

# **Improving Fractional Frequency Reuse (FFR) for Interference Mitigation in Multi-tier 4G Wireless Networks**

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This thesis is submitted in partial fulfilment of the academic requirements  
for the degree of  
Master of Science in Electrical Engineering  
in the Faculty of Engineering and The Built Environment  
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As the candidate's supervisor, I have approved this dissertation for submission.

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Signed: \_\_\_\_\_

Date: \_\_\_\_\_

# Declaration

I declare that this thesis is my own work. Where collaboration with other people has taken place, or material generated by other researchers is included, the parties and/or materials are indicated in the acknowledgements or are explicitly stated with references as appropriate.

This work is being submitted for the Master of Science in Electrical Engineering at the University of Cape Town. It has not been submitted to any other university for any other degree or examination.

Oluwadamilare Daniel ADEYEMO

Name

19/12/2014

Date

# **Dedication**

**...To the Glory of God Almighty, who has our days written out in His Book**

**..... To my Parents, for being the best a child can ever wish for**

## Abstract

The need to provide quality indoor coverage for mobile network users in an indoor environment has become paramount to communication service providers (CSPs). Femto-cells due to their low capital expenditure (CAPEX) and operating expenditure (OPEX) have seen widespread adoption as a possible solution to the indoor coverage challenge. The major drawback of its adoption is the possibility of erratic but significant interference to both the Femto-cell and the Macro-cell tiers owing to their Ad-hoc mode of deployment.

The Fractional Frequency Reuse (FFR) is an interference mitigation scheme, due to its effectiveness and low complexity; it has been proposed to be an efficient technique of solving the problem of interference in the cross-boundary region. In this study, a critical analysis of the existing schemes revealed that Femto-cell users at the border between the cell centre region (CCR) and the cell edge region (CER) suffer cross-boundary interference. An algorithm that integrates a buffer zone between the existing CCR and CER has been developed to solve the cross-boundary interference challenge experienced by the Femto-cell users.

A system level simulation implemented in MATLAB was used to evaluate the developed algorithm. The network performance (in terms of user-achieved signal-to-interference-plus-noise ratio (SINR) and its daughter metrics such as channel capacity and throughput) was estimated. In terms of the SINR, the performance improvement recorded for Femto-cell users at the border region after the implementation of the buffer zone was more than eighty per cent (80%). There were significant improvements in terms of the channel capacity and throughput for the Femto-users present at the buffer region with the implementation of the developed algorithm.

The Hybrid frequency reuse concept was incorporated into the proposed scheme to determine the extent of the buffer region in the cell and ensure fair reuse of resource blocks (RBs) between the Femto-cell users at the CCR and those at the CER. The granularity with which spectral resources can be allocated to subscribers in the Orthogonal Frequency Division Multiple Access (OFDMA) physical layer of the fourth generation communication network was exploited in the development of the proposed scheme.

Finally, the FFR with buffer scheme ensures overall quality of experience improvement for network subscribers at both tiers of the network with an expected minimal increase in control plane signalling between the nodes present in the network.

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## List of Acronyms

3GPP	3 <sup>rd</sup> Generation Partnership Project
ADC	Analog to Digital Converter
AMC	Adaptive Modulation and Coding
ASE	Area Spectral Efficiency
CA	Carrier Aggregation
CAPEX	Capital Expenditure
CCR	Cell Centre Region
CER	Cell Edge Region
CP	Cyclic Prefix
CQI	Channel Quality Indicator
CRBM	Cognitive Resource Block Management
CSG	Closed Subscriber Group
CSI	Channel State Information
CSP	Communication Service Provider
DAS	Distributed Antenna System
FDD	Frequency Division Duplex
FDMA	Frequency Division Multiple Access
FFR	Fractional Frequency Reuse
FRF	Frequency Reuse Factor
HeNB	Home enhanced Node B
HUE	Home User Equipment

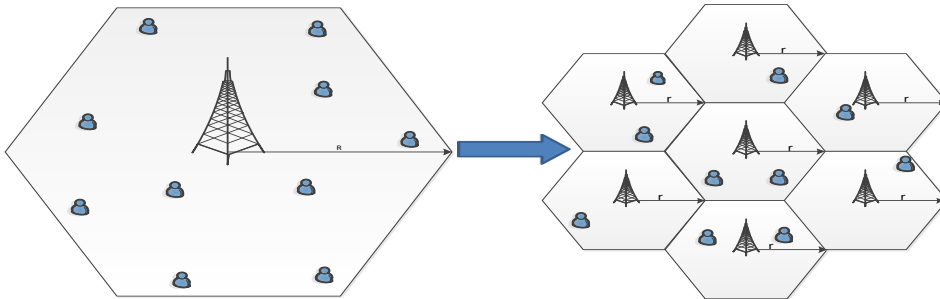
LTE-A	Long Term Evolution-Advanced
MAC	Media Access Control
MeNB	Macro enhanced Node B
MIMO	Multiple Input Multiple Output
MME	Mobile Management Entity
MUE	Macro User Equipment
OFDMA	Orthogonal Frequency Division Multiple Access
OSG	Open Subscriber Group
OSI	Open System Interconnection
OPEX	Operational Expenditure
PHY	Physical Layer
QoS	Quality of Service
RF	Radio Frequency
ROI	Region of Interest
SC-FDMA	Single Carrier-Frequency Division Multiple Access
SCTP	Stream Control Transport Protocol
S-GW	Serving Gateway
SON	Self Organizing Network
SINR	Signal to Interference plus Noise Ratio
TDMA	Time Division Multiple Access
TDD	Time Division Duplex
TTI	Transmission Time Interval
UE	User Equipment
UMTS	Universal Mobile Telecommunications System

# Chapter 1

## 1 Introduction

### 1.1 Cellular Communication

The challenge of provisioning quality data rate to subscribers has caused the telecommunications network field to be subject to constant but gradual development. The increasing number of subscribers and proliferation of gadgets such as smart phones, tablets and laptops that constantly request bandwidth intensive services such as video on demand (VOD), online gaming and other social networking activities, have kept the pressure up on mobile communication technologies. This has ensured their constant evolution in terms of providing better quality of service (QoS) and reliability to users [1],[2].



**Figure 1.1: The Cell-shrinking concept**

The concepts of cell shrinking i.e. replacing high power base station covering a large geographical area with more low power transmitters is illustrated in Fig. 1.1. Cell shrinking provides improved overall network capacity and quality of experience. This gave rise to the different cell types that are currently in existence in terms of coverage size. Currently, main classifications of the different cell types in descending order of their coverage area are Macro-cell, Micro-cell, Pico-cell and Femto-cell. Reduction in the cell sizes gives better area spectral

efficiency (ASE) and ensures improved quality of experience for end users but the cohabitation of different cell sizes with the frequency reuse concept give rise to interference.

Improving interference mitigation schemes is crucial and its combination with other areas of communication systems such as coding, modulation and multiple access schemes has helped to enhance network performance. This is evident in terms of theoretically achievable data rate of generational evolution of communication technologies depicted in Table 1.1 [3]

**Table 1.1: Theoretical data-rates of mobile communication technology generations [4]**

<b>Network Generations</b>	<b>Approximate Data Rate</b>
<b>1G</b>	28 – 56 Kbps
<b>2G</b>	144 Kbps
<b>3G</b>	0.384 – 2 Mbps
<b>4G</b>	0.1 – 1 Gbps

First generation (1G) networks used frequency division multiple access (FDMA) physical (PHY) layer technology. FDMA divides the frequency spectrum into channels. The adjacent channel interference can result if proper mitigation approach is not implemented. Therefore, guard bands are incorporated between consecutive channels to prevent the adjacent channel interference. The introduction of the guard bands, while effectively reducing adjacent channel interference, leads to inefficient spectral usage in FDMA.

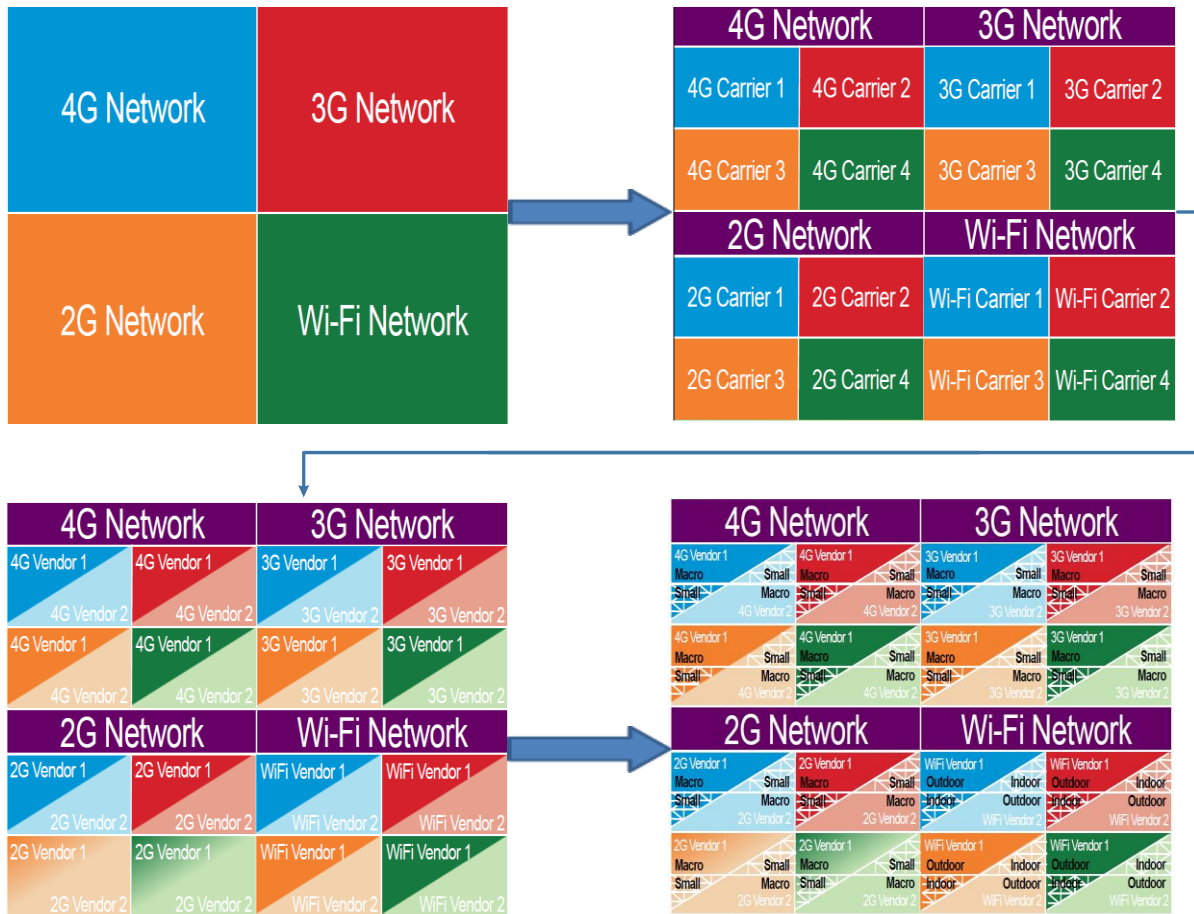
Second generation (2G) systems make use of time division multiple access (TDMA) whereby resources are allocated to users in time. The time component is split into slots that are accessed by the users in a periodic manner. Legacy frequency reuse schemes are used to perform interference management activities and to ensure high desired signal content at the receiver.

Third generation (3G) networks employed code division multiple access (CDMA) scheme at the physical (PHY) layer of the open system interconnection (OSI) model. Here, resource allocation is not done in time or frequency but orthogonal codes are used to spread signal energy over the frequency spectrum in order to allow multiple users to be separated at the receiver. The 3G networks are interference-limited with the system requiring effective power control algorithms so as to prevent the users from degrading the channel conditions of each other and causing reduction in capacity. For Fourth Generation (4G) systems, the location of resource allocation protocols has been illustrated in Appendix A in terms of OFDMA.

The Fourth generation (4G) networks utilized the technology of orthogonal frequency division multiple access (OFDMA) at its physical (PHY) layer. The multi-carrier and narrow band nature of this technique makes the implementation of different interference mitigation schemes with varying degree of complexities possible.

## **1.2 Heterogeneous and Multi-tier Networks**

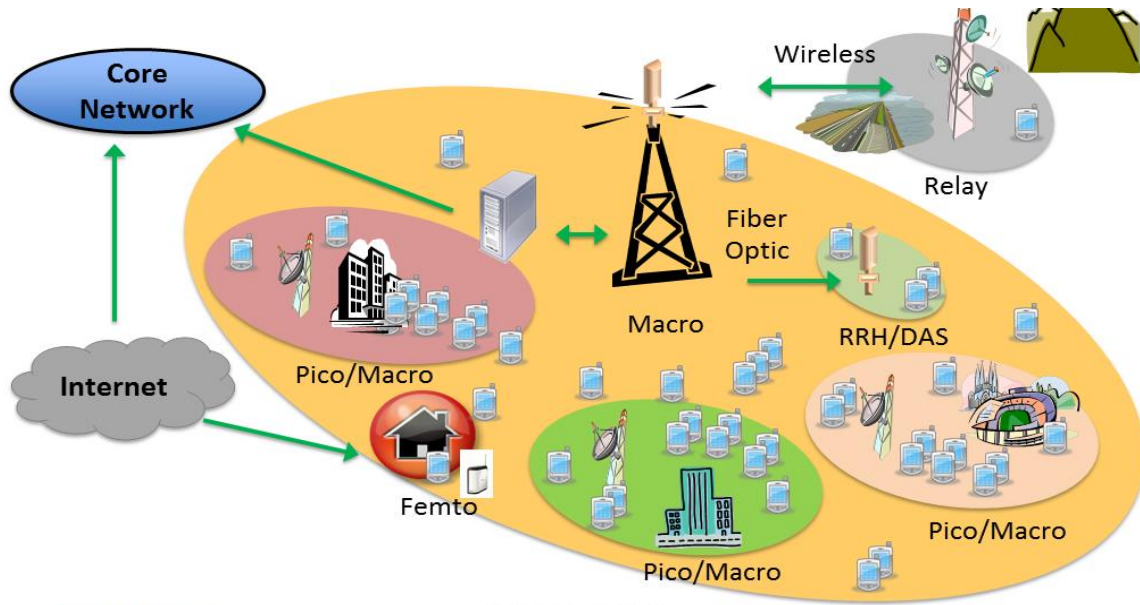
A typical communication service provider's (CSP) network which comprises different mobile communication technologies is illustrated in Fig. 1.2 [4]. The Heterogeneous networks are an attractive means of improving mobile network capacity. A HetNet typically consists of multiple radio access technologies, architectures, transmission solution with varying transmission power [5].



**Figure 1.2: Compositional Structure of Heterogeneous Networks [4]**

The Multi-tier Networks illustrated in Fig. 1.2 and Fig. 1.3 [4] can be regarded as a subset of heterogeneous networks whereby for a single CSP, radio access techniques varying in their transmission power are deployed to provide coverage to subscribers in order to ensure that the quality of service (QoS) requirements of the users' applications are satisfied by the network.

They are deployed overlying each other in a geographical region and the concept of cell shrinking explained earlier is exploited to improve wireless capacity of the network [6].



**Figure 1.3: Multi-tier Network Concept [4]**

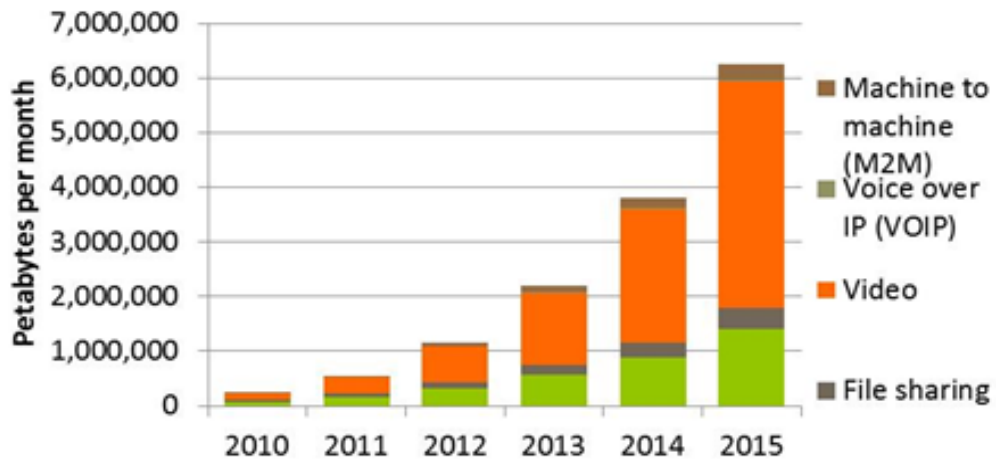
With Multi-tier networks, if all the tiers are open, users can easily connect to the tier that provides the best Signal to Interference plus Noise Ratio (SINR) and a maximised network performance can be experienced by the subscribers at all times.

### 1.3 The Indoor Coverage Challenge

Due to signal attenuation with respect to distance, multipath fading and wall losses, radio waves used suffer heavy degradation in signal strength or amplitude as they cross over from the outdoor to the indoor environment, but the need for CSPs to provide high data rate communication in indoor areas cannot be overemphasized.

From surveys, it has been established that more than fifty per cent of voice calls and over seventy per cent of data calls are originating from indoor environment [7]. Also, the survey results as depicted in Fig 1.4 [8], show that services which are used often in indoor environment such as video streaming (online gaming) are on the rise in terms of usage and will continue to be for the next few years. In fact, by 2018, more than seventy nine per cent of total global consumer IP

traffic will be video traffic[8]. All these factors when combined together make providing quality indoor coverage a priority for network operators. Furthermore, the new networking paradigm of machine to machine (M2M) communications and the Internet of Things (IoT), which will give rise to applications that will see heavy deployment in indoor environments such as smart homes and other industrial applications (e.g. robotics control in factories) are also some reasons buttressing the push for a better coverage in indoor areas.



**Figure 1.4: Global mobile traffic forecast (Cisco VNI) [8]**

Femto-cells which are small base stations with relatively low transmit power and small radius of coverage have been proposed to solve the indoor coverage problem in a cost-efficient manner. Femto-cell networks deployment will face challenges that current standards are yet to address. By examining the OSI protocol stack, critical performance issues are likely to evolve at the physical (PHY) and transport layer. The physical (PHY) layer challenges will also affect media access control (MAC) layer and will involve issues regarding radio resource management and interference mitigation. For the transport layer, issues of concern to network designer are traffic load balancing between the Macro-cell and Femto-cell tiers, mobility management, backhaul congestion management and optimization of control plane signalling. In this dissertation, the focus will be on the interference mitigation at the physical (PHY) layer.

## **1.4 Interference Mitigation with Spectrum Reuse**

When two or more wireless communication instances are initiated in a multi-tier network on the same channel, interference occurs and it adversely affects the overall network performance even leading to total outage at the target receiver if the total interfering signal power supersedes that of the desired signal. In order to solve the interference problem, partitioned (fixed) reuse and shared reuse have been considered for a multi-tier network consisting of Macro-cells and Femto-cells [6], [9],[10]. The partitioned reuse mode divides the available spectrum into two separate portions, which are then used by each network tier. Adopting partitioned reuse ensures that interference between tiers of the network is significantly reduced. The demerit of this approach is that underutilization of the spectra resources in either tier of the network can occur.

The second approach shares the frequency resource between the two tiers of the network i.e. full inter-tier frequency reuse. This provides higher capacity but also increases the exposure of network nodes to inter-tier interference. Since the Femto-cells have a tight constraint on the available transmit power and they access the spectrum using similar technique of underlay spectrum access of the cognitive radio paradigm, they suffer more from significant interference contributed by the Macro-cell tier.

With the PHY layer technology of OFDMA for 4G networks, legacy interference mitigation techniques can further be optimised to provide better interference mitigation schemes that are very efficient and results to lesser reduction in trunking capacity per cell. This is because Orthogonal Frequency Division Multiple Access (OFDMA), through the usage of narrowband subcarriers, provides a more granular means of allocating radio resources to users in the network in both time and frequency.

## **1.5 Fractional Frequency Reuse (FFR)**

Legacy cellular communication networks implement the concept of frequency reuse to increase the overall network capacity. The power of radiated electromagnetic signals reduces as the distance of signal propagation increases [11]. Therefore, the same frequency channels are reused at spatially separated locations. The demerit of frequency reuse is the loss in trunking or

channel capacity that a single cell can provide to users in its coverage region and often times, trade off needs to be made between the trunking capacity that is desired per cell and the level of interference exposure that network designers want for users to be exposed.

Fractional frequency reuse builds on the traditional frequency reuse schemes and it strives to improve the spectrum available per cell while keeping the interference levels at bearable minimum. N.Saquib *et al.* in [12] and Lee *et al.* in [13] adopted FFR to multi-tier networks containing Macro-cells and Femto-cells. Their analyses showed the effectiveness of the adoption of FFR schemes to mitigate interference. FFR requires minimal information exchange between the tiers that constitute the network making it perfectly suitable for Femto-cells that will be unable to pack complicated circuitry due to its reduced price. FFR is also suitable for interference mitigation on both uplink and downlink. The existing FFR designs failed to provide a suitable mechanism to cater for user equipment connected to Femto-cells at the boundary region between the CCR and the CER and this was clearly pointed out by the authors of [12]. It is therefore paramount to look for ways of mitigating this cross-boundary interference and create a more optimized FFR scheme for multi-tier networks.

## 1.6 Aim and Objectives

In this research work, critical consideration of the FFR techniques that are in existence will be carried out. Furthermore, a method of overcoming the cross-boundary interference difficulty that mars the performance of currently existing frameworks will be proposed. The research objectives are;

- To investigate the performance degradation caused by overlaying Femto-cells on a Macro-cell network with each tier reusing the spectral resources of each other.
- To implement a FFR scheme that incorporates a cell centre region 2 (CCR2) or buffer zone into a mobile cellular network.
- To determine the optimal radius or area of the buffer zone taking into consideration relevant and realistic network constraints and assumptions.

## 1.7 Research Questions

- What level of performance degradation can be expected if Femto-cells are overlaid on the same spectral infrastructure as with a Macro-base station in a single cell?
- What level of improvement can be achieved in terms of per user capacity and throughput if a buffer zone is incorporated into the existing FFR-3 scheme at the boundary region between the pre-existing cell centre and cell edge region?
- What will be the optimal radius (area) for the cell centre region 2 (Buffer zone) at which the performance of the network is maximised for the users of both tiers present in the network?

## 1.8 Scope of Research

This research considers mainly multi-tier networks that consist of a Macro-cell tier and a Femto-cell tier only. The hexagonal cellular model is used for all analytical activities and relay tiers were not considered. All analyses and simulations implemented are system level simulations unless if otherwise stated. The two tiers of the network both implement the OFDMA physical layer as the multiple access technique.

## 1.9 Dissertation Outline

In this chapter, the future traffic pattern was discussed to buttress the drive for better coverage in indoor environment by CSPs. A concise introduction to the concept of heterogeneous cellular communication networks with emphasis on interference mitigation and considerations for Femto-cell deployment was also given. The problem of interference was highlighted and the benefits attached with this study were stated.

