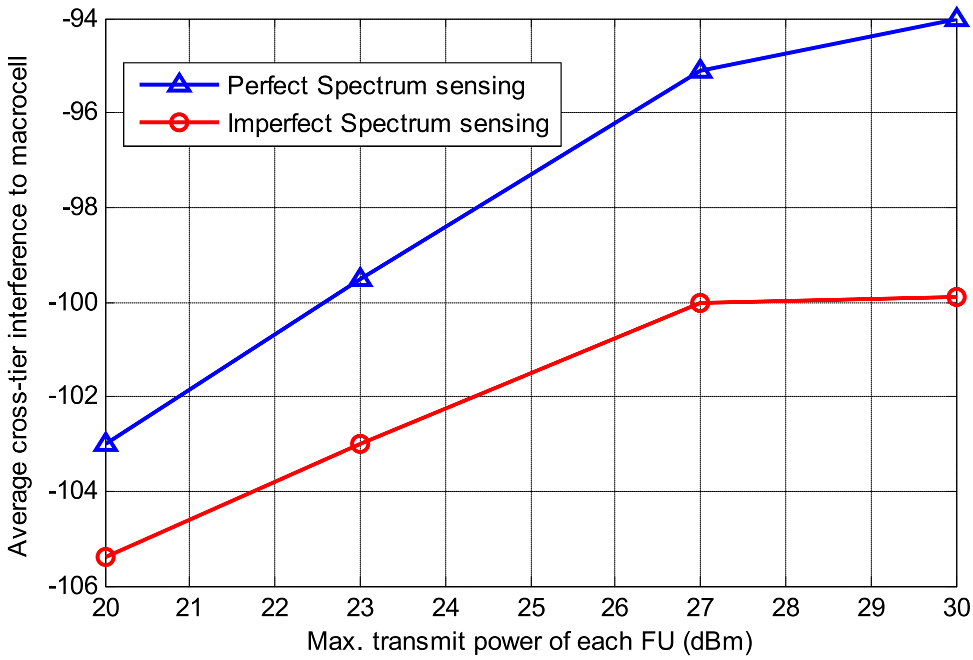


Figure 6.2 Average cross-tier interference to macro cells

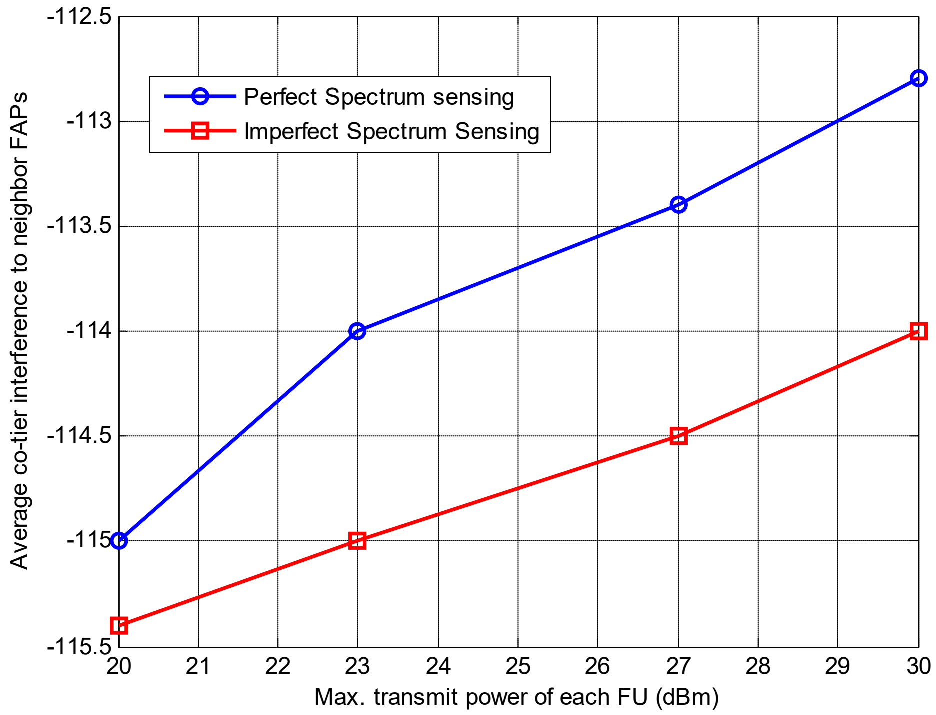


Figure 6.3 Average co-tier interference to neighbor FAPs

The Figure 6.3 gives the information of the average co-tier interference caused for neighboring FBS on each subchannel when the maximum transmit power of the each FU is increasing. The graph explains the comparison of the imperfect SS with perfect SS. The average cross-tier and co-tier interferences caused with different power levels are listed in Table 6.3. The total capacity of K cognitive FCs variation with different co- tier and cross-tier interference limits. The proposed algorithm with higher co and cross-tier interference limits, $I_{th,n}^{FF}$ and$I_{th,n}^{MF}$, provides a higher overall capacity of K cognitive FCs, because of the higher transmit power used by users under the slacker constraint of co and cross-tier interference. Here the threshold