In chapter 2, the background on coverage techniques that have been used in the past or still in existence to solve the indoor coverage challenge will be discussed. The proposition of Femto-cells was put forward and the benefits of deploying Femto-cells in comparison with other approaches were highlighted. The Long Term Evolution-Advanced (LTE-A) specifications which

this dissertation is based on were studied with emphasis on its PHY layer technology and resource allocation to network subscribers.

Chapter 3 discusses interference in multi-tier networks, and the various mitigation approaches that exist in literature with their merits and demerits. The concept of frequency reuse for interference mitigation in single tier networks and modification attempts for multi-tier networks were highlighted.

Chapter 4 presents clearly the proposed algorithm for the FFR-3 with the buffer technique to solve the identified challenge with minimal additional overhead for the multi-tier network. Discussions about the analytical derivation of system parameters and resource partitioning for users belonging to each tier of the networks were also presented.

In chapter 5, MATLAB codes developed from our algorithm were used to perform system level simulations to demonstrate the improvement in performance that the FFR-3 with buffer technique has on the network. A single cell Macro-cell-Femto-cell network was initially analysed before extending the analysis to a seven-cell network. The Signal to Interference plus noise ratio (SINR), system capacity and throughput were some of the performance metrics evaluated.

Chapter 6 gives the concluding remarks. Concise discussions relating to the performance of the proposed FFR-3 with buffer technique were presented and future works that could be done in line with our analyses were put forward.

## **1.10 Chapter Summary**

This chapter has given a brief but concise insight into mobile communication technologies, focussing on the need to provide improved data rate and its relationship with interference mitigation. The need to provide quality radio access to indoor users due to increment in indoor traffic and the solution provided by Femto-cells deployment were highlighted. Discussions regarding the interference challenge that the co-channel deployment of Femto-cells posed to the whole network was presented, as well as the need to improve the already existing frameworks in order to make them more robust and efficient.

## **Chapter 2**

### **2 Indoor Communication and 4G Femto-cells Overview**

#### **2.1 Chapter introduction**

In this chapter, a holistic approach is taken to present the challenges that face indoor wireless communication. The solutions that have been proposed were examined and their associated strengths and weaknesses, which led to the proposal of Femto-cells, were pointed out. The air interface (OFDMA) of LTE Femto-cells as it pertains to resource allocation was discussed. Furthermore, the logical architectures that are needed to be considered when integrating the Femto-cells into an existing network were also presented.

#### **2.2 Improving Indoor Communication**

With the shortcomings of the regular Macro-cells to serve subscribers in indoor environment efficiently becoming evident, CSPs decided to implement solutions that can effectively tackle this problem and provide high quality coverage to subscribers in indoor environments. The proposed solutions can be broadly categorized into Outdoor approach and Indoor approach. These are discussed in the succeeding sections.

#### **2.3 Outdoor Approach**

This method seeks to improve indoor signal quality by increasing the quality of the outdoor signals in order to reduce the attenuation suffered by electromagnetic waves as they cross over from the outdoor to the indoor environment. More Macro-cells or outdoor micro-cells could be deployed in a given geographical area to increase the signal power per distance. The demerit of this method is that, it is not very efficient and it is also costly as a lot of capital expenditure is incurred in the process of increasing the Macro base-station density in a given area.

## 2.4 Indoor Approach

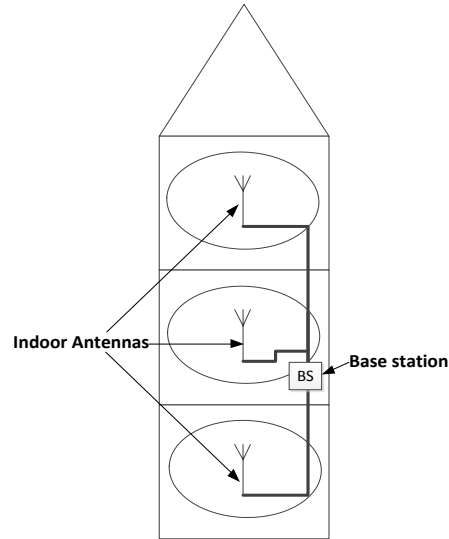
The need to optimize radio coverage directly in indoor environment led to the development of the following systems for the improvement of indoor radio propagation.

### 2.4.1 Indoor Repeaters

These devices extend the coverage area of a cell. They are useful in areas which are sparsely populated with limited network coverage. They can also be used to enhance the capacity of a network at cell edges by improving the SINR. These attributes make them suitable for usage in indoor environment for performance improvement of existing Macro-cells [14]. They pick up the outdoor signal that has been attenuated by the walls of the building, amplify it and then re-transmit the signal in the indoor area. There are generally two types of relays, they are; Active and Passive. Active relays are more advanced and they perform the decoding, error correction and reshaping of the attenuated received signal before re-transmission while Passive relays on the other hand, just pick up the attenuated signal, amplify it and retransmit without performing any signal processing on the signal. Active repeaters are generally more expensive when compared with passive repeaters.

### 2.3.2 Distributed Antenna System (DAS)

The idea of a DAS was first proposed in the 1980s [14] and it entails locating antennas at different floors of a building to provide homogeneous coverage. Instead of a single antenna radiating at a very high power, Saleh *et al* in [15] proposed that multiple smaller antennas, each radiating at lower power levels can be used to cover the same area. In order to adequately improve network efficiency, the overlap between the coverage areas of each antenna must be reduced and the coverage areas of the antennas should fit the shape of the building as much as possible. Fig. 2.1 gives a visual illustration of the concept of DAS.

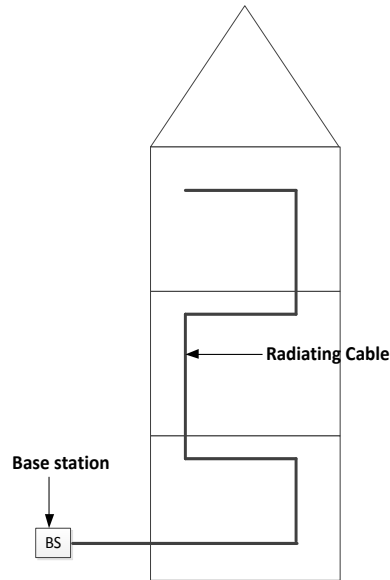


**Figure 2.1: Distributed Antenna System in a 3-floor Building adapted from [14]**

There are Passive and Active DAS. Passive DAS makes use of components such as Coaxial cables, Splitters and Taps to split the signals among the antennas and they give satisfactory performance at frequency range 900MHz-2100MHz but at higher frequencies, signals suffer degradation which affects transmission quality. Active DAS gives better performance by incorporating electronic components and fibre optic cable albeit at a higher cost.

### **2.3.3 Radiating or Leaky Cable**

This is a metallic wire, similar to a standard coaxial cable, that acts as a long antenna and capable of radiating and receiving electromagnetic energy all along its length. This makes it very suitable for long and narrow environments such as indoor corridors, tunnels and even elevators [16]. It is directly connected to the base station, which could be located outside or inside the indoor environment.



**Figure 2.2: Radiating or Leaky Cable in a 3-floor building [14]**

Fig. 2.2 gives a simple visualization of an indoor leaky cable deployment. The advantages of the radiating cable include uniform energy distribution and also radio coverage provision at extensive distances away from the base station although it has the demerits of time-consuming installation, regular cleaning of the cable because dirt depreciates its performance and also, finding space for its installation could be most times challenging.

### 2.3.4 Small Base-stations

These are the alternatives to the previously discussed techniques to improve indoor radio coverage. Instead of seeking the means to indirectly improve the indoor signal quality by first improving the radio coverage of the outdoor environment or extending the coverage of outdoor base stations into the interior of buildings with the use of DAS or Radiating cables, a much more interesting approach is to deploy small base stations directly inside the buildings. Two different types of Indoor base stations are in existence and they are discussed in the sub section below.

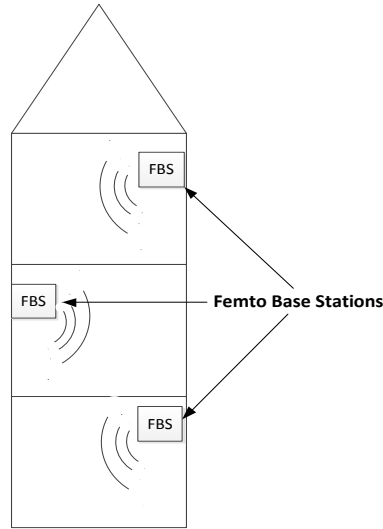
### **2.3.5 Pico-cells**

These base stations could be deployed at outdoor locations such as street corners. They generally have transmission power ranging from hundreds of milliwatts to a few watts. They can provide a radius of coverage that is above one hundred metres. The reduction in coverage region that they provide when compared with Macro-cells and micro-cells allows for the provision of more capacity and higher data-rate to end users connected to them. Pico-cells are not a hundred per cent self-configurable; hence, the network operator is still responsible for deploying and maintaining them. The above demerit led to the introduction of the other type of small indoor base station called Femto-cells.

### **2.3.6 Femto-Cells**

As the need to increase their presence in terms of the provisioning of quality signal coverage and high data rates in indoor environments becomes more important [7], CSPs decided to look for a lasting solution to this problem in a very cost-effective manner. This led to the development of Femto-cells.

Currently, the smallest base station in existence, Femto-cells or Femto Access Points (FAPs) are described in [14] as “cellular network access points that connect standard mobile devices to a mobile operator’s network using residential DSL, cable broadband connections, optical fibres or wireless last-mile technologies”. These are completely user deployable as they are a hundred per cent auto-configurable. In addition, the end users are solely responsible for the Capital expenditure (CAPEX) and Operational expenditure (OPEX) costs incurred for the installation and continuous maintenance of the FAP. This makes Femto-cells more cost-effective to CSPs when compared with Pico-cells that have to be deployed and maintained by a CSP.



**Figure 2.3: Femto Base Stations in a 3-floor building adapted from [14]**

If the same amount of bandwidth resource is made available to a big cell and a small cell (using the cell radius as the parameter to differentiate the sizes), more users are likely to be in the coverage area of the big cell while less number of users will be in the coverage area of the small cell. Therefore, if a round robin scheduler is considered, less frequency resource allocation will be available to each of the users attached to the big cell while the smaller cell users get more frequency resource allocated to them. Hence, the small cell users enjoy increased data rate and overall service QoS. Femto-cells make the realisation of the latter scenario possible thereby making its deployment of much interest to CSPs.

**Table 2.1: Power and coverage comparison of Base station types**

Cell Type	Typical Coverage radius	Transmit Power Range
Macro	>1 km	20W – 160W
Micro	250 m – 1 km	2W – 20W
Pico	100-300 m	250mW – 2W
Femto	10-50m	10mW – 200mW

The summary of power and coverage analysis of the different type of base stations presently in existence are given in Table 2.1 while the differences between the Pico-cell and Femto-cells are clearly illustrated in Table 2.2

**Table 2.2:** Structural comparison of Pico-cell and Femto-cell

<b>Parameters</b>	<b>Pico-cell</b>	<b>Femto-cell</b>
<b>Installed by</b>	Network operator	By the end-user
<b>Connection to the Core network</b>	Coaxial, Fibre Optic	ADSL, Cable
<b>Price</b>	Cheap	Very cheap
<b>Capacity</b>	10-50 users	3-5
<b>Coverage range</b>	<100m	<30m

Femto-cells are deployed in an ad-hoc manner as users can buy and install them anywhere they desire. A single user or home can have more than one, depending on the size of the home and the number of occupants or subscribers that will be connecting to the Femto-cell infrastructure. These attributes of Femto-cells make it important for some special design considerations to be taken into account before their widespread deployment. Furthermore, since Femto-cells will not be managed by the CSP on whose infrastructure they will be attached, capabilities such as self-configuration, self-optimization and self-healing are needed to be built into each of the Femto-cells and their respective sub-network. These capabilities, when incorporated enable the network to be a self-organising network (SON). A self-organising network requires minimal human involvement for seamless operation. Processes such as planning, configuration and optimization need to be incorporated into a set of autonomous or automatic functions.

## **2.4 Self-Configuration**

Due to the plug and play nature of Femto-cells and the fact that they are user-commissioned, it is very important that once switched on, the Femto-cells are able to communicate and integrate into the existing network. The Femto-cells set up their software and other parameters such as neighbours list, handover configuration, pilot power and attached subscribers. All these must be done with minimal interruption to existing base stations. Femto-cells that are already switched on can also run their self-configuration phase algorithms if new base-stations or features are detected in the network [17].

## **2.5 Self-Optimization**

Network measurements are carried out periodically by each Femto-cell and are processed. Femto-cells use these measurements to modify their algorithms and adjust parameters that are variable to suit changing conditions of their environment. Examples of metrics that can be optimized are the outage probability, channel capacity and the level of interference mitigation that can be provided.

## **2.6 Self-Healing**

This involves capabilities built into Femto-cells to enable them recover from situations of coverage loss, loss of connectivity to the core network and capacity failure. These could be due to radio board failure, channel processing implementation error, misconfiguration, power outage and back-haul connectivity failure [18]. Outage detection is a self-healing function that determines cells that are in outage conditions. After a downed Femto-cell has been correctly detected, the outage compensation procedure is initiated to reduce the effect of coverage loss and throughput reduction. Compensation procedure encompasses modification of parameters such as transmission power and channels allocated to nearby Femto-cells. Self-healing activities are aimed at reducing the impact of outages on the subscribers through rapid tuning of parameters of Macro and Femto-base stations present in the network.

## **2.7 Femto-cells Operating Modes**

Femto-cells will operate in the open subscribers group (OSG) access mode or the close subscribers group (CSG) access mode. With the OSG access mode, any user that belongs to the network is allowed to connect to a Femto-cell if they receive an SINR from the Femto-cell that is higher than that from the Macro-cell to which they were initially attached. For the CSG access mode, only users belonging to a subscribers' list are allowed to be attached to a Femto-cell. CSG is the common mode of deployment since Femto-cells are user-deployed. OSG mode is useful when Femto-cells are deployed by a CSP itself for coverage in areas such as airports, stadia or street corners where Pico-cells can also be used.

CSG mode of deployment contributes more interference because User Equipment (UE) that is far away from their attached Macro-cells radiate at higher power levels, but if connected to a nearby Femto-cell, the power needed is reduced. A unit of Macro User Equipment (MUE) radiating at an increased power level causes severe interference to nearby Femto-cell base stations if they share the same set of resource blocks. The type of access mode proposed to mitigate this challenge is the Hybrid access mode.

The Hybrid access mode is similar to the CSG with the difference that some UE not belonging to the subscribers' list of a particular Femto-cell can still connect to it. They are given some level of service but they will not be able to get any preferential treatment and will be charged higher for any service they use as compared to UE belonging to the subscribers list. This type of deployment is more likely to be found in relatively large office buildings and it is important for subscribers to know the different charging policies that apply [19]. The CSG access mode was assumed in the investigation that was conducted in this dissertation.

## **2.8 Advantages of Femto-cells**

From the foregoing discussions, both the subscribers and the CSPs will benefit from the deployment of Femto-cells and some of these benefits include;

- Good signal quality for indoor subscribers leading to improvement in call (voice, video or data) qualities i.e. the Femto-cell provides all-time 5-bar coverage.
- Reduction in the power usage of terminal equipment in indoor areas as lesser level of radiation is needed because of proximity to the indoor cell; this enhances the battery life of an UE.
- Indoor traffics are off-loaded to Femto-cells and this ensures that fewer numbers of Macro-cells are needed in a geographical area. This reduces the capital expenditure (CAPEX) for the CSP and releases the resources that can then be used to serve the outdoor users better.
- Simplification of site survey and planning process for network roll out or optimization activities.
- Deploying Femto-cells reduces a CSP's Churn rate. The Churn rate is defined as the percentage of subscribers who stopped using an operator's service for one reason or the other at a given period. It has been established through surveys that poor indoor coverage is the major churn-causing factor for CSPs.
- Femto-cells create more demand for data-services thus increasing the revenue for the CSP. It also helps the development of add-on services such as Femto-zone or home zone where subscribers can get added bundle packages for voice and data at a lower cost.

## **2.9 LTE Femto-Cell Physical Layer Structure**

### **2.9.1 OFDM/OFDMA**

Wireless channels are characterized by frequency selective fading impairments. This causes different channels to experience different levels of fading depending on the channel's frequency. Frequency selectivity results from the phenomenon of multipath signal propagation that characterizes indoor and urban environments. Radio access technologies using wideband signals such as the 3G UMTS-CDMA systems can suffer extensive distortion. This makes signal recovery at the receiving end difficult and leads to overall network performance degradation.

Narrowband signals as illustrated in Fig. 2.4 provide better resistance against frequency selectivity and this gives rise to multicarrier modulation technologies such as orthogonal frequency division multiplexing (OFDM). In OFDM, each subcarrier is orthogonal to each other; hence, the overlapping of subcarriers without causing inter-symbol interference (ISI) is made possible. This makes it more spectrally efficient when compared to FDMA as more symbols can be packed into a given bandwidth.

The analysis done in this thesis is focused on interference coordination and mitigation for Macro-cell networks overlaid with Femto-cells in LTE-A networks which meets the requirements of the ITU-R's IMT-Advanced specifications for 4G networks. On the downlink, LTE-A builds on the framework of ordinary LTE and it sits on the Orthogonal Frequency Division Multiple Access (OFDMA) technique as its physical layer technology. The Single Carrier Frequency Division Multiple Access (SC-FDMA) is used on the uplink because it is cost-efficient and conserves power. The next section gives a brief detail of OFDMA as it applies to LTE with emphasis on resource allocation.

## 2.9.2 OFDMA Resource Grid Structure

LTE supports both frequency division duplexing (FDD) and time division duplexing (TDD).

The basic time unit is  $T_s$  and it is defined as  $T_s = 1/(15000 * 2048)$  seconds or about 32.6 nanoseconds.

A single frame in LTE has 10ms time duration (Fig. 2.6). For FDD, the whole frame is dedicated to either downlink or uplink. The frame is shared between uplink and downlink in the case of TDD.

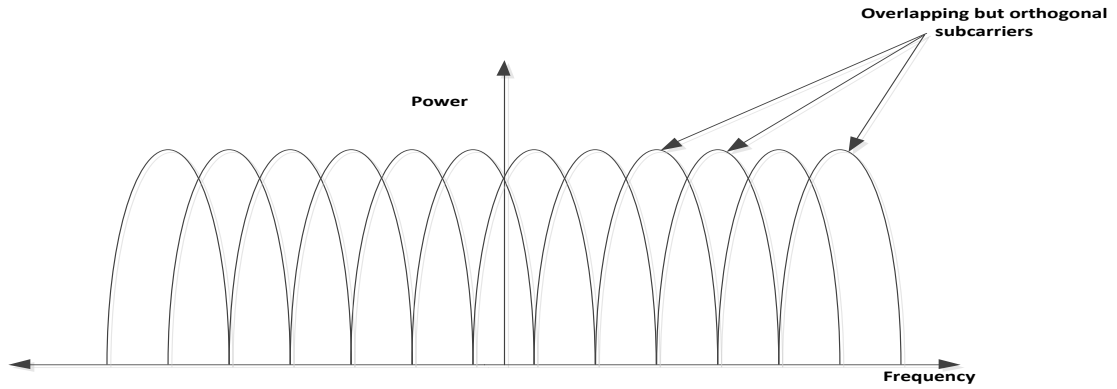
One frame contains 10 sub-frames with each sub-frame having 1 ms time duration (Fig. 2.6).

Each sub-frame contains two slots of 0.5 ms duration.

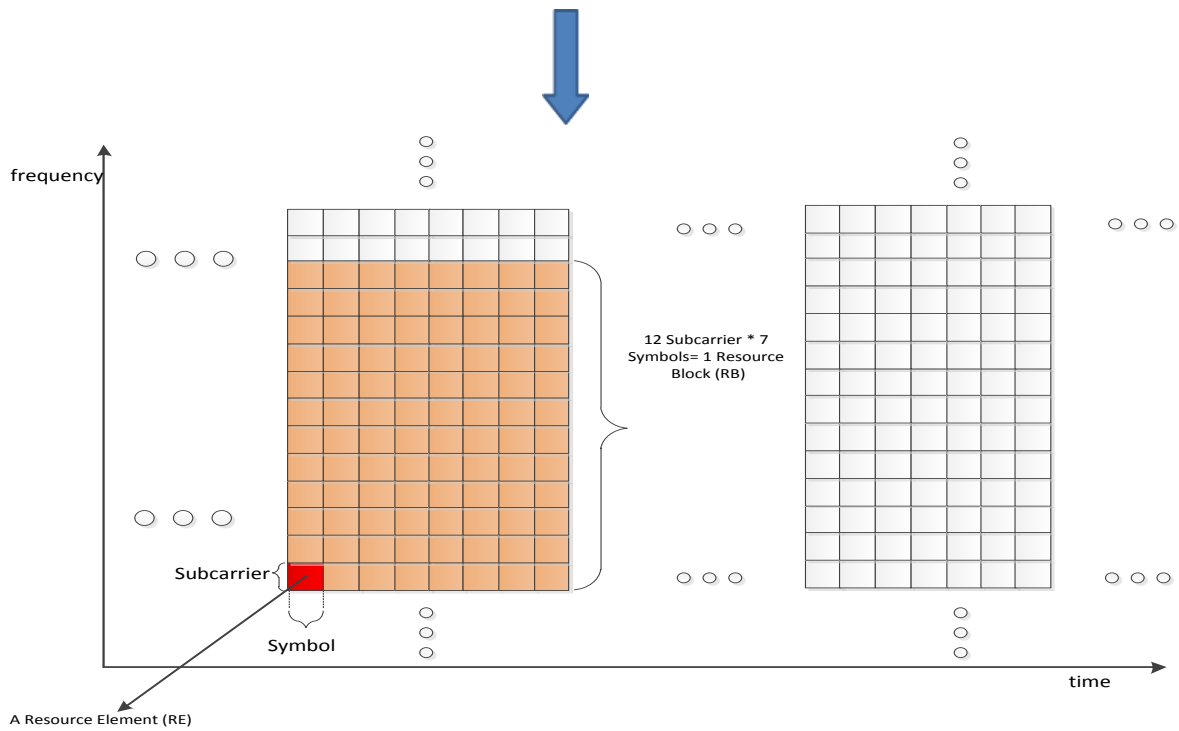
A single slot contains seven OFDM symbols and a slot also corresponds to a resource block (RB) in the time domain.

The smallest modulation element in LTE is called a Resource Element (RE) and it is a 15 KHz subcarrier (frequency axis) by one symbol (time axis). These resource elements are aggregated into resource blocks (RBs). Twelve consecutive sub-carriers in the frequency domain and seven symbols in the time domain form a single resource block. LTE supports multiple modulation schemes such as QPSK, 16-QAM, 64-QAM. These with other parameters such as coding rate and the channel quality indicator (CQI) are used to determine the number of bits that makes up a symbol, which is modulated onto a single RE during a transmission stream. This is a concept referred to as adaptive bit loading [20]. The adaptive bit-loading scheme ensures that the better the channel condition, the higher the radio access bearer (RAB) or modulation order used.