fixed is -100 dBm. The average number of subchannels assigned by the proposed algorithm to each FU is more when compared with the existing algorithm, which will meet the capacity requirements.

Table 6.3 Average cross-tier interference to neighbor FAPs

Parameter	Perfect Spectrum Sensing			Imperfect or Practical Spectrum Sensing		
	Each FU transmit power (dBm)					
	20	**23**	**30**	**20**	**23**	**30**
Average co-tier interference caused to neighboring FCs on each subchannel (dBm)	-115	-114	-112.8	-115.4	-115	-114.1

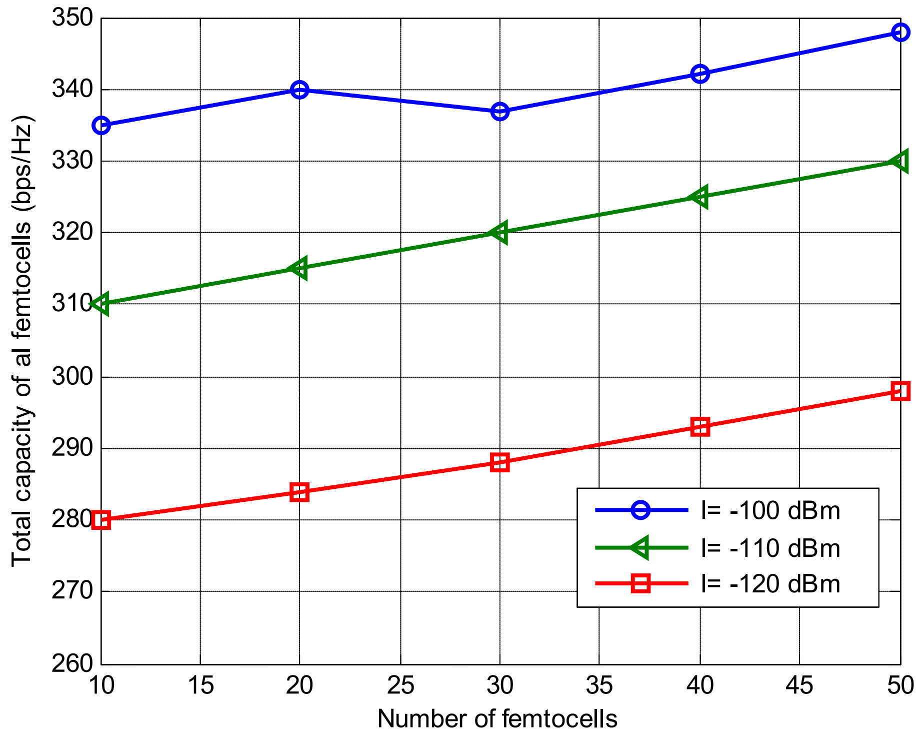


Figure 6.4 Overall capacity of all femtocells

The above Figure 6.4 shows the overall capacity achieved by all femtocells for different interference threshold values with increase in number of femtocells in the network are tabulated in Table 6.4. As the number of FCs increases the capacity of the system also increases. When the interference limit is less the capacity of the femtocells are more.

Table 6.4 Overall capacity of all femtocells

Parameter	I= -100 dBm			I= -110 dBm			I= -120 dBm		
	Number of femtocells								
	10	30	50	10	30	50	10	30	50
Total capacity of all femtocells (bps/Hz)	335	337	348	310	320	330	280	288	298

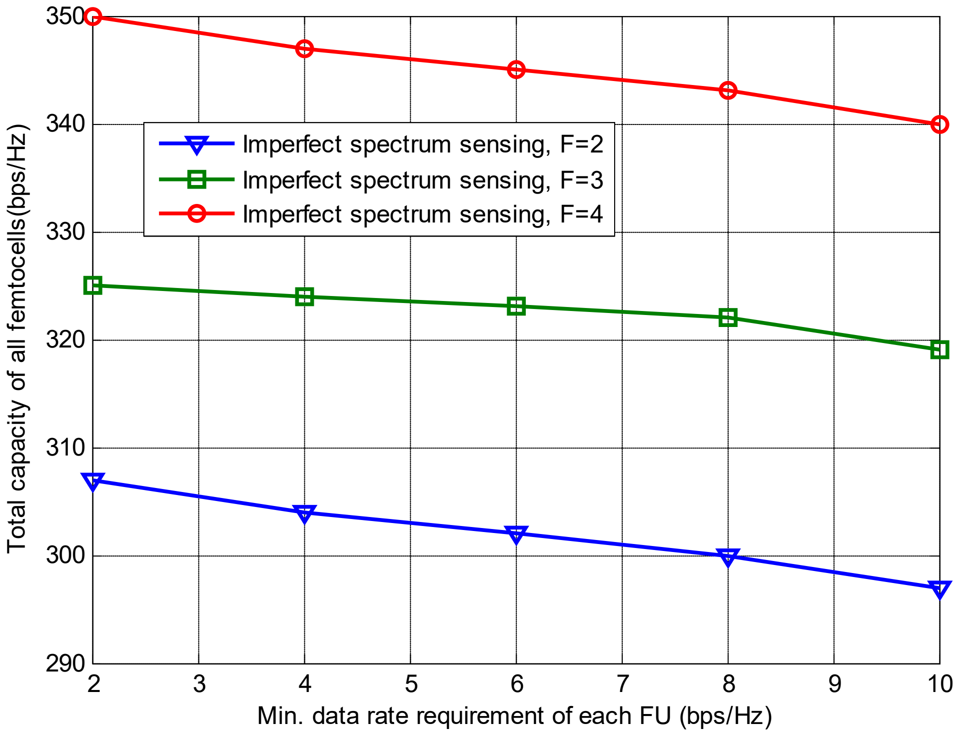


Figure 6.5 Total capacity of all FCs with minimum data rate requirement of each FU

The Figure 6.5 shows the overall capacity of all Femtocells when minimum transmit data rate requirement of each FU increased from 2 bps to 10 bps. It gives the information about the variation of total capacity as the number of users in the FC increases. When the number of femtocells are 10 and the interference threshold is -100 dBm. The total capacity of femtocell decrease as the minimum data rate requirement increases are discussed in Table 6.5.

Table 6.5 Total capacity of all femtocells with Practical spectrum sensing (F=2, 3 and 4)

Parameter	F=2			F=3			F=4		
	Minimum required data rate of each FU (bps/Hz)								
	2	6	10	2	6	10	2	6	10
Total capacity of all femtocells (bps/Hz)	307	302	297	325	323	319	350	345	340