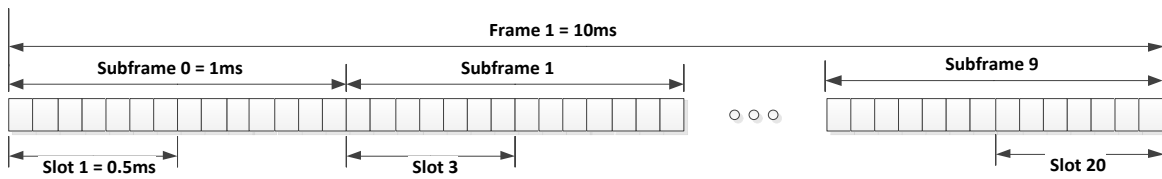
As a result, data rate delivered to users with OFDMA can be diverse as there are different combinations of parameters with a high degree of freedom available for system design. This makes finding an optimal operating condition of the network challenging and often times, the concept of optimality can be subjective and largely determined by the type of service a CSP wants to deliver to its subscribers.



**Figure 2.4: OFDMA Subcarriers**



**Figure 2.5: LTE Resource allocation illustration in the Time and Frequency domain**



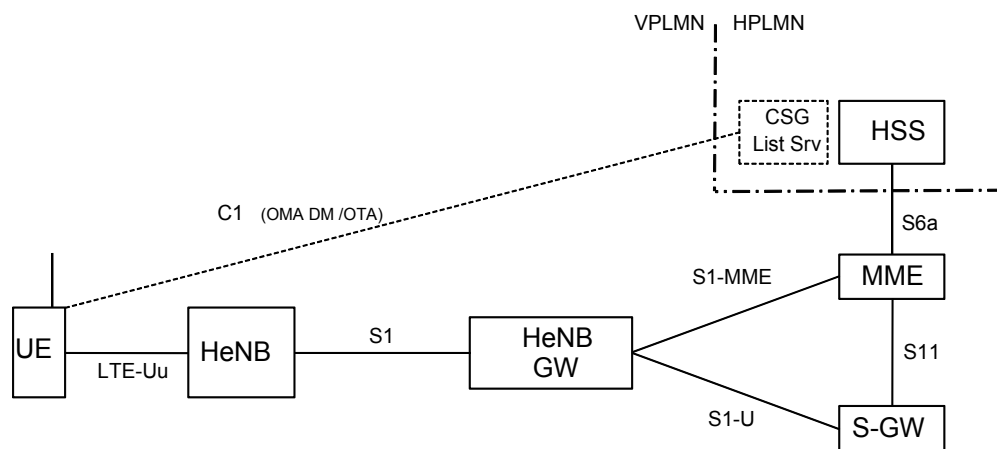
**Figure 2.6: LTE Frame Structure**

LTE-A adds capabilities such as Multiple Input Multiple Output (MIMO) antennas to provide spatial diversity or spatial multiplexing in order to enhance performance and carrier aggregation (CA) techniques.

Interference will result if two different base stations, either Macro or Femto schedule a resource block to be used for data transmission between their respective users at the same time and frequency.

## 2.10 LTE Femto-Cell Logical Architectures

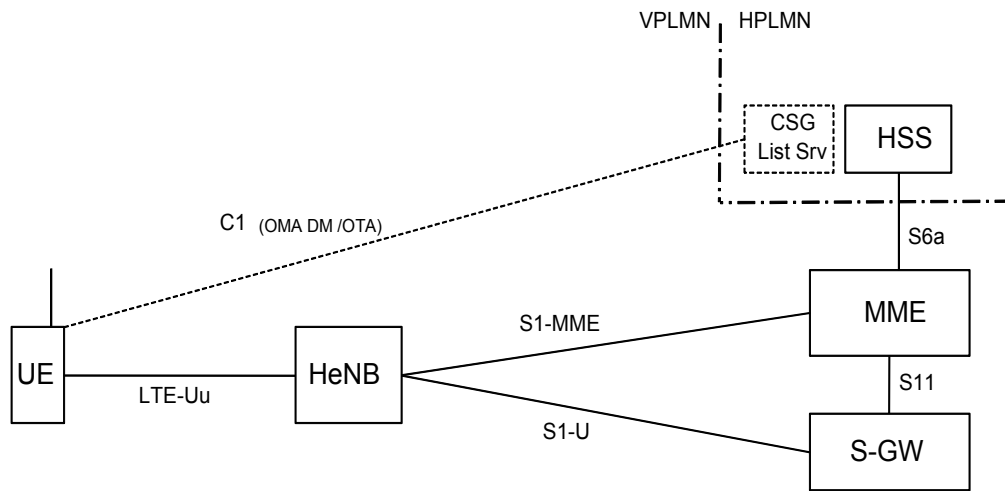
The Third Generation Partnership Project 3GPP workgroup specified three architectural variants for the deployment of Femto-cells in a geographical environment [21] [22]. Since a CSP that wants to deploy Femto-cells already has an existing infrastructure in place, it is important to consider an architecture that is not intrusive and cumbersome to implement. The architecture also has to be scalable and easy to evolve in case of future adjustments. The differences in the variants lie in how the Home enhanced Node B (HeNB) is connected to the Evolved Packet Core of the LTE network on both the control and user plane.



**Figure 2.7: LTE Femto-cell Logical architecture (Variant 1) [22]**

The variant 1 is given in the Fig. 2.7. This architecture incorporates Home eNodeB gateways (HeNB-GWs) which help to aggregate the traffic coming from the deployed HeNBs in

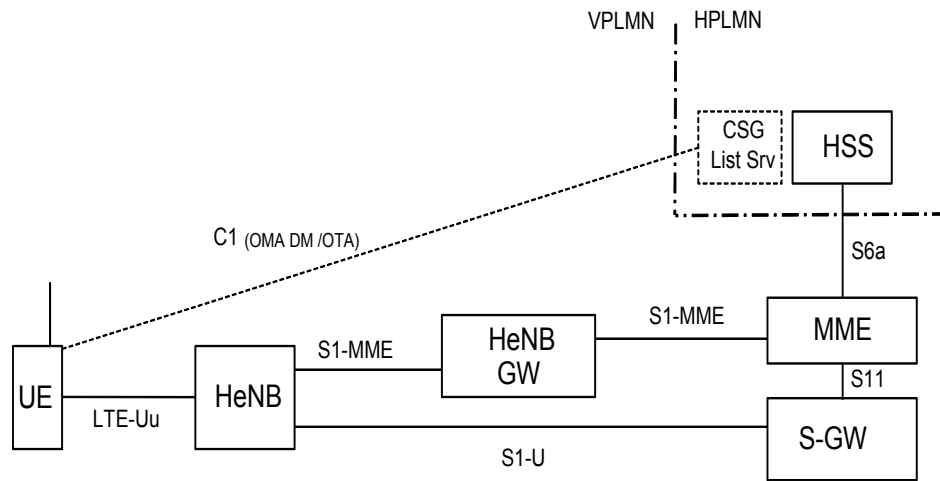
the network on both the user plane (S1-U) and the control plane (S1-MME) before sending the traffic to the core of the network. The advantage of this variant is that the increase in the number of deployed Femto-cells does not lead to a corresponding increase in the control plane signalling between the access and the core network. In the situation of massive HeNB failure that can occur due to power failure, the Mobile Management Entity (MME) in the core will not be overloaded when the HeNBs come back online. Furthermore, this approach provides better network security as the IP addresses of the core network elements are not revealed to the UE. Useful information regarding interference coordination or mitigation can also be exchanged over the S1-MME interface between the HeNBs and the MeNB. The variant 2 depicted in Fig. 2.8 removes the HeNB-GW present in variant one and favours direct connectivity of the HeNBs to the core of the CSP. With this architecture, the MeNBs and the HeNBs are connected to the core with similar technique. Its benefit is that there are less failure points in the system and it does not include an additional single point of failure.



**Figure 2.8: Femto-cell Logical architecture (Variant 2) [22]**

Furthermore, latency and system level processing are reduced since the HeNBs are directly connected to the core on both the control and data plane. The challenge of this variant is that increase in the number of deployed HeNBs will result in more frequent Stream Control Transport Protocol (SCTP) signalling which can lead to MME overload. Switching of HeNBs on and off by the user leads to similar problems. Therefore, variant 2 can only effectively support a scenario where few numbers of HeNBs are scattered over the coverage area of a CSP.

In order to solve the problem of possible control plane overload of the MME in variant 2, the HeNB-GW was re-introduced in variant 3 similar to variant 1 but it only terminates control plane signalling from the HeNBs. The user plane is directly connected to the S-GW at the core of the CSP. The variant 3 is depicted in Fig. 2.9, with this architecture; increasing number of HeNBs does not lead to SCTP overload towards the MME.



**Figure 2.9: Femto-cell architecture (Variant 3) [22]**

The demerits associated with the variant 3 include the possibility of an overload situation in the S-GW when the number of HeNBs deployed in the network increases. In addition, the presence of the HeNB-GW on the control plane reduces redundancy and load-balancing possibility as the HeNBs can only connect to one HeNB-GW at a time.

In order to deploy a convenient interference mitigation or coordination scheme, it is important to understand the type of Femto-cell logical architecture that will be employed in the network. This ensures that suitable design approach as to the exchange of control signals between the network entities is taken. Further extension in connectivity between HeNB and MeNB over the X2 interface has also been proposed by the related SDOs[23].

## 2.11 Chapter Summary

In this chapter, the various techniques that have been proposed to provide high quality signal coverage in the indoor environment have been examined. The challenges of existing

systems and the benefits of using Femto-cells have also been highlighted. The associated problem of Femto-cells interference has been discussed. In the next chapter, the extent of performance degradation, which can result when Femto-cells are deployed in the network without proper interference mitigation, will be presented using a standardized LTE simulator. Afterwards, a survey of interference mitigation schemes in literature will also be presented.

# Chapter 3

## 3 Literature Review

### 3.1 Chapter Introduction

In this chapter, the Vienna LTE simulator was used to analyse the degrading impact of interference on channel capacity when Femto-cells are deployed over a Macro-cell network to buttress the need for interference mitigation techniques in modern wireless communication networks. The various categories of interference in multi-tier heterogeneous radio access networks are given with emphasis on Macro-cell overlaid with Femto-cells. Broad related works will then be discussed with more attention on the efforts in literature that were directed at interference coordination and avoidance techniques such as Fractional Frequency Reuse (FFR). The shortcomings discovered in existing works are noted and the proposed solution is clearly highlighted.

### 3.2 The Vienna LTE Simulator

In order to meet the requirements and specification of the 3GPP workgroup for LTE and LTE-Advanced, development of new technologies and modifications to existing ones are needed to be implemented on the different generic layers that constitute a digital communication system. Research efforts directed towards developing the technologies and investigating their performance under different conditions are usually difficult to synchronize and reproduce among various industrial and academic laboratories. This is due to lack of full disclosure of the nature of input data, assumptions made, values of system parameters used etc. This can make the reproduction of results reported in academic papers challenging for other researchers willing to continue from where a previous investigative effort stopped.

The Vienna LTE simulator was developed by authors of [24], [25] as a platform that aids the alignment of research efforts directed at achieving the LTE specifications as given by the 3GPP workgroup. This serves as a common testing ground for implementing ideas and checking

the results of analysis that can easily be reproduced and improved. This software package has link level and system level simulators as separate entities built on the MATLAB platform, and employs the Object Oriented Programming (OOP) development technique. The Vienna LTE simulator was used in this work instead of OPNET, OMNET or NS-3 because it was specifically designed for LTE and LTE-Advanced simulation purposes. Unlike the other simulators, which can be used for testing generic network communication protocols and different standards, the Vienna simulator is streamlined only for LTE related research purposes.

Link level simulations are used to investigate the performance of channel estimation techniques, tracking and prediction algorithms, Multiple Input Multiple Output (MIMO) gains, adaptive modulation and coding (AMC) including its feedback [24]. Other features such as the receiver structure with reduced complexity, channel modelling, channel encoding and decoding are also implementable using the Vienna LTE link level simulator.

System Level simulations on the other hand is useful for testing schemes that are network related such as resource allocation and scheduling, interference management, network planning and optimization, call admission control and multi-user handling [24]. Results of experiments from the Link level simulator such as the values of the received signal strength under different network link conditions, which are mapped to produce the channel quality indicator (CQI), are used as a benchmark for the system level simulator to ensure uniformity and reproducibility of results in both set of simulators.

In this section, the system level simulator was used to investigate the performance of a mobile network that initially consisted of only Macro-cells. Femto-cells were then overlaid on the Macro-cell and the channel capacity metric of the network was checked and compared with the result achieved when only the Macro-cells were deployed. Minimal interference mitigation was implemented and this was done to demonstrate and ascertain the impact of the deployment of Femto-cells on the Macro-cell network.

### 3.2.1 Scenario 1: Macro-cell only deployment

The Vienna LTE simulator was installed in MATLAB (R2009b) and a Macro-cell only network as shown in Fig. 3.1 was generated. The codes used for generating this network are given in appendix A. The operating frequency was set at 2 GHz with a bandwidth of 5 MHz, which corresponds to 25 resource blocks (RB). A  $2 \times 2$  MIMO antenna configuration was implemented. A 19-cell layout was considered, with MUE uniformly and randomly distributed all over the coverage area. The throughput statistics are taken from users in the first and the second tier of the network. The cell with cell ID 11 is the central MeNB while cells with IDs 12, 16, 10, 5, 6, and 7 make up the second tier as can be seen in Fig. 3.1.

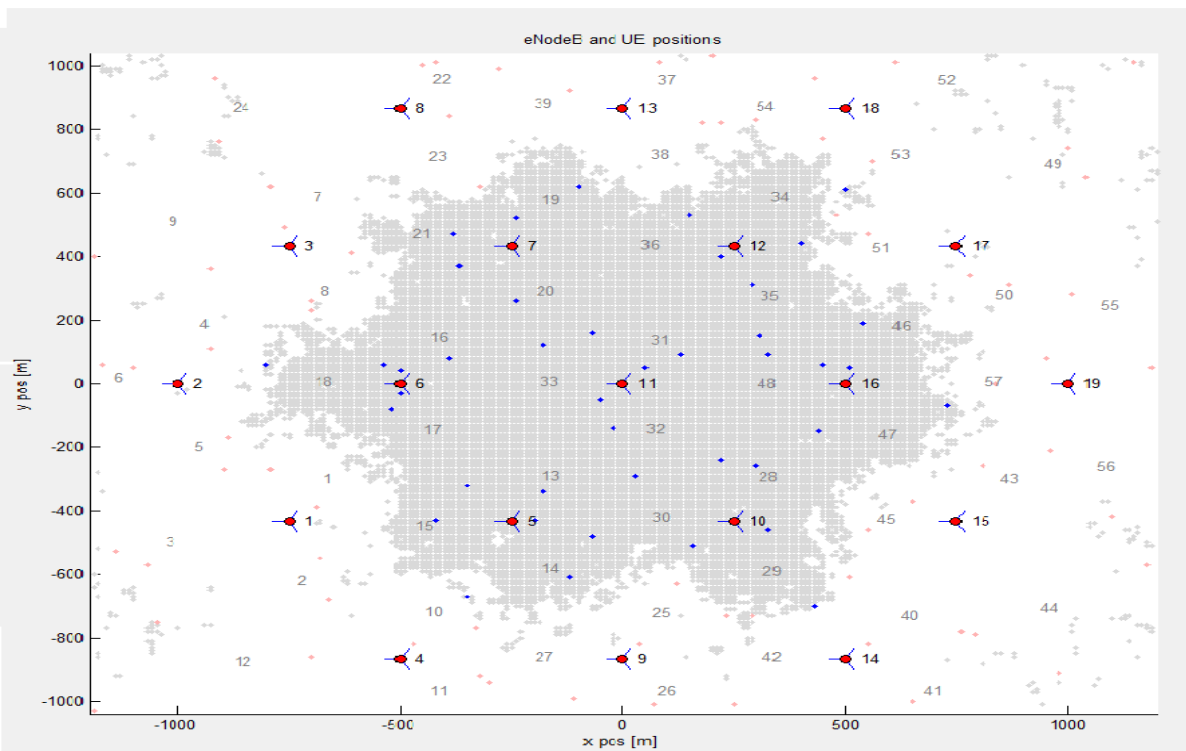
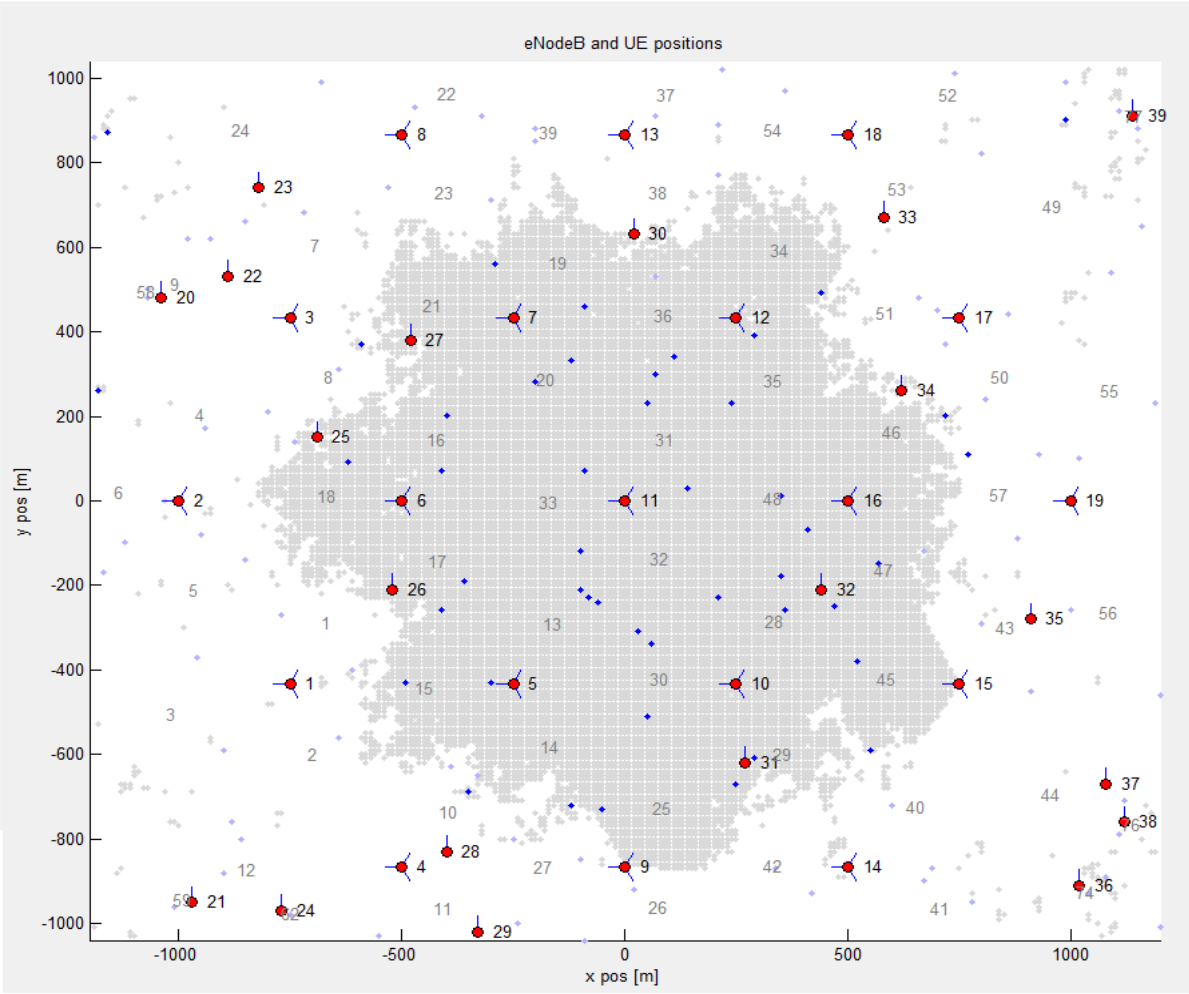


Figure 3.1: Macro-cell only scenario

### 3.2.2 Scenario 2: Femto-cells overlaid on Macro-cell.

The System level simulator was setup similar to the previous scenario. Femto-cells were deployed on the network in a random pattern that is similar to what can be expected in a real life

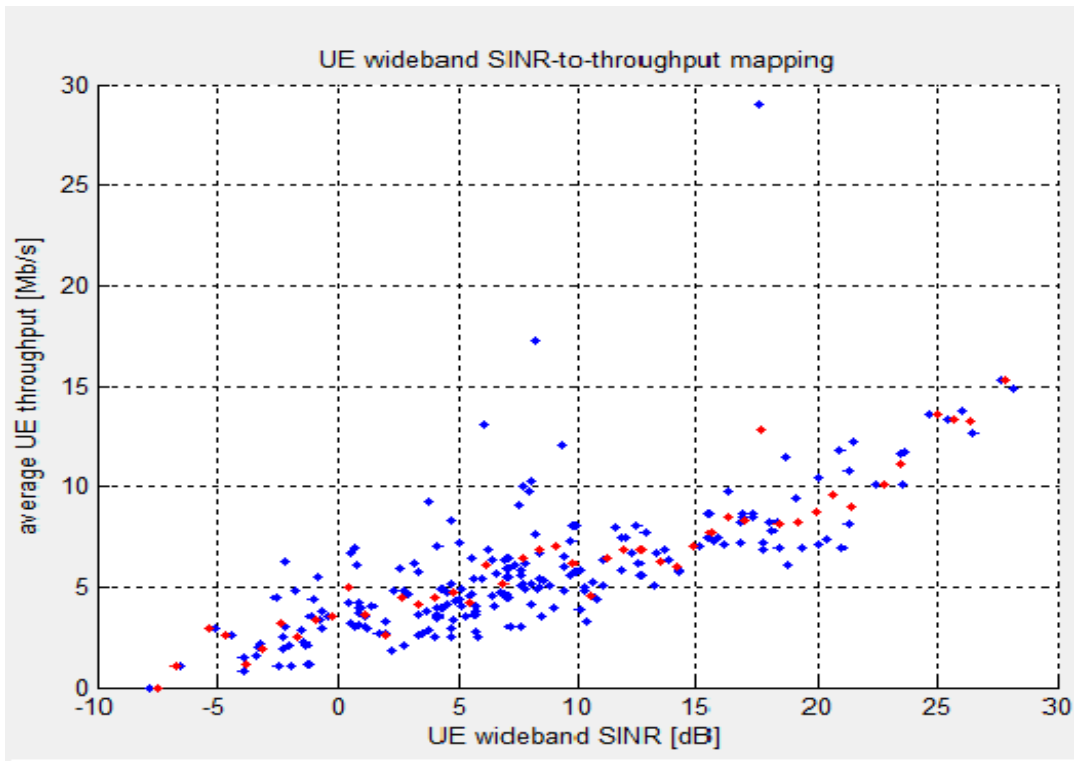
situation. In order to make objective comparisons between the two sets of deployment scenarios, the parameters given in appendix A were kept constant for both sets of simulation run. The Femto-cells were deployed randomly in the region of interest and no interference mitigation technique was implemented. The available bandwidth was shared between the Femto-cells and the Macro-cells. Maximum of two users were attached to each of the Femto-cells and each Femto-cell antenna radiates in an omnidirectional pattern. The units of UE were kept static during the simulation run and the statistics were taken over a transmission time interval (TTI) of ten.



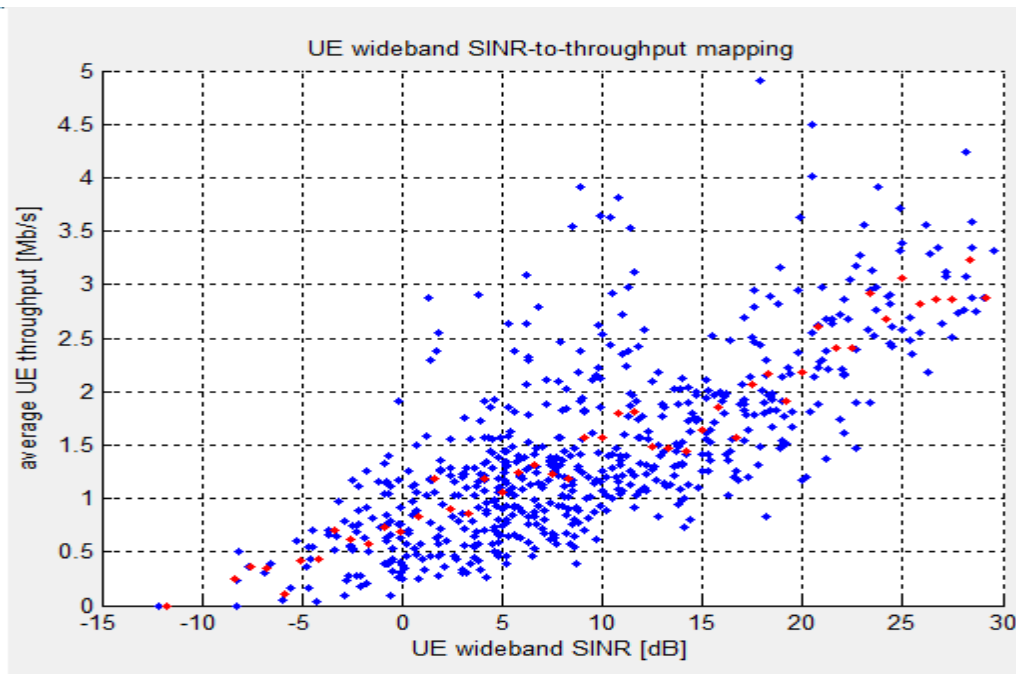
**Figure 3.2: Macro-cells Overlaid with Femto-cells Scenario**

The region of interest (ROI) was kept constant in both scenarios but it is more difficult to control radiation pattern of the Femto-cells due to their Ad-hoc mode of deployment. This makes the coverage area in Fig. 3.2 slightly larger than that of the Macro-cell only scenario.

The average UE throughput for all the users in the network was employed as the main performance metric. This is because of its importance in determining the quality of experience of the users attached to a network operator and its reliance on the SINR experienced by each user.



**Figure 3.3: Throughput for Macro-cell user only Scenario**



**Figure 3.4: Throughput for Macro-cell overlaid with Femto-cells Scenario**

Fig. 3.3 shows the average throughput in Mbps that is achieved by the UE equipment in a single tier network that consists only of Macro-cells as shown in Fig. 3.1. It can be deduced that the average throughput of the units of UE ranges from 0 Mbps to 15 Mbps based on the channel quality between each of the user and their attached Macro-cell. Considering the Macro-cell overlaid with Femto-cells throughput graph in Fig. 3.4, there was a decrease in the achieved average throughput of the users (ranging from 0 to about 5 Mbps). From this, it can be seen that while Femto-cells offer a means of improving signal coverage and allowing more users connection to the network, sub-optimal overall network performance can result without the implementation of proper interference mitigation schemes. The outcome of this analysis using the Vienna LTE simulator supports the findings of earlier research efforts in [26] and [27] into the study of the performance of multi-tier networks where other analytical platforms were used.

As a result of this, efforts have been geared towards finding interference solutions that will justify the widespread adoption and deployment of Femto-cells. Low cost price of Femto-cells implies moderate hardware and processing capabilities, therefore, interference solutions that require modest computational complexity are desired.

### **3.3 Interference Categorization**

In Multi-tier cellular networks, the presence of more than a single network infrastructure or RAT that backhauls user data traffic to the core of the network operator leads to two different interference scenarios, which are the Cross-tier and Co-tier interference. The categorization is important in order to deploy the most effective interference mitigation approach that best suits the interference scenario. This is because there exists a relatively vast degrees of freedom and parameters that need to be optimized depending on what is required of the network performance which can either be the maximization of the area spectral efficiency (ASE), or the maximization of achievable throughput in each tier of the network [28].

#### **3.3.1 Cross-Tier Interference**

This interference occurs among network entities that belong to different tiers or layers (or cell-types located in the same geographical region) of a network. The aggressor, which is the entity causing the interference belongs to a different layer of the network with respect to the victim, which is the entity that suffers from the interference contributed by the aggressor. The level of cross-tier interference contributed depends on the density of the aggressors in a geographical region and their transmit power on the shared or adjacent spectrum resource [14].

#### **3.3.2 Co-Tier Interference**

Co-tier interference on the other hand occurs between network elements that belong to the same layer or tier of the network i.e. interference resulting from the transmission and reception activities of both the base stations and mobile user terminals connected to the same infrastructure type (e.g. Macro-cells or Femto-cells) of a network operator in a given geographical area. Femto-cell to Femto-cell co-layer interference can occur due to low isolation between houses or apartments in which the Femto-cells are deployed [14] though the generally low transmission power of Femto-cells and the high likelihood of attenuation due to walls reduces the intensity of the Femto-cell co-tier interference.

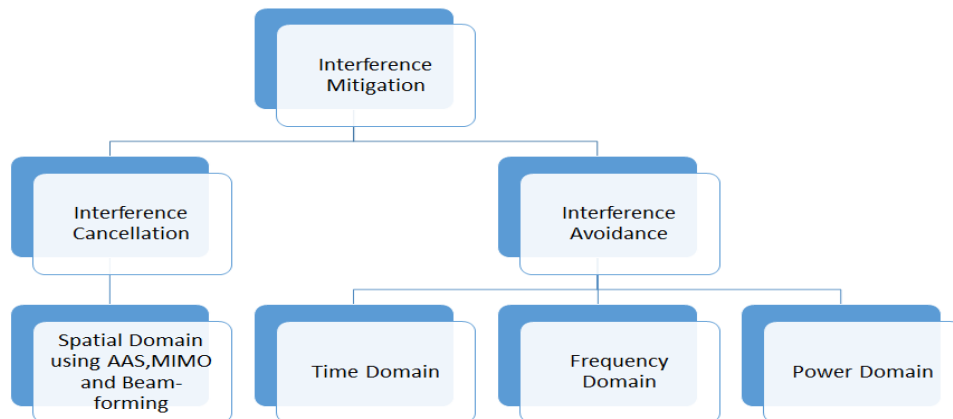
A summary of the different interference situations that can occur in a two-tier network comprising of Macro-cells and Femto-cells is given in Table 3.1

**Table 3.1:** Interference Scenarios

<b>Aggressors</b>	<b>Femto BS</b>	<b>Macro BS</b>	<b>Femto UE</b>	<b>Macro UE</b>
<b>Victims</b>				
<b>Femto BS</b>	N/A	N/A	Co-Tier Downlink	Cross-Tier Uplink
<b>Macro BS</b>	N/A	N/A	Cross-Tier Uplink	N/A
<b>Femto UE</b>	Co-Tier Downlink	Cross-Tier Downlink	N/A	N/A
<b>Macro UE</b>	Cross-Tier Downlink	Co-Tier Downlink	N/A	N/A

### 3.4 Interference Management in Heterogeneous Networks

Interference management and mitigation methods can be broadly categorized into interference cancellation and interference avoidance schemes (Fig. 3.5).



**Figure 3.5:** Approaches to Interference Mitigation

Interference cancellation schemes operate in the spatial domain and employ advance signal processing techniques to cancel out the interfering signal from the desired signal. Interference avoidance on the other hand uses orthogonal transmission either in the frequency domain or in time domain to mitigate interference. Also, power control approach to interference avoidance ensures that the desired signal's transmission power is increased while that of the interfering signal is reduced using complex algorithms. Further overview of these techniques is presented in succeeding sections.

### 3.4.1 Clustering of Femto-cells

This form of interference mitigation in Multi-tier heterogeneous networks involves the grouping of Femto-cells located in a geographical region together under a control node which can be a Femto-cell System Controller (FSC) as proposed in[29]. The FSC is attached to all the MeNBs that comprise the network of the mobile operator. Each FSC is connected to the HeNBs in the network and it is able to access their location via information exchange on the back-haul links. This approach is suitable to CSPs that possess the infrastructure to provide both fixed and mobile services. The spectrum is divided into two; one portion is dedicated to Macro-cell communication while the other is shared between the Macro-cell and the Femto-cells. The dedicated portion helps to ensure that the downlink (cross-tier) interference is totally mitigated and used for communication between the MeNB and MUEs that are close to the Femto-cells. A clustering algorithm is used to determine the proportion of the spectrum resource to be shared between the two-tiers and this partially depends on the density of the Femto-cells in the network. The clustering algorithm calculates the threshold distance which is the distance below which Femto-cells are allocated to different clusters in order to prevent severe co-tier and cross-tier interference. Simulation result of this implementation shows that high spectral efficiency is achieved with the probability of cross-tier spectrum reuse as high as 97.4%. This solves the UE downlink dead-zone problem considerably.

The Femto-cell coordinator in a group of other Femto-cells is simply referred to as the header in the proposition made by H. Widiarti *et al.* in [30]. The scheme was based on the IEEE 802.16m standards but can be adopted with slight modification for LTE since similar physical

layer technique of OFDMA is used by both framework. The Low Duty Operation (LDO) mode specified in IEEE 802.16m is exploited to implement a design that mitigates cross-tier interference.

The idea is to reduce the number of unnecessary available interval (AI) that is transmitted by the HeNBs on the air interface when no UE is attached. The HeNB can switch to the LDO mode when there is no HUE attached but from time to time, it switches to AI in order to determine if an HUE has entered its coverage to commence synchronization. The concept of clustering of Femto-cells is used to group ‘member’ HeNBs under a ‘leader’ HeNB.

When no UE is attached to the member HeNBs, it is only the leader HeNB that alternates between the AI and UnAvailable Interval (UAI) to sense if a HUE has entered the coverage region of any member HeNB that belongs to its group. With this procedure, a HeNB will receive the preamble signal from the leading HeNB. If the received preamble signal power is above a particular pre-defined threshold, then the HeNB connects to this leading HeNB’s cluster but if it is below the pre-defined threshold and there is no preamble signal above the threshold from another leading HeNB, then the new HeNB forms a new cluster. The HeNB will then be the leader of the newly formed cluster.

The advantages of this technique include mitigation of cross-tier interference and reduction in the energy utilised by the HeNBs. The more the number of UAI in a LDC, the more the interference reduction time (IRT), the lesser the intensity of cross-tier interference and the lesser the energy consumed by the HeNBs in the network. Numerical and simulation analysis presented by the authors showed a gain in IRT and energy saving of up to ninety per cent.

Another implementation that incorporates the concept of clustering was put forward in [31]. Here, to replace the FSC of [29] and leader HeNB of [30], Distributed Antenna System (DAS) was proposed. The DAS composes of signal processing modules and remote antenna units (RAUs) which are radio frequency (RF) antenna element modules. Multiple RAUs are aggregated through optical fibre to a common processing unit (CPU). The DAS will be installed close to the geographical location of a virtual cluster of HeNBs. It will serve as an interface between the

MeNB and the HeNBs. CSG mode of operation was assumed, ensuring that the units of MUE in the network will not be able to communicate through nearby Femto-cells.

Consequently, the MUE transmission generates interference at each of the Femto-cell cluster in the network and the HeNB evaluates its SINR value in order to determine if there is the need to mitigate interference. If the SINR value has been degraded below a threshold value above which symbol decodability is impossible, then the Femto-cell is considered to be in outage and it requests the cooperation of the DAS for interference mitigation.

A complex process similar to interference cancellation with the usage of antenna arrays as described in [32] was employed. The target Femto-cell picks up both the desired and undesired signals, other CPUs in the cluster also pick up interfering signals to the target Femto-cell. The signals to the Femto-cells and the CPUs are then fed to a common point after the analogue to digital converter (ADC) in the digital communication system of the target Femto-cell; here they are processed to cancel out each other with only the desired signal emanating from the process. The advantage of inserting DAS was demonstrated through simulations and a linear improvement in the spectral efficiency of the users was recorded. Without the DAS, all users recorded a spectral efficiency below 2bps/Hz. With the DAS insertion, more than ninety per cent (90%) got an average capacity of 2bps/Hz. Femto-cell clustering provides an effective means of mitigating both cross-tier and co-tier interference but its implementation is tedious and requires complex circuitry for the Femto-cells.

### **3.4.2 Cooperative Frequency Scheduling**

Unlike the dedicated channel access where the spectrum is rigidly divided between the network tiers in a cell, this technique emphasizes the sharing of the whole frequency spectrum between the Macro-cell and the Femto-cells that constitute the network. The work presented by the authors of [33] considered a two-tiered network with the Femto-cells deployed in closed subscriber group mode and the Femto-cells can only share spectrum that is being used by the Macro-cell at a distance that is far away enough. This ensures that a minimal or no interference is contributed by the Macro-cell to the Femto-cell reusing the shared spectrum.

The Femto base station first obtains the scheduling information used by the Macro base station at the centre of the cell to communicate to its attached MUE. This could be done through the backhaul or using over the air method (OTA) whereby the Femto-cell connects to the Macro-cell just as a mobile station would do through a dedicated channel. In the second stage of this technique, the Femto-cells perform spectrum sensing of its immediate environment to find the occupied spectral resources by the units of MUE; it then determines the spectral opportunities by comparing the sensing results with the scheduling information received from the Macro base station at the first stage.

The attached units of HUEs are scheduled by the Femto-base station using the spectrum opportunities discovered. An assumption is that in a well-designed communication system based on OFDMA, almost all resource blocks are allocated to the users. The scheduling information obtained from the Macro-cell by the Femto-cell will indicate that the spectrum is almost occupied. However, since quite a number of the units of MUE will be located far away from the coverage region of a Femto-base station at a given period, the HeNB can utilize the resource blocks of such far away units of MUE.

Through spectrum sensing, the Femto base station will continuously avoid resource blocks that are used by units of nearby MUE. Simulation was carried out using the Okumura-Hata Model path loss model and performance investigations centred on the interference power with respect to the distance and round trip delay (RTD). In addition, the error probability, which is computed as the sum of probability of missed detection PMD and probability of false alarm PFA during the sensing phase, was calculated.

Result analysis confirmed that the ICI is minimal for delays lesser than the cyclic prefix (CP) but a sharp increase was recorded as soon as the CP is exceeded due to excessive delay spread. The impact of ICI decreases at larger distances due to increased path loss making it possible for the Femto-cell to reuse such resources with lesser chances of interference degradation.

### 3.4.3 Cognitive Techniques

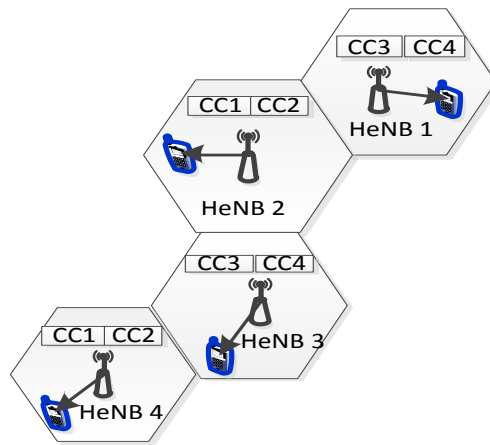
Cognitive interference mitigation is another technique that was put forward to deal with both cross-tier and co-tier interference in multi-tier heterogeneous wireless networks [34]. Real life situational analysis of Macro-cell overlaid with Femto-cells networks indicates that random deployment of Femto-cell will be wide spread since users deploy Femto-cells without network planning by the operator. Moreover, since Femto-cells are paid for by the customers, it is reasonable that users permitted by the owner of the Femto base station will be the ones allowed to connect to the network through the Femto-base station i.e. the Femto-cell will operate in closed access mode in most cases. Proponents of cognitive interference mitigation approach in [35] also cited lack of coordination between the Macro-cell base station and the Femto-cell base station or the increase in overhead signalling when such coordination is present as a disadvantage that can be overcome if the cognitive approach is adopted.

The authors of [36] proposed the cognitive resource block management (CRBM) concept where the need for coordination between the two tiers of the network is totally eliminated. The Femto-cell after it is switched on performs initial configuration and then senses the channel periodically in order to identify the RBs that are occupied by the Macro-cell. Out of  $T_s$  total frames, one frame is used for sensing and the remaining  $T_s-1$  frame is used for data transmission and reception, it is assumed that the Femto-cells are synchronized and they use the same frame for sensing. A threshold is set and the received interference power on the sensing frame is compared against the threshold. If the received interference power exceeds the threshold, the RB is said to be occupied by the Macro-cell, otherwise the RB is considered free. Free RBs are used by the sensing Femto base station to schedule its attached units of UE. Intra-tier interference can arise if more than one Femto base station senses a RB to be free and schedule their units of UE simultaneously on it; therefore, the authors proposed using the Gibbs sampler or game theoretic approach to mitigate intra-tier interference between the Femto-cells.

Zhang *et al.* in [37] proposed another method for Femto-cells co-tier interference mitigation using the cognitive approach. They divided the whole frequency spectrum into component carriers (CC) and the Femto-cells are required to sense the component carriers, detect

the energy on each CC and choose the one discovered not to be in use. There are two different categories of CCs, primary component carriers (PCCs) and secondary component carriers (SCCs). The PCCs are also referred to as the anchor CCs and they carry both control and data channel while the SCCs are referred to as the aggregate CCs and they are controlled by the PCC in order to fulfil the data rate requirements of a user when the capacity of only PCC is not enough [38]. The Femto-cell senses its environment to detect if there are neighbouring Femto-cells, if none is detected, it chooses a CC as the PCC arbitrarily; otherwise, it detects the broadcast channel to determine the CCs that are already in use by its neighbours. The following criteria, in order of importance are used by the Femto-cells to choose its own PCC;

1. Select the CC that is not in use by any neighbour as the PCC
2. If all the CCs are in use, select the one being used by the furthest neighbour
3. In case of dense deployment of Femto-cells whereby all the CCs used by the furthest neighbour is also in use by a nearby Femto-cells, then rule 2 is applied to only the CCs that is used by the lowest number of neighbour Femto-cells.



**Figure 3.6: Co-tier interference management through cognitive approach**

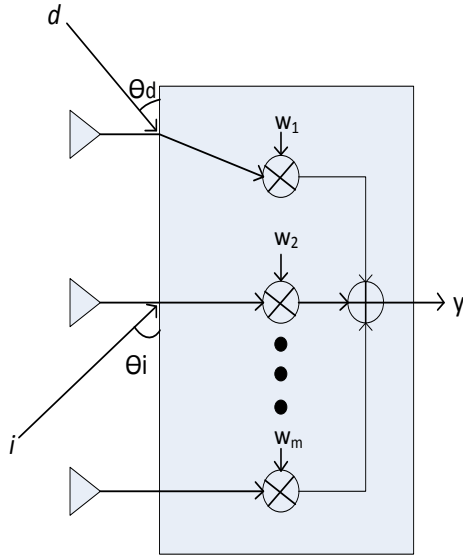
Illustration of this technique is given in Fig. 3.6. In the network, there are four CCs, when HeNB 1 switches on, it arbitrarily chooses any of the available CCs (CC3 and CC4), since HeNB 2 is a direct neighbour of HeNB 1, it senses the CCs and automatically avoids the ones being used by HeNB 1. HeNB 4 is neither a direct neighbour of HeNB 1 nor 2 so it selects any pair of

available CCs (here, CC1 and CC2). Through inter-HeNBs coordination, when HeNB 3 arrives into the network, it receives the information about the CCs that is used by its adjacent neighbours and in order to avoid co-tier interference, it selects the CCs that are different from those used by HeNBs 2 and 4. Simulation analysis shows an improvement in co-tier interference suffered by each of the HeNBs and a better data rate was achieved when compared with another cognitive based HeNB co-tier interference management method [34].

#### **3.4.4 Beam forming**

Beam forming is an interference cancellation technique. With Beam forming, multiple antennas are employed to focus the directivity of the antenna beam in order to discriminate between the desired signal and the interfering signals[32]. Both the desired and interfering signals arrive at the receiver's antenna elements (signals  $d$  and  $i$  in Fig. 3.7), a set of weights  $w_1, w_2, \dots, w_m$  are optimally assigned to each of the antenna elements to selectively attenuate the interfering signal  $i$  coming in from an unwanted direction. An amplifying weight is assigned to the antenna element receiving the desired signal  $d$  coming from the wanted direction. This improves the SINR property of the output signal  $y$ .

S. Park *et al.* in [39] employed an orthogonal random beam-forming-based cross-tier interference reduction scheme for two-tier Femto-cell networks. This beam subset selection strategy maximises the throughput of the Macro-cell base station by optimizing the trade-off between the multiplexing gain and the multiuser interference. A max-throughput scheduler that suppresses the cross-tier interference with an adaptively reduced number of beams was adopted.



**Figure 3.7: Interference mitigation using beam forming [14]**

The number of beams used by the Macro-cell depends on the number of MUE units in the coverage of the Macro-cell base station, therefore, the lower the number of MUE units, the lower the number of beams used by the Macro-cell base station. It also depends on the distance of the MUE units to the MeNB, the farther they are, the better the spatial diversity [40]. This provides spatial opportunities for Femto-cell transmission. To further improve the overall performance of the network, distributed power control strategy was combined with opportunistic channel selection. Analytical and numerical simulation results show that the collaborative strategy reduced cross-tier interference in two-tier networks.

### 3.4.5 Power Control Techniques

Interference mitigation using power control algorithms aims to directly reduce the transmission power of the nodes that make up a network. This leads to reduction in the extent of interference contributed by network nodes to each other. Power control algorithms are deployable for both cross-tier and co-tier interference situations. The major advantage of this approach is that the nodes that make up the separate tiers of the network can use the entire bandwidth with interference coordination [34] [41].

Power control solutions to interference mitigation can be categorized as assistance or non-assistance based. Assistance based schemes make use of coordination between the HeNB and the MeNB tier, while for non-assistance based there is no such coordination. They are also categorized in terms of conceptual architecture i.e. either centralized or distributed. Centralized power control requires a central controller that makes use of universal information of all the link gains for interference coordination. This approach may lead to heavy signalling and high latency in the network [41]. Distributed power control technique on the other hand, performs localized interference mitigation at the nodes of each network tier.

Power control algorithms are often time embedded in other schemes. The advantages of adopting and implementing these algorithms include mitigation of interference for the purpose of increasing network capacity, prolonging battery life by the conservation of energy or support of services QoS by adapting power requirement to match varying channel condition [42].