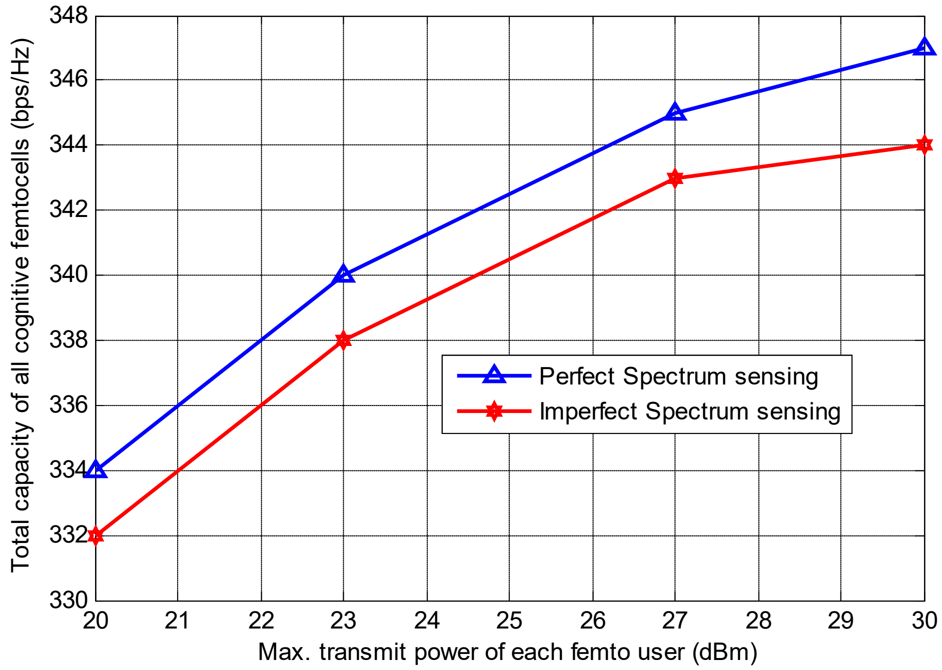


Figure 6.6 Overall capacity of all cognitive femtocells

The Figure 6.6 explains the variation in total capacity of all cognitive FCs when the transmit power raises from 20 dBm to 30 dBm. When the number of users in each femtocell is F=4 and the number of FCs in MC is K=10 and the other parameters used for simulation are minimum data rate of 9 bps/Hz for all the users and the interference threshold of -100 dBm is listed in Table 6.6. The overall capacity of FCs increases with increase in maximum transmit power.

Table 6.6 Total capacity of all cognitive femtocells

Parameter	Perfect Spectrum Sensing			Imperfect or Practical Spectrum Sensing		
	Each FU transmit power (dBm)					
	20	**23**	**30**	**20**	**23**	**30**
Total capacity of all the cognitive FCs (bps/Hz)	334	340	347	332	338	344

6.6 SUMMARY

In this chapter, a joint power and sub-channel allocation algorithm for cognitive FCs with hybrid access is proposed, by considering minimum data rate requirement of the user, fairness among FCs when assigning subchannels, co and cross-tier interference limits, and practical spectrum sensing. Simulation results have shown that the proposed scheme converges quickly and outperforms the existing algorithms in terms of capacity of cognitive femtocells and subchannel reuse efficiency.

CHAPTER 7

CONCLUSION AND FUTURE SCOPE

The thesis investigated on Interference limited resource allocation techniques in macro-femto cellular networks. The major contributions of this thesis and possible ways to improve in future are discussed in this chapter.

7.1 CONCLUSION

The main contributions done in the research work are the development of interference limited resource allocation techniques for macro-femto cellular networks. The work can be distinctively divided into four modules, namely co-tier interference mitigation in femtocell networks through efficient frequency reuse, Cross-tier interference reduction in macro-femto cellular networks through Paraunitary filter bank based spectrum sensing, Dynamic Spectrum Allocation in Hybrid Access Cognitive Femtocell Networks by using Game Theoretic Approach and Dynamic Spectrum Allocation in Hybrid Access Cognitive Femtocell Networks with Practical Spectrum Sensing.

1. Interference Mitigation in Femtocell Networks through Efficient Frequency Reuse

In the first part of the research work an efficient frequency reuse has been proposed for mitigating interference in co-channel femtocells. In the proposed method, interference can be limited by assigning the PSCs to the CEUs and by assigning the SSCs to the CCUs. PSCs are orthogonal to each other, so the interference in the cell edge region is reduced. The subchannel allocation has been done based on the neighbour table construction, interference graph and conflict resolution. After subchannel allocation resources are allocated based on the interference known resource allocation algorithm. Results show that the proposed EFR technique yields improved performance over conventional techniques in terms of performance metrics like Spectrum Efficiency, Spectrum Utilization, Fairness Index, Throughput, Number of iterations and Outage Probability.