### **3.4.6 Considerations for MIMO implementation**

In [43], analysis was carried out in order to ascertain the increment in interference that the incorporation of MIMO antennas which is a main feature of LTE contributes to Multi-cellular LTE networks. Additional considerations used in the modelling of the interference of each base station include the Adjacent Carrier Interference power Ratio (ACIR) and the deployment environment clutter loss denoted by ( $Ah$ ). It was specified that an additional level of isolation, which is a function of the number of antenna elements used in each cell and given as,  $10 \times \log(N)$  dB be incorporated in order for LTE cells to coexist successfully.

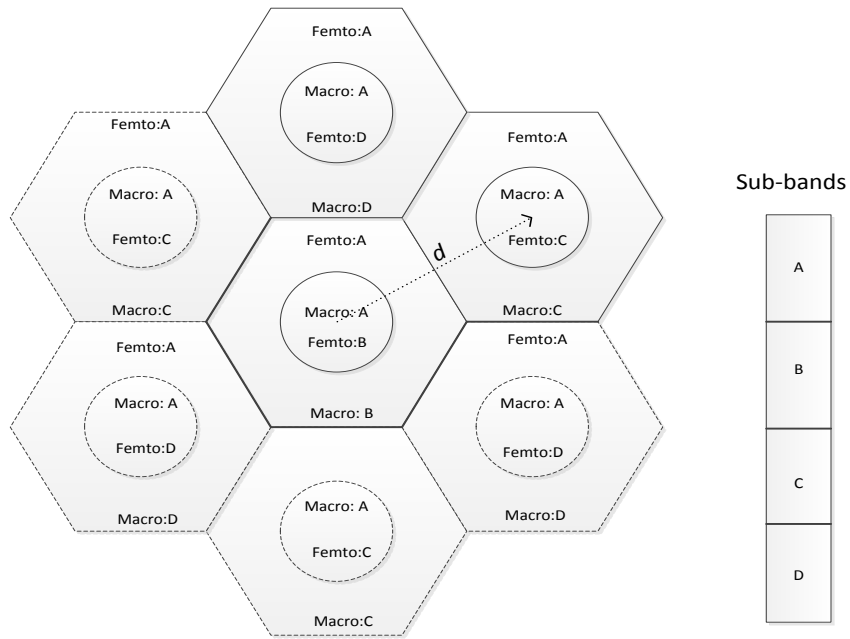
## **3.5 Fractional Frequency Reuse**

Conventional frequency reuse schemes are the legacy techniques for interference mitigation in wireless cellular networks. The frequency resource is divided into blocks that are allocated to each cell in the network. Using non-overlapping blocks of frequencies leads to improved interference mitigation in the network but also reduces the trunking capacity of each of the cells. Fractional frequency reuse improves the legacy frequency reuse scheme by dividing each

cell into sub-areas and then employing a frequency reuse factor (FRF) of unity in certain areas and using FRF greater than unity in other areas. This improves trunking capacity while interference mitigation is still ensured. There are different variants of FFR and these are further discussed.

### **3.5.1 Strict-Fractional Frequency Reuse**

In this framework, the network is divided into cell clusters ( $N$ ) of 3 and each cell is further divided into the centre and edge region. A FRF of 1 is adopted in the centre region of the cells that constitute the network while a FRF of  $N$  is employed at the cell edge region. The users at the centre region therefore do not contribute co-tier interference to the users at the edge region. Also, Inter Cell Interference between the centre regions of adjacent cell will be negligible depending mainly on the inter cell distance ( $d$ ). Higher values of ( $d$ ) will produce lower values of ICI. Bringing Femto-cells into consideration, the frequency allocation between the Macro-cell and the Femto-cell in each region is done orthogonally such that the Femto-cell in the centre region uses the sub-bands that are used by the Macro-cell in the edge region. Femto-cells at the edge region then use the sub-bands that are used by the Macro-cell at the centre region. A total of  $(N + 1)$  sub-bands are therefore needed when deploying S-FFR. Strict-FFR employing a cluster size ( $N$ ) of 3 in a seven-cell network is illustrated in Fig. 3.8.



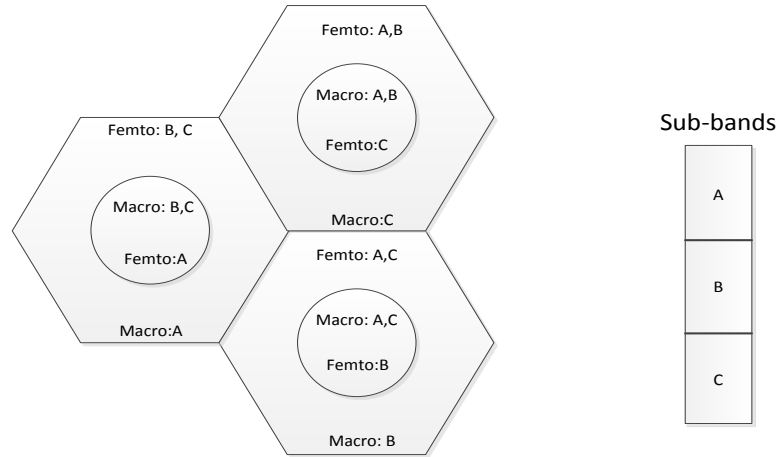
**Figure 3.8: Strict FFR with  $N = 3$**

### 3.5.2 Soft Fractional Frequency Reuse

This interference mitigation technique employs similar frequency allocation procedure to that of the S-FFR. Here, the centre region Macro user devices are allocated the sub-bands being used by other Macro users at the cell edge region of neighbouring cells within the cluster. For a cluster of  $N$ -cells, the total number of available sub-channels in a cell is divided into  $N$  sub-bands with one sub-band assigned to each of the edge zones. Femto-cells that will be overlaid on the existing Macro-cell infrastructure are allocated resources that are orthogonal to that of the Macro-cell in both the cell centre and cell edge region of the cell as illustrated in Fig. 3.9.

It can be seen that SFR is more bandwidth efficient when compared to Strict-FFR because the units of MUE at the centre regions are allowed to use the sub-band that is used by the MUE units at the edge region of neighbouring cells albeit at an increased risk of interference to the MUE units. The Femto-cells at the edge region have more channel options to choose from when compared with strict-FFR and this reduces co-tier interference. The disadvantage of this is that, Femto-cells transmit generally at a low power level and they will be open to cross-tier

interference. This will be more pronounced at the boundary between the cell centre and the cell edge region.



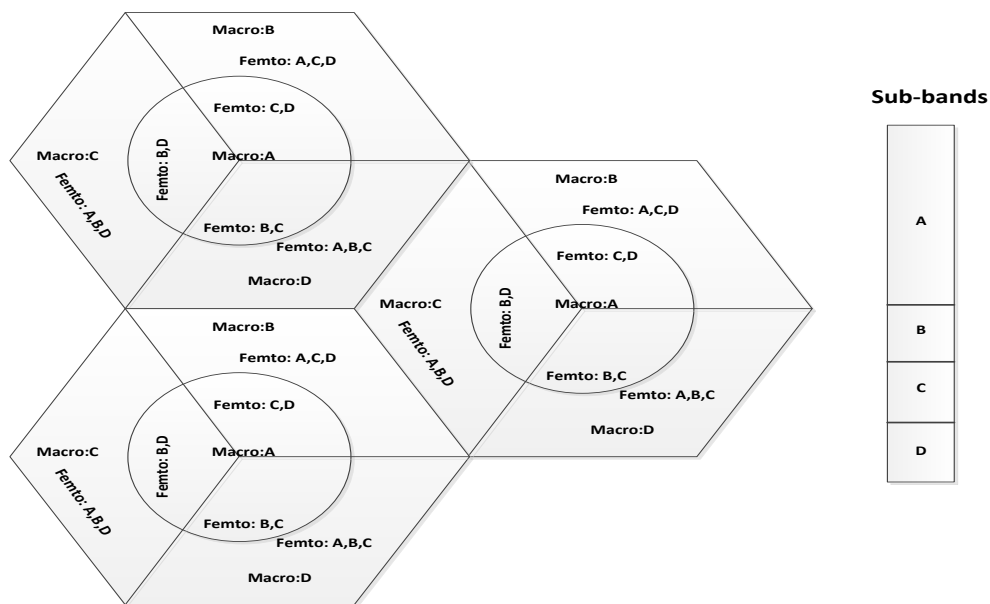
**Figure 3.9: Soft FFR with N = 3**

### 3.5.3 FFR-3 Scheme

In this scheme, the Macro-cell coverage area is divided into the centre and the edge zones. In addition to this partitioning, the cell is further divided into three (3) sectors. This reduces the number of neighbouring cells that contributes interference to each sector as depicted in Fig. 3.10. The whole frequency resource pool is divided into two, one half is dedicated for use in the centre zone, the other half is further divided into three sub bands and assigned to the three edge regions (in each sector). In a similar manner to strict-FFR and Soft-FFR, a Femto-cell chooses a sub-band that is not used by the Macro-cell in the cell region in which it is located. This means that when the Femto-cell is located in the centre zone of a particular sector, it will refrain from using the sub-band that is used by the Macro-cell at the centre region and at the edge region.

Power-control algorithms are also developed in order to minimise inter cell interference between the centre regions of the cells that makes up the network and to ensure that the SINR at

the cell edge is sufficient to satisfy user Quality of Service (QoS). Generally, the Macro-cell transmits at a lower power level to users at the cell centre region while a higher transmit power is used on sub-channels allocated to the edge regions. Parameters that can be optimized in FFR-3 scheme include the FRF of the edge zones, the centre zone radius and the proportion of the frequency resources to be allocated to the centre and edge region such that the overall network throughput is maximized. D. Lee *et al.* in [44] used simulations to arrive at the conclusion that increasing the number of sectors in a single cell beyond three does not produce a correspondingly distinct increase in the performance of the network in terms of the SINR.



**Figure 3.10: 3-cells layout of FFR-3 scheme**

FFR has the advantage of interference mitigation with less complexity making it suitable for interference mitigation in networks containing Femto-cells [10].

### 3.6 Interference Challenge in FFR-3 Scheme

A frequency reuse factor of unity is desirable for the radio planning of LTE because all the cells can reuse the whole spectrum that is available to the mobile operator thereby maximising the capacity and carried traffic of each cell and the entire network. The challenge of an FRF of unity

is increased interference. FFR-3 scheme with Femto-cells makes it possible for a FRF of unity to be used in each cell of the network though an FRF less than unity is used in each sector of the cell but overall, the whole spectral resource is exhausted in each cell as shown in Fig. 3.10. However, observing the existing scheme more carefully, it can be seen that Femto-cell users attached to a Femto-cell at the border between the centre region and the edge region will suffer from considerable interference if they reuse the same sub-band (A) used by the MeNB at the centre region. This will lead to performance degradation and inefficient use of Sub-band (A) by the HeNBs at the edge regions in all the three sectors of the cell.

Most previous analysis gave more preference to the Macro UE before the consideration of resource allocation to the HUE. As much as this is an acceptable strategy, the Communication service providers (CSP) need to ensure that a subscriber who made personal investment by purchasing a self-owned small base station experiences good Quality of Service (QoS). This is important because such investment will be made solely with the aim of enjoying the best service the operator can offer to the subscriber. To ensure fairness, this should be regardless of the position in which the user is located in the cell. From previous research analysis and design where a single cell has been divided into centre and edge regions, the problem of Femto-cells and Femto user equipment located at the area close to the CCR was pointed out but no effective solution has been proffered [12]. In order to further ensure efficient usage of the available sub-bands, a FFR-3 scheme that incorporates a buffer region at the cross-boundary between the centre and edge region is proposed.

### **3.7 Chapter Summary**

In this chapter, investigation of performance degradation as a result of interference between nodes present in a multi-tier network has been presented using the Vienna LTE simulator. The various interference scenarios have also been discussed. Furthermore, an exhaustive review of interference mitigation schemes has been put forward. The cross-boundary interference scenario in the efficient FFR-3 scheme was also highlighted. In the next chapter, the proposed FFR-3 with buffer scheme that will solve the cross-boundary interference challenge will be presented in detail and an anticipated performance improvement will be discussed.

# Chapter 4

## 4 System Design and Parameters

### 4.1 Introduction

In Macro-cell-Femto-cell multi-tier networks, interference mitigation techniques employing fractional frequency reuse involve the partitioning of frequency resources from two perspectives. The first aspect is the partitioning of resources among network elements that belong to the same tier of the network and the second aspect involves cross-tier frequency resource partitioning. This is easily detected in the related works discussed under the FFR schemes section in the preceding chapter. In this chapter, a framework that tackles the cross-tier interference at the border of the centre and edge regions as implemented in traditional FFR-3 schemes will be developed and presented. The solution seeks to incorporate a buffer zone into the CER and utilize the frequency resources allocated to the Femto-cells more efficiently.

### 4.2 Indoor Propagation

Conventional wireless communication systems were designed with basic consideration for outdoor usage. Geographical characteristics of the environment such as presence of obstruction between the transmitter and receiver that leads to multipath were used for empirical path loss modelling. For indoor transmission, additional factors have to be taken into consideration.

These factors include

- Reflection from and diffraction around objects such as walls and floors within the room
- Transmission loss through walls, floors and other obstacles
- Channelling of energy, especially in corridors at high frequencies and,
- The motion of people and objects in the room i.e. at either ends of the radio links.

Services can be characterized by their data-rate needs in order to ensure quality of service requirements. Impairments in the radio channel that directly affect these services are given in the Table 4.1.

**Table 4.1:** Indoor Services and their propagation impairments [45]

<b>Services</b>	<b>Characteristics</b>	<b>Propagation impairments of concern</b>
<b><sup>1</sup>Wireless Local area Network Connectivity for Voice and Data calls</b>	High data rate, single or multiple rooms, non-real time, point to multipoint or each point to each point	<ul style="list-style-type: none"> <li>• Temporal and spatial distribution of path loss</li> <li>• Multipath delay</li> <li>• Ratio of desired to undesired mode strength</li> </ul>
<b><sup>1</sup>Indoor Wireless Video</b>	High data rate, multiple rooms, real time, mobile or portable, point to point	<ul style="list-style-type: none"> <li>• Temporal and Spatial distribution of Path loss</li> <li>• Multipath delay</li> </ul>
<b>Indoor paging</b>	Low data rate, multiple floors, non-real time, mobile, point-to-multipoint	<ul style="list-style-type: none"> <li>• Temporal and spatial distribution of Path loss</li> </ul>
<b>Wireless Private Business Exchange (WPBX)</b>	Medium data rate, multiple rooms, single floor or multiple floors, real time, mobile, point-to-multipoint	<ul style="list-style-type: none"> <li>• Temporal and spatial distribution of Path loss</li> </ul>

### 4.3 Adopted Empirical Path loss Models

In this analysis, empirical path loss models were chosen for three different scenarios. The first considers transmission between the MeNB and its attached MUE. The MUE is considered to be in an outdoor area. The second considers transmission between a HeNB and its attached HUE. The HeNB and the HUE are both considered to be in an indoor environment. Losses due to wall attenuation were considered for the indoor propagation. The third considers interference transmission from the centre MeNB to a HUE that is located in an indoor position. These equations can be found in Table 4.2.

For the analysis done, only static nodes were considered in order to avoid additional complexities thereby ensuring tractability and correct interpretation of the results that will be gotten within the scope of the dissertation's objectives as given in chapter one.

### 4.4 Analytical and Simulation System Model

The considered network consists of  $M$  Macro-cell base stations and  $F$  Femto-cell base stations. The total available channel is  $B$ . Each user is assigned sub-channel  $b \in B$  that satisfies its required minimum data-rate  $R_{\min}$ . The total power available to each Macro base-station (MBS) is  $P_{MT}$  and the total power available to each of the Femto-cell is  $P_{FT}$ . The transmit power of Femto-cell  $F \in FBS$  on sub-channel  $b$  is  $P_{F,b}$  while that of a MBS  $M \in MBS$  on a sub-channel  $b$  is denoted as  $P_{M,b}$ . Considering fractional resource allocation between the two tiers of the network, the maximum power constraint of a Femto-cell is given as

$$\sum_{b=1}^{B_F} P_{F,b} \leq P_{FT} \quad \forall b \quad (4.1)$$

Where  $B_F$  is a constant denoting the total number of sub-channels allocated to the Femto-cell, which is a function of the region in which the Femto-cell is present inside the coverage area of a Macro-cell.

Similarly, for the Macro-cells present in the network, the maximum total power constraint is

$$\sum_{b=1}^{B_M} P_{M,b} \leq P_{MT} \quad \forall b \quad (4.2)$$

Where  $B_M$  is the total number of sub-channels available to the MeNB  $M$ . The channel gain between a MeNB  $M$  and its attached Macro-user equipment (MUE)  $m$  on sub-channel  $b$  is  $G_{M,m,b}$ . The signal suffers path loss  $P_L$ , which is a function of the distance between the MeNB or HeNB and their attached MUE or HUE respectively. The specification given by the ITU-R for indoor propagation [45] was used to develop the path loss equations adopted for the Femto-cells as discussed in section 4.2. The channel gain is affected by lognormal shadowing  $X_\alpha$  in dB and Rayleigh fading  $|h_{M,m,b}|^2$ . If a single tier network with only Macro-cells is considered first, the channel gain is given as

$$G_{M,m,b} = 10^{-(P_L + X_\alpha)/10} \times |h_{M,m,b}|^2 \quad (4.3)$$

If the serving MeNB  $M$  transmit a data symbol  $x_m(b)$ , the received signal at the MUE  $m$  is given as

$$y_m(b) = \sqrt{P_{M,b}} \cdot G_{M,m,b} \cdot x_m(b) + \sum_{i \in \Omega, i \neq M} \sqrt{P_{i,b}} \cdot G_{i,m,b} \cdot x_i(b) + n_m(b) \quad (4.4)$$

$x_i(b)$  is the interfering data symbol of neighbour MeNB  $i$  and  $n_m(b)$  is Gaussian noise with variance  $N_o$ . It should be noted that preceding analysis and equations have only accounted for co-tier interference between MeNBs in the network. The extent of interference is a function of the number of base-stations reusing same frequency to transmit to their attached units of UE and their transmitting power. In usual cases, the transmitting power of all base stations is kept regulated at a constant value except for scenarios that employ dynamic power allocation.

The signal to interference plus noise ratio (SINR) of Macro-user  $m$  on channel  $b$  is given by

$$\gamma_{M,m}(b) = \frac{P_{M,b} \cdot G_{M,m,b}}{I_{M'}(b) + N_o} \quad (4.5)$$

$I_{M'}(b)$  is defined as the out of cell interference contributed by the set of neighbouring Macro-cells  $M'$  in the network sharing the sub-channel  $b$  at the same time and it is expressed as

$$I_{M'}(b) = \sum_{i \in M'} P_{i,b} \cdot G_{i,m,b} \quad (4.6)$$

In order to specify a range of acceptable performance, system configured values of maximum and minimum SINRs are denoted as  $\gamma_{\max}$  and  $\gamma_{\min}$  respectively. At any time  $t$ , before a serving MeNBs can use a sub-channel for transmission and ensure correct decoding of  $x_m(b)$ , the condition  $\gamma_{M,m} \geq \gamma_{\min}$  must be satisfied.

The received signal power at allowable maximum interference is

$$y_{\min} = \frac{P_{M,b} \cdot G_{M,m,b}}{\gamma_{\max}} - N_o \quad (4.7)$$

The received signal power at minimum interference is also given as

$$y_{\max} = \frac{P_{M,b} \cdot G_{M,m,b}}{\gamma_{\min}} - N_o \quad (4.8)$$

Therefore, the achievable link rates for the scenarios can be determined by using the Shannon's capacity equation [6] and this is given as

$$C_{M,m}(b) = \begin{cases} 0, & \gamma_{M,m}(b) < \gamma_{\min} \\ \log_2(1 + \gamma_{M,m}(b)), & \gamma_{\min} \leq \gamma_{M,m}(b) \leq \gamma_{\max} \\ \log_2(1 + \gamma_{\max}(b)), & \gamma_{M,m}(b) > \gamma_{\max} \end{cases} \quad (4.9)$$

The equation 4.8 implies that at high interference levels, the total achievable channel capacity for users attached to the Macro-cell is low and with reduced interference, the channel capacity achieved by the users improves.

With Femto-cells overlaid on the coverage region of a Macro-cell, the channel gain between a Femto-cell  $F$  and its attached HUE  $f$  on sub-channel  $b$  is

$$G_{F,f,b} = 10^{-(P_L + X_\alpha)/10} \times |h_{F,f,b}|^2 \quad (4.10)$$

The SINR experienced by the HUE scheduled on sub-channel  $b$  is evaluated as

$$\gamma_{F,f}(b) = \frac{P_{F,b} \cdot G_{F,f,b}}{I_M(b) + I_{F'}(b) + N_o} \quad (4.11)$$

Where  $P_{F,b}$  is the transmit power of the HeNB on sub-channel  $b$ ,  $I_M(b)$  and  $I_{F'}(b)$  are the interference contributed by the embedding MeNB and the set of neighbouring HeNBs. If the indoor deployment of Femto-cell is considered and they are assumed to be placed in relatively far apart position, interference from neighbouring HeNBs will be minimal because of heavy attenuation to signals from wall losses and low transmission power of the FBSs.

The channel link rate for a HUE  $f$  attached to Femto-cell  $F$  on subcarrier  $b$  can therefore be given as

$$C_{F,f}(b) = \log_2(1 + \gamma_{F,f}(b)) \quad (4.12)$$

Furthermore, the overall throughput of the serving MeNB  $M$  is given as

$$T_M = \sum_M \sum_b \beta_{M,b} C_{M,b} \quad (4.13)$$

while the overall throughput of each of the HeNB are given as

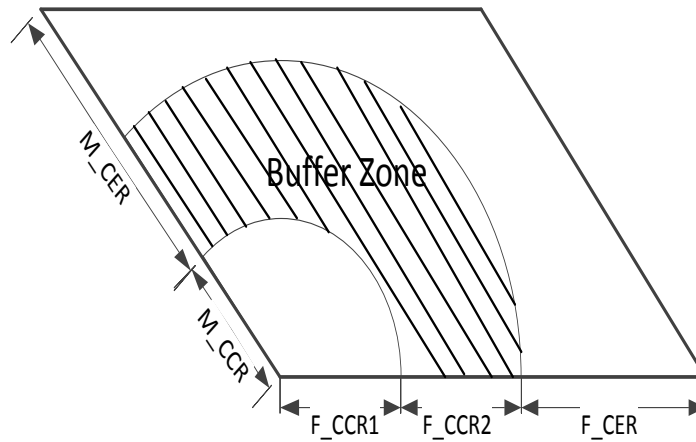
$$T_F = \sum_F \sum_b \beta_{F,b} C_{F,b} \quad (4.14)$$

Where

$$\beta_{M,b} \text{ and } \beta_{F,b} = \begin{cases} 1, & \text{If subcarrier } b \text{ is used by MeNB } M \text{ or HeNB } F \\ 0, & \text{otherwise} \end{cases} \quad (4.15)$$

## 4.5 The Buffer Zone

This is an area created out of the CER of traditional FFR-3 scheme and it applies to the Femto-cells alone. Here, the Femto-cells located close to the centre MeNB and are exposed to extensive interference from the MeNB if they use similar spectrum resource[29] will use RBs that are orthogonal to those contained in the sub-band used by the MeNB at the CCR of the traditional FFR-3 scheme. The illustration of the implementation of the buffer zone in a single sector is given in Fig. 4.1.



**Figure 4.1: Typical Regions of a Single Sector in the Proposed Scheme**

## 4.6 Proposed Hybrid Spectrum Sharing Scheme

This section presents the hybrid spectrum-sharing concept and proposes it as a means of determining the radius or regional area of the CCR2 (buffer zone).

From the Shannon Hartley theorem [11], the available bandwidth ( $W$ ) together with the SINR plays important roles in the determination of the achievable channel capacity between the transmitter and the receiver. As a result of this, it is desirable that the whole spectrum available in the network be not partitioned but be reused with a FRF of unity. However, in a Multi-tier network, an FRF of unity is characterized with the demerit of substantial interference because the

receivers are exposed to a high level of both cross-tier and co-tier interference. Considering a single cell of a multi-tier network that comprises a MeNB with overlaid HeNBs, the total network capacity  $C_T$  is given as [28]

$$C_T = C_M + \sum_{f=1}^F C_{fi} \quad (4.16)$$

Where  $C_M$  and  $C_{fi}$  are the achievable capacity contributed by the centre MeNB and each of the Femto-cells presents in the network respectively. Considering an FFR-3 implementation, the total available bandwidth  $W$  is shared into  $w_M$  for the centre MeNB and  $w_F$  for the HeNBs.  $w_M$  is further split into  $w_{m,CCR}$  and  $w_{m,CER}$  while  $w_F$  is also split into  $w_{f,CCR}$  and  $w_{f,CER}$ , where  $w_{m,CCR}$ ,  $w_{m,CER}$ ,  $w_{f,CCR}$ , and  $w_{f,CER}$  stand for the portion of the licensed spectrum that is given to the MeNB in the CCR and CER and the portion that is given to the HeNB in the CCR and CER respectively. If the whole spectrum is reused in a single cell, the area spectral efficiency of the cell can be expressed as

$$\eta = \frac{C_T}{W} = \frac{C_m + \sum_{f=1}^F C_{fi}}{w_{m,CCR} + w_{m,CER} + w_{f,CCR} + w_{f,CER}} \text{ (bits/s/Hz)} \quad (4.17)$$

If the Femto-cells present in the cell are only considered, the Femto-cell spectral efficiency per cell area is given as

$$\eta_{femto} = \frac{\sum_{f=1}^F C_{fi}}{w_{f,CCR} + w_{f,CER}} \text{ (bits/s/Hz)} \quad (4.18)$$

Furthermore, if the Femto-cells present in the network are considered on a more granular scale of the sector and region they belong to, the spectral efficiency of the users in the CER of Sector 1 is

$$\eta_{femto,CER} = \frac{\sum_{f=1}^{F_{CER}} C_{fi}}{w_{f,CER}} \quad (4.19)$$

Where  $F_{CER}$  is the total number of active Femto- user equipment present at the CER. From the FFR-3 resource allocation scheme for Sector 1,

$$w_{f,CER} = w_A + w_C + w_D \quad (4.20)$$

In the hybrid frequency reuse method, both shared and partitioned reuse modes are possible. In the CER, each HeNB can choose its usage mode based on the reuse selection criterion and other applicable conditions.

In the proposed scheme, the traditional CER is further separated into CCR2 and a new CER which depends on the usage mode selected by the HeNB. If the HeNB favours partitioned reuse, it belongs to the CCR2 while HeNB that favours shared reuse will be located in the new CER.

Considering the downlink transmission of both the MeNB and HeNB to their respective users, the throughput for the partitioned reuse is

$$C_{f,partitioned} = w_{C,D} \log_2(1 + \gamma_{f,partitioned}) \quad (4.21)$$

Where  $w_{C,D}$  consists of RBs present for Femto-cell transmission in the CCR2 (i.e. the buffer zone) and  $\gamma_{f,partitioned}$  is the SINR for transmissions taking place in the partitioned region.

It should be noted that the partitioned area in the CER is the region at which the HeNBs are using sub-bands that are orthogonal to the centre MeNB (i.e. F\_CCR2 in Fig. 4.1) while the shared area of the CER is that at which the HeNBs start using the same sub-band as the centre MeNB (i.e. F\_CER).

For the shared reuse, the throughput is expressed as

$$C_{f,shared} = w_A \log_2(1 + \gamma_{f,shared}) \quad (4.22)$$

The partitioned SINR is given as

$$\gamma_{f,partitioned} = \frac{P_f \cdot G_{F,f,k}}{\sum_{f'=1}^{n_{f'}-1} P_{f'} \cdot G_{F',f,k} + \Delta f N_o} \quad (4.23)$$

Where  $P_f$  is the transmit power of the target HeNB,  $G_{F,f,k}$  is the channel gain which is dependent on path loss between the HeNB and its attached HUE,  $P_{f'}$  is the transmit power of all interfering HeNB and  $G_{F',f,k}$  is the channel gain between the interfering HeNBs and the target HUE.  $\Delta f$  is the subcarrier spacing and  $N_o$  is the noise power. If it is assumed that appropriate co-tier interference mitigation scheme is adopted for the Femto-cell tier and that wall losses also contribute to isolation of the Femto-cells from each other, then the first term of the denominator of equation 4.21 tends to zero, therefore

$$\gamma_{f,partitioned} \cong \frac{P_f \cdot G_{F,f,k}}{\Delta f N_o} \quad (4.24)$$

For the case of shared spectrum usage, the SINR can be calculated as;

$$\gamma_{f,shared} = \frac{P_f \cdot G_{F,f,k}}{\sum_{f'=1}^{n_{f'}-1} P_{f'} \cdot G_{F',f,k} + P_M \cdot G_{M,f,k} + \Delta f N_o} \quad (4.25)$$

The terms of equation 4.23 remain the same as that of equation 4.22. Here  $P_M$  is the transmit power of the centre MeNB and  $G_{M,f,k}$  is the channel gain between the interfering centre MeNB and the target HUE.

The second term in the denominator of equation 4.23 is significant as long as the target HeNB and HUE are in relatively close proximity to the centre MeNB but this term will start to decrease as the HeNB and HUE move farther away from the MeNB. Therefore, as the HeNB distance to the centre MeNB increases, the shared SINR ( $\gamma_{f,shared}$ ) starts to improve. The number of RBs present in the sub-band A is greater than the combined bandwidth of sub-bands C and D ( $w_A > w_C + w_D$ ), therefore, more resource blocks can be allocated to the HUE that will be reusing sub-band A per unit transmission time interval (TTI).

In other words, when the HeNB and the HUE are located at a distance from the centre MeNB such that the interference contributed by the centre MeNB ( $P_M G_{M,f,k}$ ) reduces substantially, the available bandwidth becomes the dominant factor when estimating the throughput and not the SINR ( $\gamma$ ). Therefore,  $C_{f,shared} > C_{f,partitioned}$  and Femto-cells now favour shared spectrum usage at a specific distance away from the MeNB. The distance  $d$  at which the downlink throughputs for both shared and partitioned usage are the same is the threshold distance  $d_{th}$ . The  $d_{th}$  is the point at which the buffer zone ends and the CER region begins for the Femto-cells in the proposed FFR-3 scheme.

$$d = d_{th}, \quad |C_{f,shared}(d) = C_{f,partitioned}(d) \quad (4.26)$$

It can be seen that this resource allocation arrangement maximises the spectral efficiency of both the CCR2 and the CER. Therefore, by introducing a more granular technique in the allocation of frequency resource in the CER of the traditional FFR-3 scheme, network performance is improved in a single sector and if replicated across all the sectors belonging to the cells that make up the network, the overall network performance can be enhanced.

#### 4.6.1 The Scaling Parameter ( $\alpha$ )

From the preceding explanations, the RBs available for the HeNBs to use for transmission at the F\_CER are more than the number of resource blocks available for use in the other sub-bands. Looking at the resource allocation at the subcarrier level and the capacity equation, the number of subcarriers allocated per HUE in the F\_CER can as a result, be scaled to diminish the impact of the interference contributed by the MeNB radiating at a higher power level. Therefore, the scaling parameter  $\alpha$  was introduced. The capacity equation for the HUE at the F\_CER is therefore modified and given as

$$C_{F,f}(b) = \alpha \cdot \Delta f \cdot \log_2(1 + \gamma_{F,f}(b)) \quad (4.27)$$

Where  $C_{F,f}(b)$  is the channel capacity achieved by HUE  $f$  attached to Femto-cell  $F$  on subcarrier  $b$ ,  $\alpha$  is the scaling parameter as explained earlier,  $\Delta f$  is the subcarrier spacing and  $\gamma_{F,f}(b)$  is the SINR experienced by HUE  $f$  on subcarrier  $b$ .

From observation, the scaling parameter must be carefully chosen putting into consideration the number of users present in the CER and fairness between the Femto users present in the CER and other regions in a sector must be ensured. This is important in order to maintain uniformity in the quality of experience of the users present in the network.

## 4.7 Network Scenarios

In this section, the descriptions of the various scenarios investigated are given and the assumed coordination procedure in terms of signalling between the nodes present in the network is explained.

### 4.7.1 Single Cell Multi-Tier Implementation

In this scenario, a single cell that contains a centre MeNB and HeNBs deployed in a uniform random distribution was considered. The frequency resources were allocated to the MeNB in the conventional pattern. The MeNB coordinates resource allocation based on the a priori assignment as given in Fig. 4.2a while the HeNB coordinates resource allocation to its users based on its location under the coverage region of the MeNB.

However, in the case of densely deployed Femto-cells, the MeNB coordinates with the HeNB-GW via the control plane as given in Fig. 2.7 (Femto-cell logical architecture Variant 1). The MeNB via the MME transmits a message containing information about the bandwidth partitioning factor, the power ratio factor and the region partitioning factor to the HeNB-GW.

Since the HeNBs are directly connected to the HeNB-GW, the MeNB shares the frequency resource allocation codebook with the HeNB-GW. Based on the location and strength of the RSRP report given by each of the HeNBs to their attached gateway, the HeNB-GW then informs the HeNBs of the range of frequency sub-band that the HeNBs are to use for

transmission. A high-level communication and signalling control flow chart is depicted in Fig. 4.3 for all the nodes that will be present in the network.

#### **4.7.2 Multi-Cell Multi-Tier Implementation**

In order to expand the analysis of the proposed scheme, a multi-cell network layout consisting of 19 cells was considered. Each of the cells was divided into three sectors and the frequency allocation was also done in each cell using a similar method as that of the single cell scenario. The Femto-cells were deployed in a uniform and random manner in the network. Since the interference extent was to be determined, a single user was attached to each of the HeNBs that were deployed in the network. The HUE units were randomly distributed in the overall network in terms of their distance to their attached HeNB. The interference contributed by the centre MeNB and other MeNBs that make up the adjacent cluster to the HeNB and HUE pairs (located at the centre cell) that were reusing the same frequency resource for transmission were determined. The allocation of resources was also done by each of the MeNBs to their attached MUE units while coordination with the HeNB-GW was used to inform the HeNBs present in the network of the frequency resource they are to use depending on their position in the network. This is similar to that of the Single cell multi-tier scenario with the signalling flow chart given in Fig. 4.3. The system parameters adopted in both the analytical and simulation evaluation conducted using MATLAB are given in Table 4.2

**Table 4.2: System Parameters**

<b>Parameter</b>	<b>Value</b>
<b>Cellular network Model</b>	Hexagonal grid, 3 sectors per cell
<b>MeNB coverage radius</b>	1 km
<b>HeNB coverage radius</b>	20 m
<b>Number of cell sites</b>	1, 7, 19
<b>Carrier Frequency</b>	2100 MHz
<b>Carrier Bandwidth</b>	5 MHz
<b>Lognormal shadowing</b>	8 dB
<b>Path loss Model (outdoor to Outdoor)</b>	$28 + 35 \cdot \log_{10}(d)$ ; $d$ in meters
<b>Path loss Model (Outdoor to Indoor)</b>	$40 \cdot \log_{10}(d) + 30 \cdot \log_{10}(f) + 49$ ; $f$ in MHz, $d$ in Km
<b>Path loss Model (Indoor to Indoor)</b>	$38.5 + 20 \cdot \log_{10}(d) + L_{\text{walls}}$ $L_{\text{walls}} = 7 \text{ dB}, 0 < d < 10$ $L_{\text{walls}} = 10 \text{ dB}, 10 < d < 20$ $d$ in meters
<b>White noise power density</b>	-174 dBm/Hz
<b>Path loss exponent (<math>\alpha</math>)</b>	4 (Urban)
<b>MeNB Transmit Power (<math>P_m</math>)</b>	46 dBm, for $CCR1_{\text{Macro}}$ 33.4 dBm, for $CER_{\text{Macro}}$
<b>HeNB Transmit Power (<math>P_h</math>)</b>	20dBm

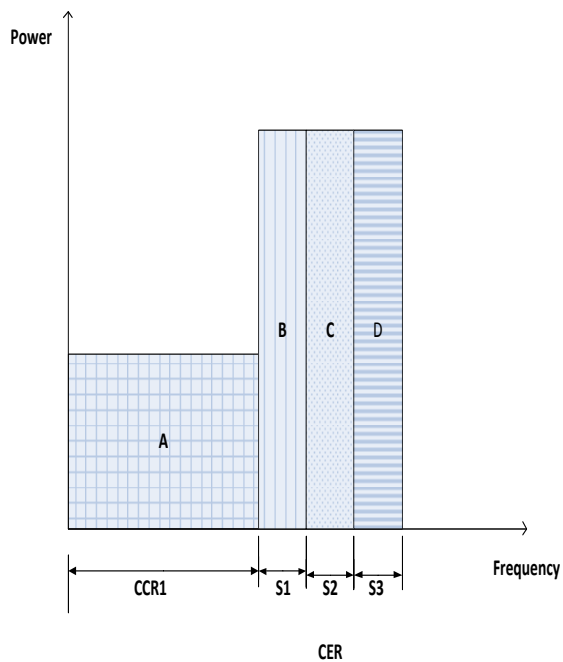


Fig 4.2a : Macro-cell frequency allocation

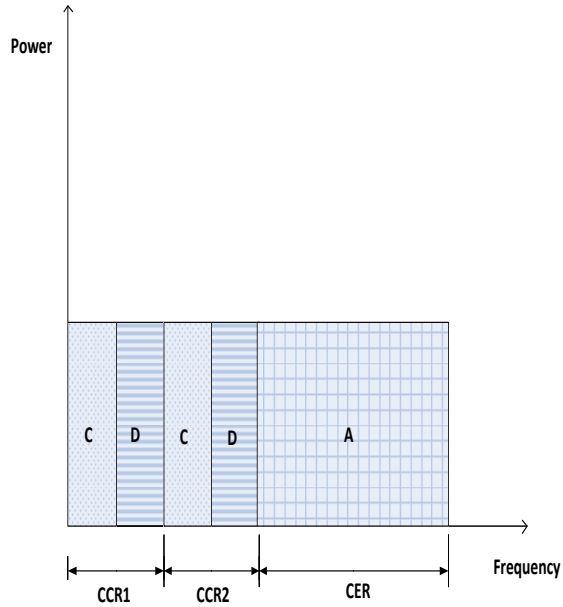


Fig 4.2b : Femto-cell frequency allocation in sector 1

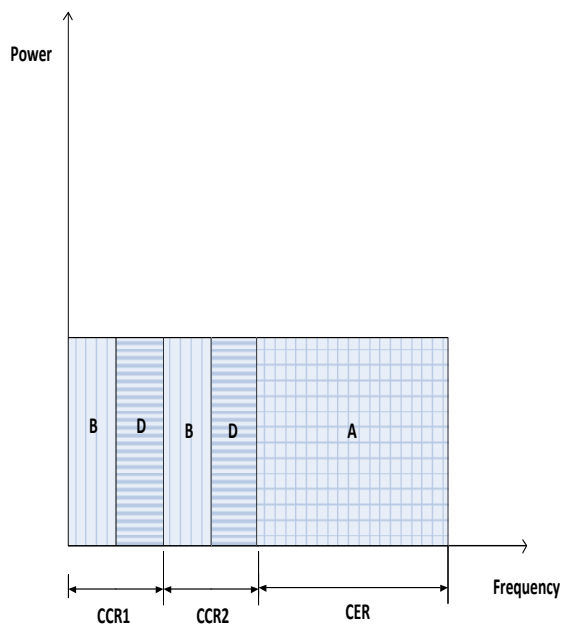


Fig 4.2c: Femto-cell frequency allocation in sector 2

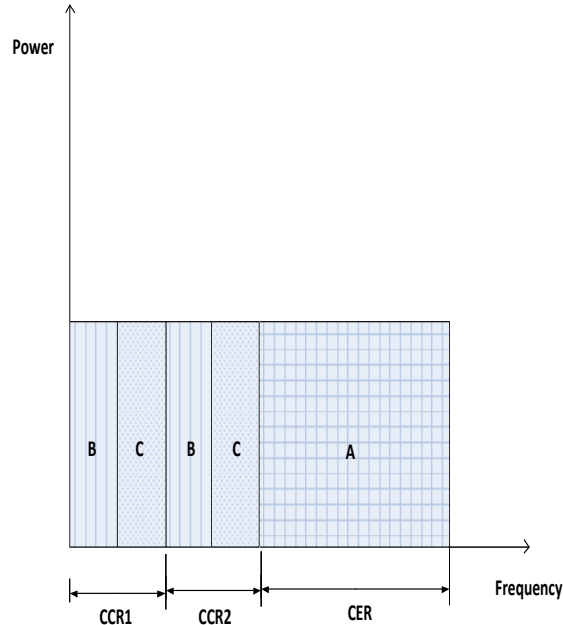


Fig 4.2d: Femto-cell frequency allocation in sector 3

**Figure 4.2: Frequency allocation in the proposed FFR-3 with buffer scheme**

The implementation pseudo-code is given below

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**Implementation Pseudo code for FFR-3 with Buffer**

---

generate\_MeNB ( ),

generate\_HeNB ( ),

generate\_MUE units ( ),

generate\_HUE units ( ),

attach\_HUE units\_to\_nearest\_HeNB

if  $0 \leq r_{\text{MUE}} \leq \text{CCR1}$

allocate\_RBs  $\in$  *Subband A*

Transmit at *P1*

elseif  $\text{CCR1} \leq r_{\text{MUE}} \leq \text{CER}$

allocate\_RBs  $\in$  *Subband B*

Transmit at *P2*

end

if  $0 \leq r_{\text{HeNB}} \leq \text{CCR1}$

allocate\_RBs  $\in$  [*Subband C, Subband D*]

elseif  $\text{CCR1} \leq r_{\text{HeNB}} \leq \text{CCR2}$

allocate\_RB<sub>s</sub> ∈ [*Subband D, Subband C*]

elseif CCR<sub>2</sub> ≤ r<sub>HeNB</sub> ≤ CER

allocate\_RB<sub>s</sub> ∈ *Subband A*

end

for M = 1 : length (MUE)

calculate\_snr (M)

calculate\_capacity (M)

calculate\_throughput (M)

end

for H = 1 : length (HUE)

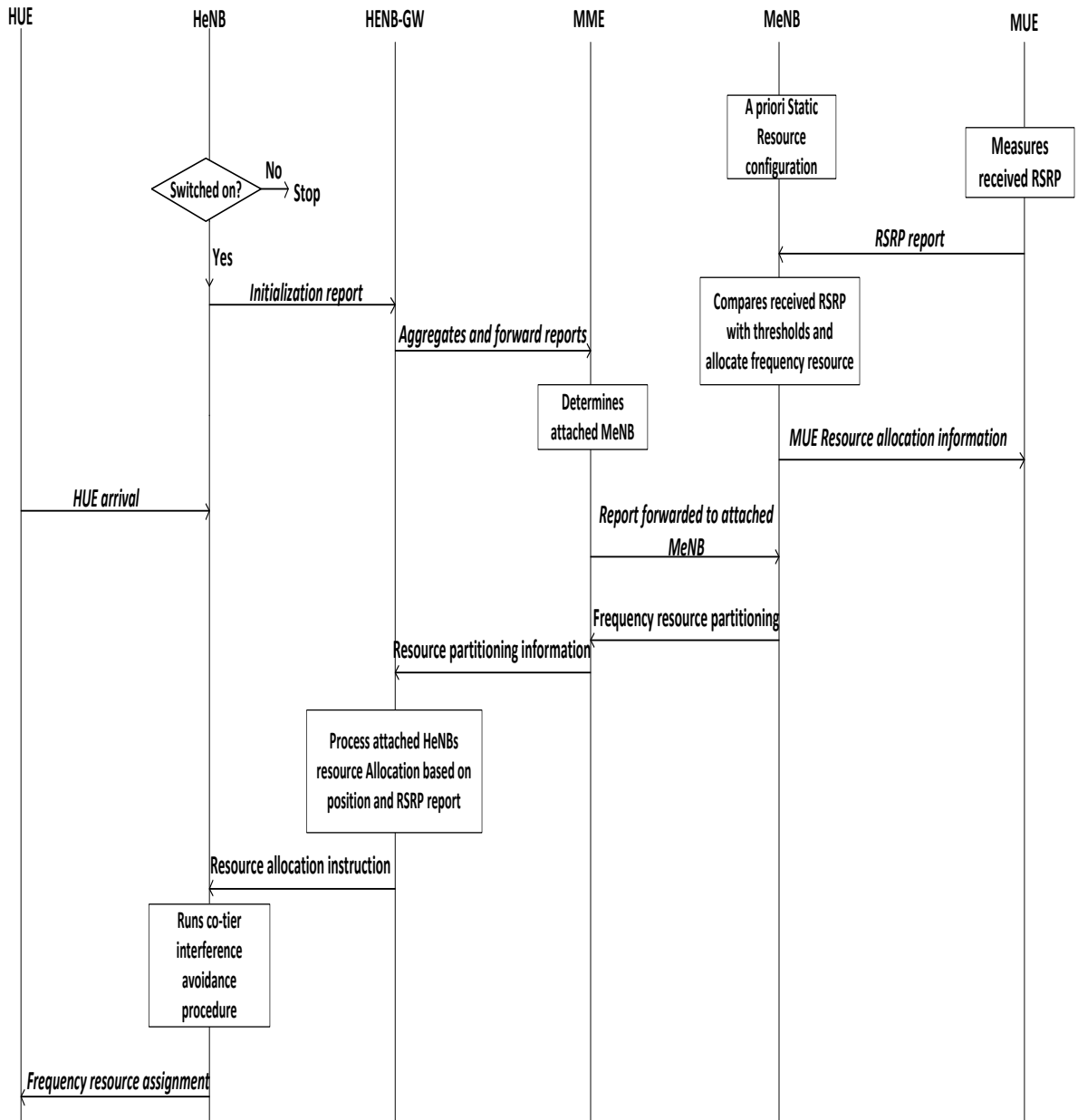
calculate\_snr (H)

calculate\_capacity (H)

calculate\_throughput (H)

end

---



**Figure 4.3: Signalling Flow-Chart for the Proposed FFR-3 with buffer Scheme**

## 4.8 Chapter Summary

In this chapter, the proposed FFR-3 scheme structure and analysis have been examined. The layout with emphasis has been placed on a single sector for clarity. The structural layout of the single sector will be replicated in all the cells constituting the network. The concept of Hybrid frequency selection procedure was introduced and proposed as a means of determining the radius (or area) of the buffer zone beyond which the HeNBs start reusing the same spectra resource with the MeNB at the CCR1. The pseudo code and the assumed signalling flow chart between the network nodes present in the analysed Multi-tier network were also put forward. In the next chapter, the outcome of the analyses carried out under the different scenarios will be discussed and conclusions will be drawn.