2. Interference Avoidance through Paraunitary Filter Bank based Spectrum Sensing in Macro-Femto Cellular Networks

In the second part of the research work Paraunitary filter bank based Spectrum Sensing (SS) method is proposed for identifying spectrum holes in the cellular band and also analyzed the SS technique performance over various multipath fading channels. Conventional ED method was taken as a reference for comparing the performance of the proposed Paraunitary filter bank method over multipath fading channels. The ROC curve is used for judging the entire detection process. The results show that PUFB method has better detection capabilities than the ED method. By employing this spectrum sensing technique in the FAPs, cross-tier interference is reduced in the macro-femto cellular networks. The results has been analyzed for all the three access schemes namely closed, open and hybrid access in terms of throughput of FUs, Interference factor of MUs and Macro and Femto sum throughput of the network. Hybrid access provides optimal results for both MUs and FUs.

3. Dynamic Allocation of Spectrum in Hybrid Access Cognitive Femtocells by using a Game Theoretic Approach

Price-bargaining and Stackelberg game theoretic approach are proposed for hybrid access cognitive femtocell networks with perfect spectrum sensing. In which both network service provider and the FC will get the benefits in terms of Network utility and throughput. In the proposed method, the macro BS reserves a portion of spectrum for guaranteeing the performance of the MUs, and the FAP gets more subchannels to improve the performance of the FUs. The corresponding resource allocation strategies were modeled as a price bargaining game, and the Stackelberg game has been employed to obtain the optimal solution. Simulation results proved that both the network service provider and the femtocell could benefit from the proposed method.

4. **Dynamic Allocation of Spectrum in Hybrid Access Cognitive Femtocell with Practical Spectrum Sensing**

Finally in the last part of the research work a price-bargaining and Stackelberg based game theoretic approach is proposed for hybrid access cognitive femtocell networks with practical spectrum sensing and minimum fairness, in which both network service provider and the femtocell both will get the benefits in terms of capacity and network utility. This problem was modeled as a joint power and sub-channel allocation for cognitive FCs, considering minimum data rate requirement of the user, fairness, cross-tier and co-tier limits of interference, and practical spectrum sensing. Simulation results proven that the proposed algorithm converges fastly and outperforms the perfect spectrum sensing algorithm in terms of cognitive femtocell sub-channel reuse efficiency and capacity.

The two major interference problems in macro-femto cellular networks called co-channel co-tier and cross-tier interferences addressed by using Efficient Frequency Reuse and PUFB based spectrum sensing techniques. For the installation of femtocells in the real time environments hybrid access is the most opted one, an incentive mechanism for hybrid access cognitive femtocells with perfect and imperfect spectrum sensing techniques are addressed based on the game theoretic approaches.

7.2 FUTURE SCOPE

The proposed algorithms namely Efficient Frequency Reuse, PUFB and Price bargaining based DSA algorithms significantly outperform the existing similar algorithms available in literatures. Several additional areas to continue the research work reported in this thesis can be suggested. The following are some of the avenues for further research. The future directions of research include more emphasis on the following areas

- The real time implementation of spectrum sensing with wide bandwidth and dynamic range introduces a great challenge in the performance of analog RF performance. Therefore, it is a crucial factor to be examined.

- Joint optimization schemes will give better results in the dense environments.
- Interference Alignment, an interesting interference handling technique can be invited to achieve maximum multiplexing gain over the interference channels. Interference leakage to the co-channel FUs can be avoided by aligning the interference signal of MUs in the same subspace at multiple FBSs.
- Interference Management techniques need to addressed when applies to mmWave Technology.
- The performance of filter bank method is analyzed only for Rayleigh and Rician fading channel. Hence the study can be extended to other fading channel conditions.
- The major issue in implementation of FBMC technique is it loses the orthogonality between the sub-carriers due to internal interference. Thus the effect of internal interference has to be reduced by incorporating techniques like interference cancellation schemes, equalization and spatial multiplexing method.
- The possible application of FBMC based cognitive radio network in the emerging area of massive MIMO that offers number of advantages can be investigated.

By using the advanced interference mitigation techniques, co-existence of co-tier and cross-tier users in same space, time and frequency domain, thereby improving the overall heterogeneous network performance.

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LIST OF PUBLICATIONS

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