# Chapter 5

## 5 Results, Discussion of Results and Analyses

### 5.1 Introduction

In this chapter, the FFR-3 with buffer scheme was evaluated using the algorithm and pseudo-code proposed in the previous chapter. Analytical evaluation of the system was done to ascertain the level of performance improvement that can be recorded for a single user attached to a HeNB in the network. Furthermore, to evaluate the performance of multiple users at different locations in the cell, simulation was done using a MATLAB implementation of the proposed algorithm. Afterwards, performance comparisons between the traditional FFR-3 scheme and the proposed scheme using relevant network performance metrics were presented.

### 5.2 Performance Metrics

This section discusses the performance metrics adopted in this analysis for evaluating the outcome of the proposed FFR-3 with buffer scheme in comparison against the traditionally existing FFR-3 schemes.

#### 5.2.1 Signal to Interference plus Noise Ratio (SINR)

This is an important performance metric of wireless communication link quality and it has several important applications. These applications may include optimising the transmission power level to achieve a desired QoS, assisting in decision making as to when handoff is to be done between base stations and dynamically adapting data rates for wireless internet application [46]. In this analysis, the SINR is used mainly as a means of determining the achievable channel capacity using the Shannon's equation. For the evaluation using MATLAB simulations, the various scenarios possible were considered for users attached to the Macro-cell and those attached to the Femto-cells.

### **5.2.2 Ergodic Capacity**

This is defined as the maximum data rate that can be sent over the channel having asymptotically small error probability averaged over the fading process [47]. If Channel State Information (CSI) is available at the transmitter [47][48], the mutual information and the transmission power between the transmitter and the receiver can be varied depending on the amount of fade in order to maximise the average rates. For the ergodic capacity metric, the long-term average data rate, which can be delivered to a user when the user does not have a latency constraint, is considered. For the analytical evaluation carried out in this work, the ergodic capacity was used for benchmarking the performance of the traditional FFR-3 and the proposed scheme that incorporates a buffer zone.

### **5.2.3 Users Throughput**

This can be described as the average rate of successful message delivery over a communication channel. In terms of spectra efficiency, the throughput is an important measure of the performance of a random access network. The throughput metric was adopted for the evaluation of the network carried out with MATLAB simulations.

## **5.3 Analytical Evaluation**

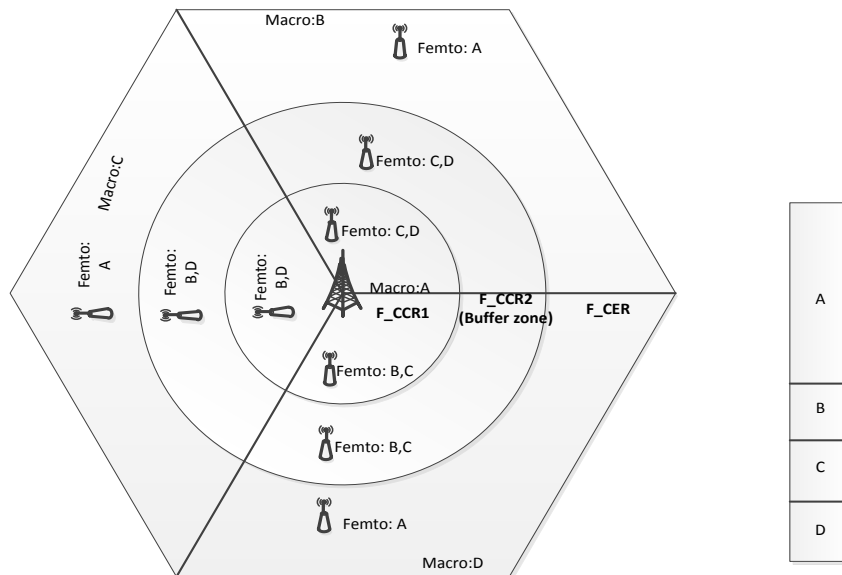
Numerical analyses based on the scenarios depicted in the Figs. 5.2, 5.3 and 5.4 were carried out and the derived SINR values were used to compute the channel capacity using an instantaneous snap shot approach. The snap shots were generated as illustrated in the figures using the worst-case scenario for the cross-tier interference. For the worst-case scenario, the HUE attached to the HeNB is assumed to be at the edge of the coverage region of the HeNB. The HUE was also assumed to be experiencing the maximum level of shadowing in the indoor area.

The Sub-band allocation scheme proposed for the FFR-3 with buffer is given in Figs. 5.1 and the scheme is replicated in all the cells present in the network for the various scenarios

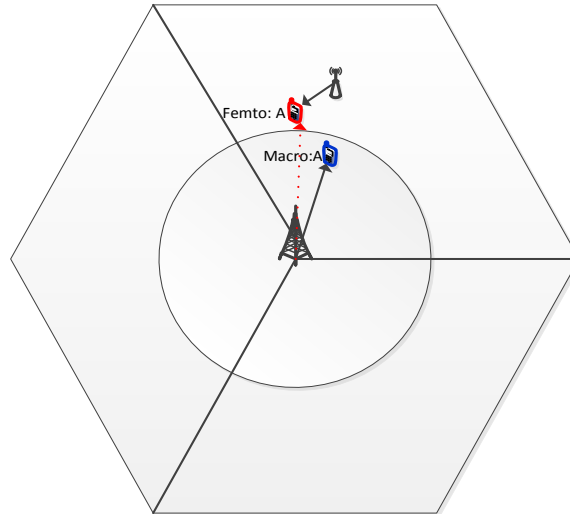
considered. The path loss experienced by both the units of UE attached to the MeNB and the HeNB that was expressed empirically in the preceding chapter is depicted in Fig. 5.7.

### 5.3.1 Single Cell-Multi-tier Network Scenario

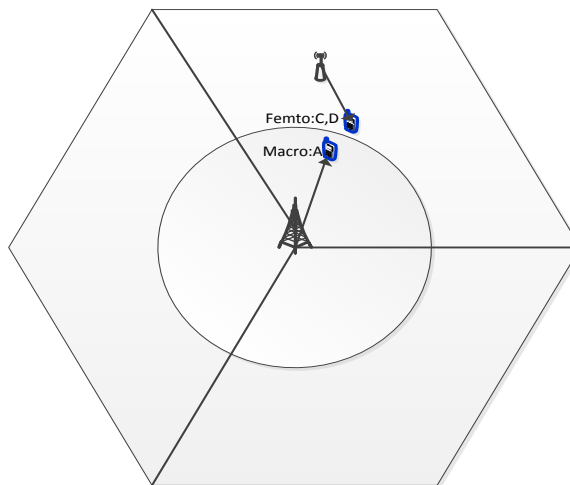
Initial estimations were based on a single hexagonal cellular structure, afterwards, a 7-hexagonal cell network layout was considered. For the single-cell analysis, the radius of the CCR 1 was set at 500 meters and that of the Cell Centre Region 2 or Buffer zone was set at 750 (i.e.  $500 \leq R2 \leq 750$ ) meters. This evaluation done was for each of the illustrations given in Figs. 5.2, 5.3 and 5.4. The outcome of the analysis was compared in terms of the achievable channel capacity as shown in Fig. 5.6.



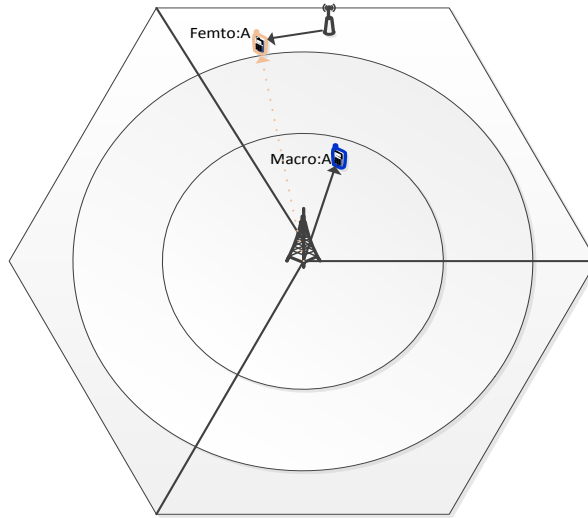
**Figure 5.1: FFR-3 with Buffer**



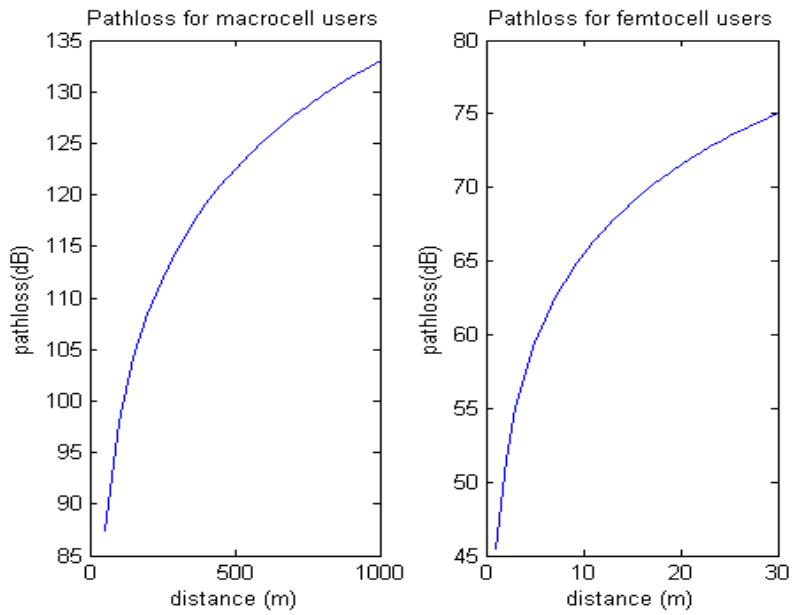
**Figure 5.2: FFR-3, no buffer with MeNB contributing Interference at the Cross-boundary region**



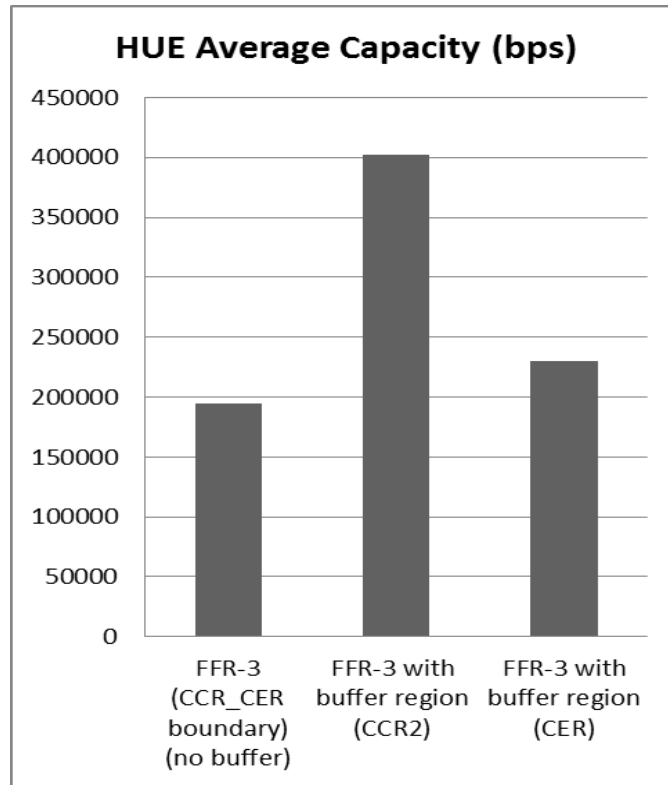
**Figure 5.3: FFR-3, buffered to prevent MeNB interference**



**Figure 5.4: FFR-3, buffer implemented and HUE sharing same Sub-band at the CER with MeNB at CCR1**



**Figure 5.5: Path loss (dB) experienced by Macro and Femto User against distance**



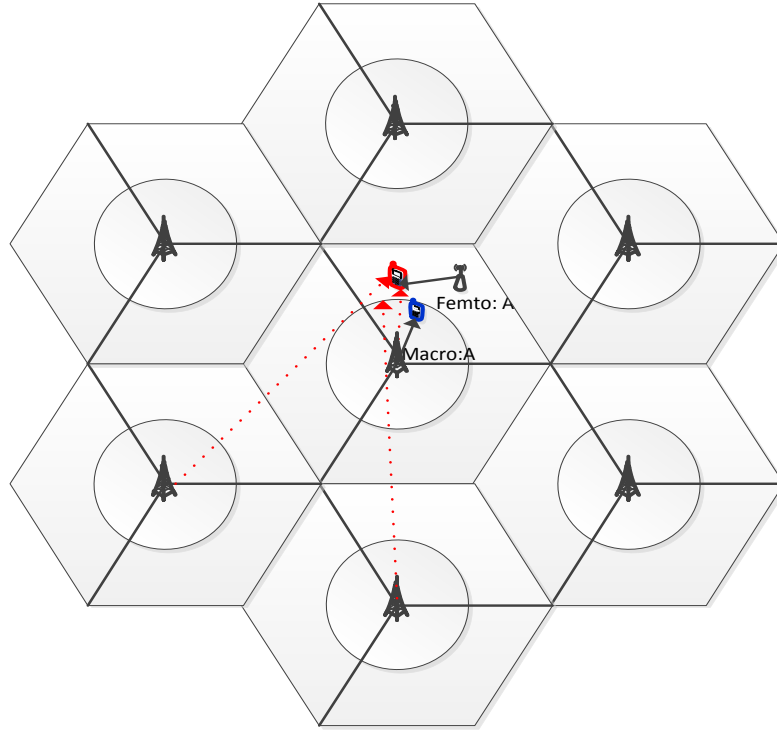
**Figure 5.6: Single Cell achieved channel capacity with the different scenarios**

From Fig. 5.6, when the MeNB was transmitting to its attached MUE and sharing the same set of RBs with another HUE as shown in Fig. 5.2, the HUE suffers a great deal from the interference contributed by the centre MeNB and this leads to a great drop in the link capacity of the HUE. This drop in performance becomes more visible when the buffer zone (CCR2) was introduced and the MeNB at the CCR1 and the HeNB at the CCR2 used orthogonal set of RBs. If Fig. 5.6 is carefully examined, the recorded improvement in link capacity with the buffer zone introduced for the HUE was around hundred per cent. Afterwards, the performance improvement that can be recorded if the same RBs are started to be reused by the HeNB at a certain distance (250 meters) away from the CCR1 was observed. It can be seen that an improvement in link capacity in the range of twenty per cent was recorded for the HUE at the proposed CER. The analytical evaluation of a multi-cell and multi-tier network implementing the same technique is given in the next section.

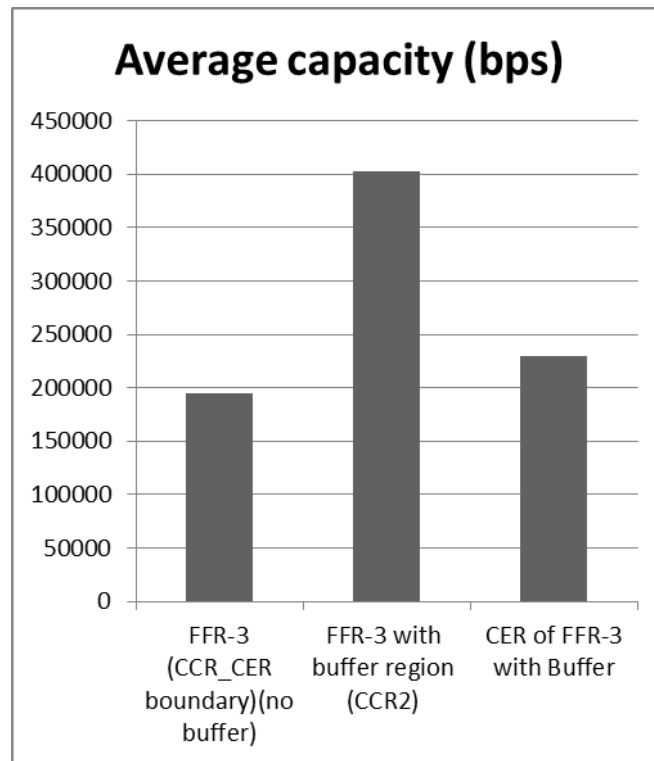
### 5.3.2 Multi-cell-Multi-Tier Network Scenario

Looking at the 7-hexagonal cellular structure layout shown in Fig. 5.5, due to the implementation of FFR-3, only two neighbouring base stations will contribute interference to any sector at the centre cell at which the evaluation is carried out. This is the benefit of sectorization with total trunking capacity of each sector as the trade-off [49]. As a result of this and the value of the inter-site distance calculated as  $\sqrt{3}R$ , where  $R$  is the cell radius, the interference caused by these neighbouring cells is minimal. The degradation they constitute to the channel capacity of the Femto user equipment that is located in an indoor environment is in the order of few hundreds bits per second (bps). This is seen by examining the result shown in Fig. 5.8 carefully and comparing it against the result shown in Fig. 5.6. After close observation, it was discovered that the performance for each of the scenarios remains almost unchanged.

Although, there were slight differences in the actual numerical evaluations but these changes (drop in performance) can hardly be detected from looking at the bar charts. This outcome also corroborates the outcome of analyses carried out in [49] which was targeted at the interference contributed by Macro-cells to Macro-cells. Therefore, it can be said that for Femto-cells and with the chosen values of parameters used in this analysis, interference contributed by other neighbouring MeNBs when sectorization is employed is not significant and can be safely neglected.



**Figure 5.7: Basic Illustration of simulation setup for seven-cells Network with FFR-3**

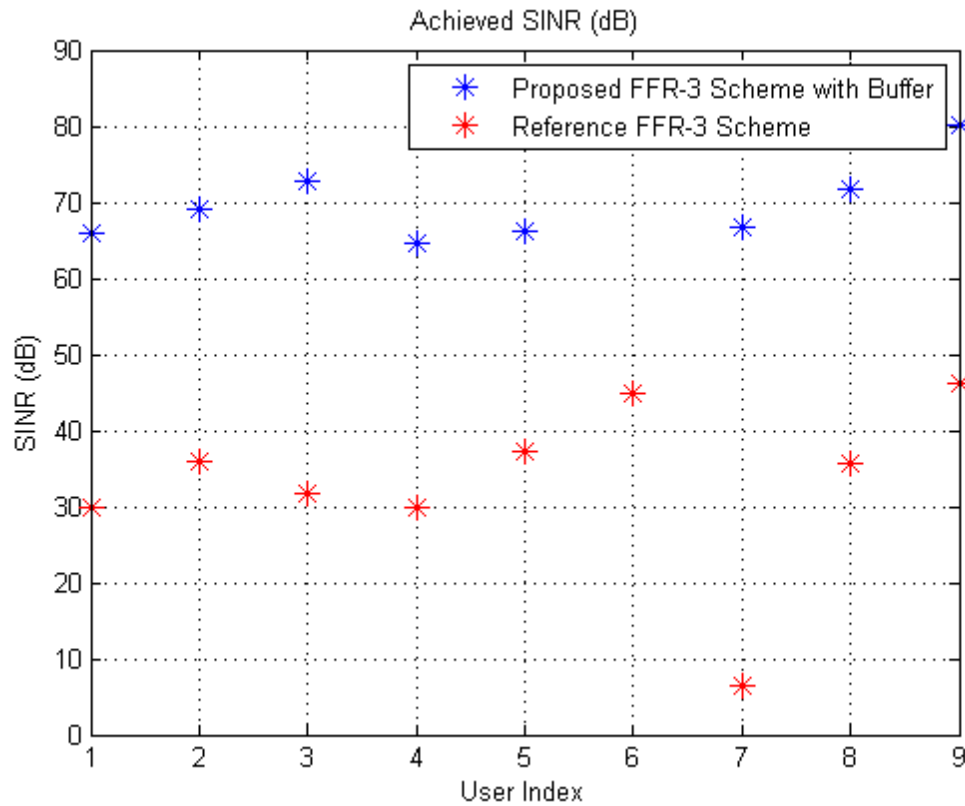


**Figure 5.8: 7 cells layout achieved average channel capacity for the three scenarios (bps)**

## 5.4 Simulation Evaluation

### 5.4.1 Achieved SINR

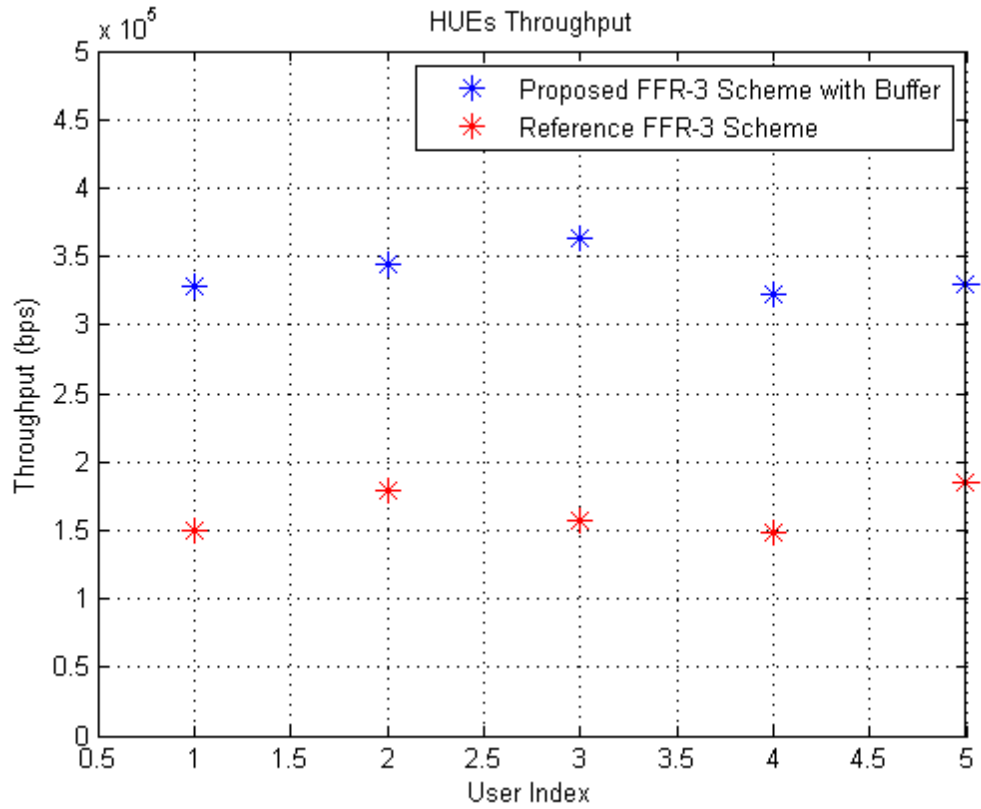
System Level simulations were carried out in MATLAB to ascertain the performance of the proposed scheme scenarios whereby multiple users are present in the network. In the simulation step that produced the SINR values shown in Fig. 5.9, nine pairs of HeNBs and HUEs were generated randomly in the buffer region. It can be clearly seen that the achieved SINR of users attached to the HeNB for the existing FFR-3 scheme is less than half of the recorded SINR when the buffer was introduced into the FFR-3 scheme.



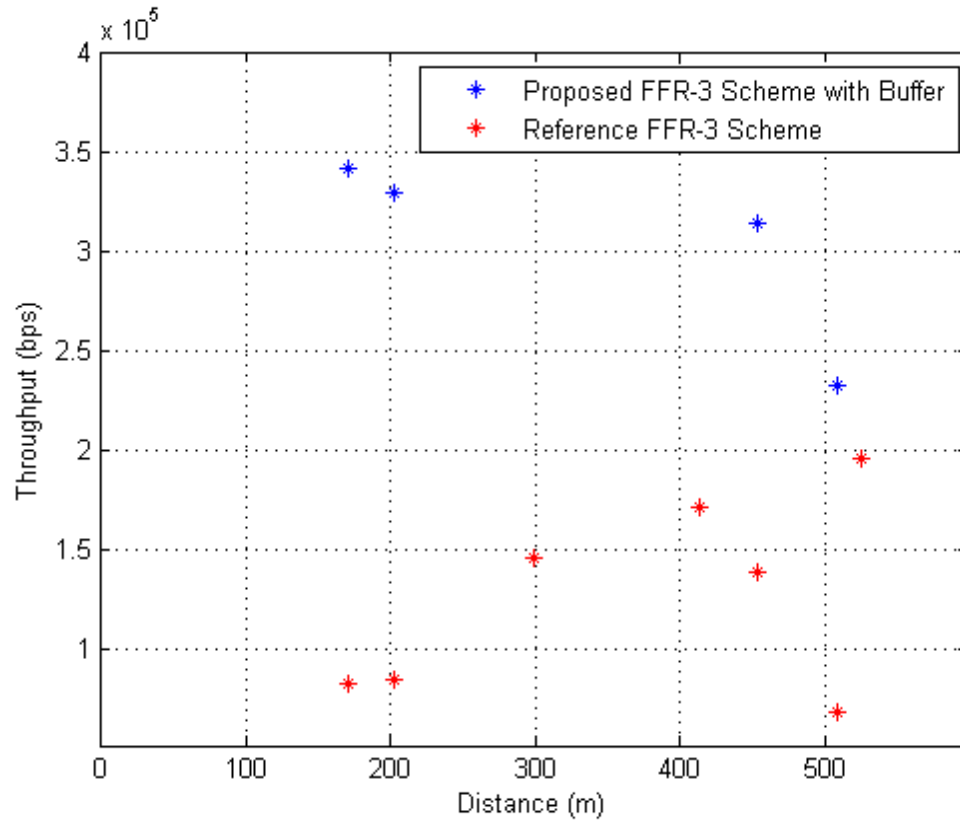
**Figure 5.9: Achieved SINR of HUE units**

For each of the HUE units, there is variation in the received signal strength of the HUE because they are placed at random location with respect to their attached HeNBs and differences in the level of slow fading experienced. Users that were placed at closer distance to their HeNB

tend to experience better-received signal power. For instance, HUE with index number 7 experienced better improvement when the buffer zone was implemented when compared with the HUE with the index number eight in Fig. 5.9.



**Figure 5.10: Per User Throughput of FFR-3 with and without buffer**



**Figure 5.11: User channel capacity against distance**

### 5.4.2 Users Throughput

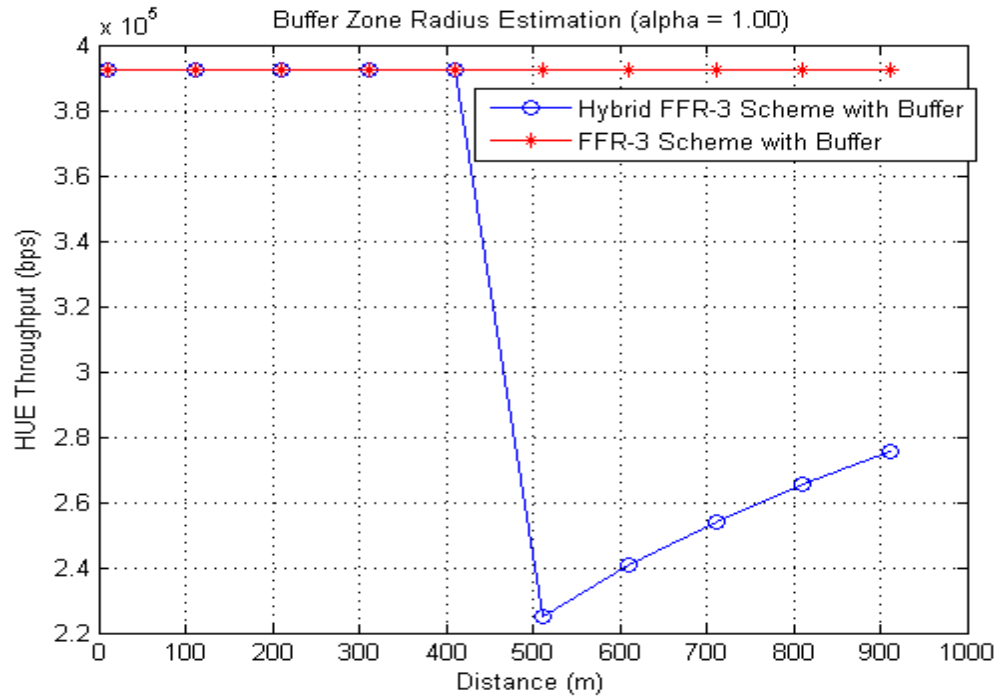
The system level simulation was further extended to examine the network performance in terms of the achieved throughput of the users deployed in the cell. Both the individual user's throughput was estimated and the achieved throughput as a function of the position of the HUE units with respect to the centre MeNB was considered. Looking at Fig. 5.10 and Fig. 5.11, it can be seen that the minimum value of the achieved throughput improvement of the HUE units is around a hundred per cent when the buffer zone implementation was compared against that of the traditional FFR-3 scheme. Interestingly, it can also be observed that as the units of HUE distance increases, the extent of the interference contributed by the MeNB reduces and the marginal improvement recorded by using orthogonal RBs between the traditional CCR and CER begins to reduce. Therefore, this demonstrates the benefit of adopting hybrid spectrum usage whereby users

that are at substantial distances away from the MeNB can then share the same RBs with the centre MeNB. This will be used to discuss the buffer zone radius estimation in the next section.

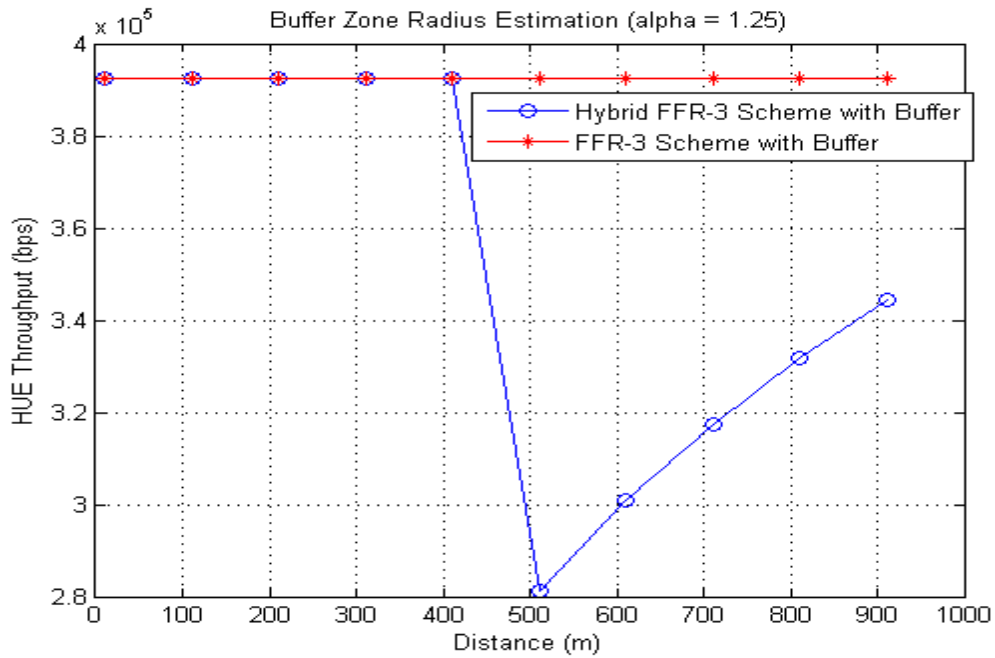
## **5.5 Buffer Zone Radius Estimation**

The preceding sections were able to demonstrate the level of improvements that can be expected if the buffer zone is adopted into the traditional FFR-3 scheme. Next, using the scaling parameter ( $\alpha$ ) discussed in the previous chapter, the implications of the value of the scaling parameter are presented. System level simulations were again used to perform the investigation.

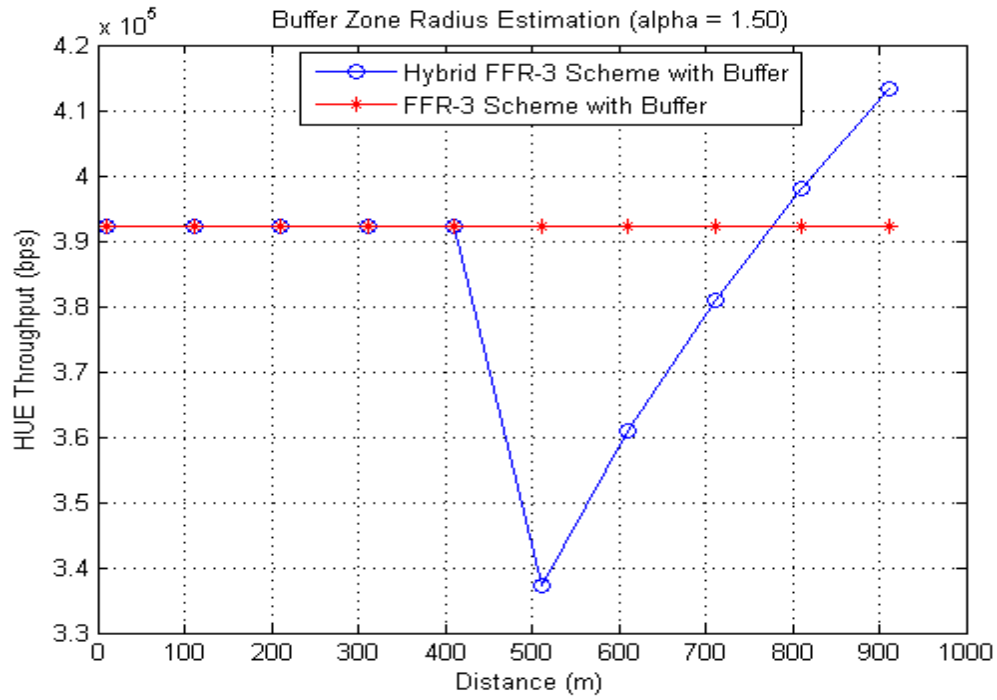
For these analyses, HeNBs were deployed at a distance of hundred metres apart and each of the HeNB has a single HUE attached to it. It was assumed that the units of HUE are placed at the same distance away from their attached HeNB and the channel was stationary over the TTI. The number of RBs assigned by the HeNB to their HUE was also kept constant. Afterwards, the same setup was repeated and the scaling parameter that determines the number of extra RBs allocated to the HeNB and HUE pair in the CER was introduced. The value of  $\alpha$  was increased between the range of 1 and 2 with a step size of 0.25. It is important to note that a continuous value can be used but for the sake of this investigation and to explain the implication of the value of the scaling parameter, the incremental step size of 0.25 was used.



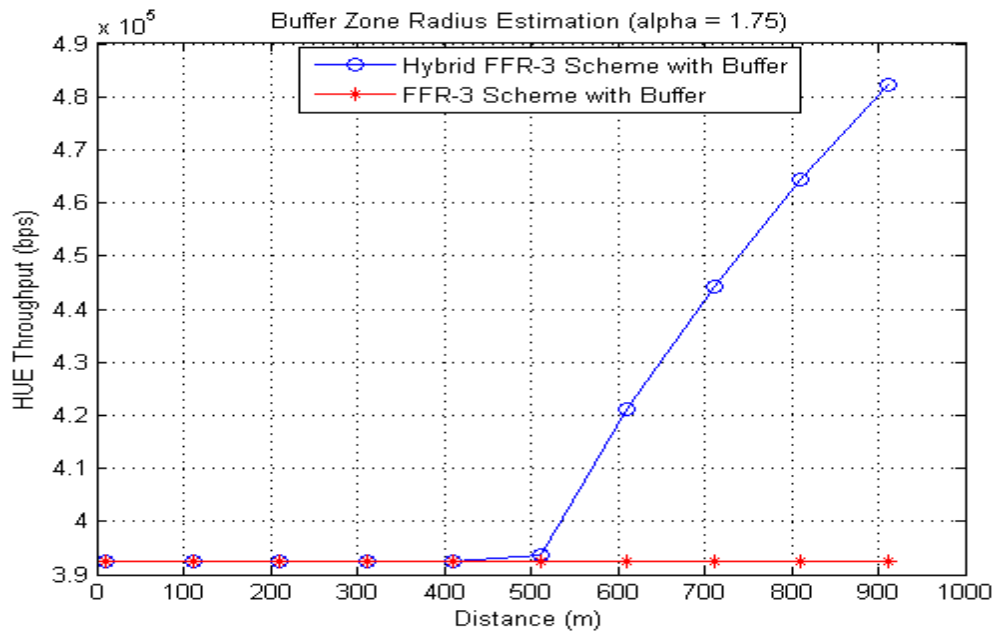
**Figure 5.12: Buffer region estimation ( $\alpha = 1.0$ )**



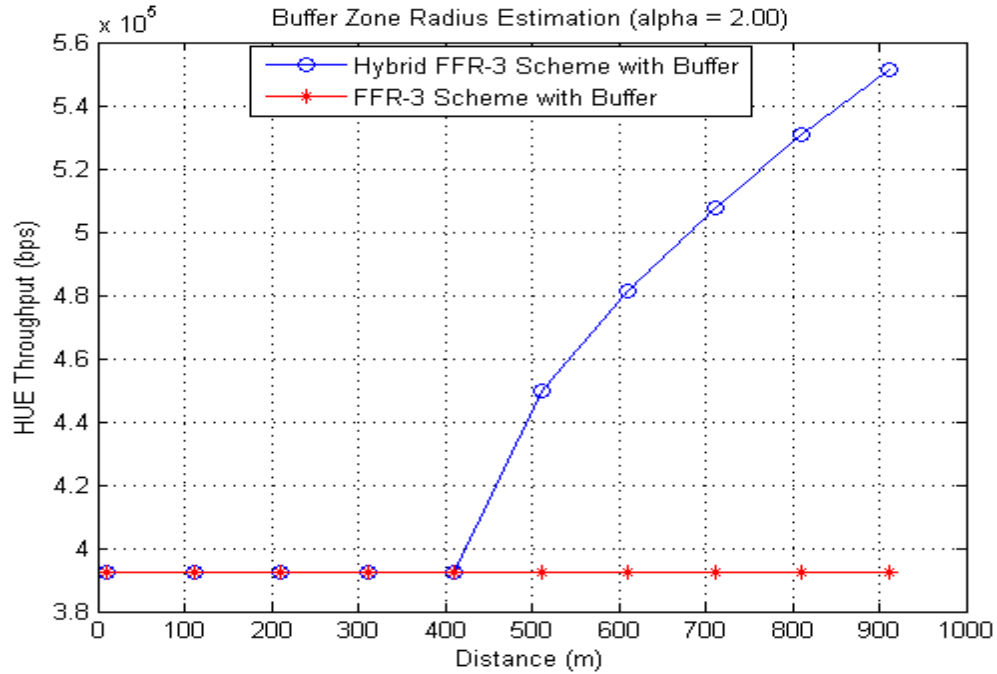
**Figure 5.13: Buffer Region Estimation ( $\alpha = 1.25$ )**



**Figure 5.14: Buffer Region Estimation ( $\alpha = 1.5$ )**



**Figure 5.15: Buffer Region Estimation ( $\alpha = 1.75$ )**



**Figure 5.16: Buffer Region Estimation ( $\alpha = 2.0$ )**

From the outcome of the simulation shown in Figs. 5.12 to 5.16, it can be seen that the step size variation of  $\alpha$  can be used to know where the CER should begin for the Femto-cells. If Figs. 5.12 and 5.13 is examined, it can be seen that  $\alpha$  value of 1 and 1.25 makes the shared usage of sub-band A by the HeNB sub-optimal as the HUE units in the CER were unable to achieve the same throughput as the units of HUE in the CCR1 and CCR2. For the step size increment of 0.5, it is observed that the HUE units employing shared reuse at the CER started achieving a similar throughput value with the HUE units employing partitioned reuse at the CCR1 and CCR2 at a distance of about seven hundred and eighty metres from the centre MeNB (placed at the origin). As the value of the scaling parameter further increased, the distance at which the HeNBs can employ shared spectrum usage with the centre MeNB starts to decrease.

When  $\alpha$  was set at 2.0 (which means doubling the number of RBs or spectrum used by the HeNB at the CER when compared to that of the CCR1 and CCR2), the throughput of the HeNB at CER supersedes that of the CCR1 and the CCR2. The CCR2 also became unnecessary and the RBs assigned to it were unused. Therefore, the scaling parameter value of two is not efficient as it causes under-utilization of the whole RBs available for transmission in the cell. In addition, the

sub-band will become insufficient to serve the units of HUE now located in a CER that has become a very large area in the cell.

The value of  $\alpha$  is significant in the Hybrid Spectrum Reuse technique proposed in this dissertation. A small value of  $\alpha$  will lead to extensive interference for Femto-cell users close to the boundary region of the CCR1 and CER and are using shared spectrum because the CCR2 will be inexistent. This is clearly shown by the graphs in Figs. 5.12 and 5.13. For the value of  $\alpha$  set to 1.5, reuse of sub-band used in the CCR1 by the MeNB is possible but this most happen at a distance of about seven hundred and eighty metres from the centre MeNB. In other words, the CER for the Femto-cells will start at about two hundred and twenty metres from the edge of the cell. This is because it is only from this point that the HUEs at the CER achieves the same throughput similar to those HUEs at the CCR1. Higher values of  $\alpha$  reduces the distance that shared reuse of sub-band between HUEs in the CCR1 and CER can start. However, if uncontrolled, the CER will become so large that the available sub-band might not be enough to cater sufficiently for the users without causing extensive intra-region interference.

## 5.6 Chapter Summary

This chapter has presented the evaluations carried out on the proposed scheme using both analytical and MATLAB simulation approaches. Evaluations done were based on both single cell and multi-cell network deployment types. It was discovered that the cross boundary interference between the CCR and the CER could be significant in terms of the degradation it causes on the performance of the link capacity achievable by the units of HUE located at this border region. This makes the adoption of the buffer zone a pragmatic solution as substantial improvement was recorded with its implementation.

Furthermore, the multiple-users evaluation done in MATLAB agrees with the initial analytical evaluation in terms of the throughput recorded for the HUE units. The effect of variations in the scaling parameter  $\alpha$  for RBs allocation to the HUE in the CER in determining the CER area was also investigated and presented. It was discovered that increasing  $\alpha$  helps to compensate for the effect of interference contributed by the centre MeNB to the HUE units at the

CER that are operating in the shared spectrum mode and reusing the same sub-band as the centre MeNB in the CCR1.

In the next chapter, the conclusion of the report is given and recommendations for future work, which can be done in line with the proposed scheme were also given.

# Chapter 6

## 6 Conclusion and Future Works

### 6.1 Introduction

In this chapter, a brief summary of what has been reported in the preceding chapters will be presented. Also discussions on the extension that future analysis can add in order to improve on what has been done in this dissertation will also be highlighted.

### 6.2 Conclusion

Femto-cells provide a solution to the challenge of provisioning high-speed communication capabilities in indoor environment. This is crucial because surveys have established that wireless communication services are requested more from indoor areas and the traditional Macro-cell infrastructure is unable to perform well in indoor areas because of signal attenuation when crossing from outdoor areas to indoor areas. The disadvantage associated with the deployment of Femto-cells is mainly the increased possibility of interference between the Femto-cell and the Macro-cell tiers of the network.

In this dissertation, the various techniques for provisioning quality indoor signal coverage have been explicitly discussed, highlighting the strengths and weaknesses of each approach. It was seen that Femto-cells provide a better solution in terms of benefits experienced by both the CSPs and the subscribers such as ease of deployment and cost effectiveness.

As a result of the Femto-cells operating on the same licensed band used by the Macro-cells, interference between the two tiers is inevitable if proper mitigation technique is not employed. A survey of the various techniques available in the literature reveals the suitability of the FFR-3 technique for interference mitigation in Multi-tier networks that consists of MeNBs and HeNBs in terms of its effectiveness and low complexity, which is important for the relatively inexpensive circuitry that will be used in the Femto-cells.

After performing critical examination of the traditionally existing FFR-3 schemes, an interference scenario that these schemes did not address was discovered. This interference possibility will occur when the MeNB is transmitting on the same RBs to its attached MUE units in the centre region at the same time when a HeNB at the boundary between the centre and the edge region, is transmitting to its attached HUE using the same RBs as the MeNB.

In this analysis, a solution to the cross-boundary interference scenario that will be experienced by the units of HUE situated at the border region of the CCR and CER of existing FFR schemes has been proposed. This approach can be employed by the cells that are deployed with any given number of sectors. It was shown through system level simulations that the interference contributed by the MeNB to the HUE units located at this boundary region can be significant thus making it important to provide a technique of mitigating this in order to improve the overall experience of network subscribers regardless of their location in the coverage region of a cell.

After the implementation of the scheme, the improvement recorded by the HUE units in the cross boundary region in terms of achieved throughput was within the range of hundred per cent. The hybrid frequency usage concept was also modified and adopted for the HUE units at the CCR2 and the CER. HeNB and HUE pair choosing the partitioned spectrum reuse scheme are said to be present in the CCR2 while those favouring the shared spectrum usage are grouped into the CER of the proposed FFR-3 scheme with buffer.

A flexible means of determining the CER area or radius was also proposed using the scaling parameter  $\alpha$ . The value of the scaling parameter has a proportional relationship with the minimum specified data rate for the HUE units at the CER and the radiating power of the centre MeNB while it has an inversely proportional relationship with the number of HUE units present at the CER. Therefore, the lower the numbers of HUE units present in the CER, the higher the value of  $\alpha$  while the higher the  $R_{min}$  and the MeNB power, the higher the value of  $\alpha$ .

Finally, the FFR-3 with buffer scheme will improve the overall performance of the network if it is implemented in all the cells that are present in the network.

### 6.3 Recommendations

Future works can include investigating the effect of non-uniform distribution of the users in the different regions of the cell on resource allocation. In the situation whereby users attached to Macro-cells in the edge area are more than what the spectrum portion allotted to that region can provide in terms of the minimum required data-rate  $R_{min}$ .

Secondly, analysis of the algorithmic complexity of the proposed scheme can also be an extension of this study. Though, it has been assumed that the additional calculation to be done by the centre MeNB only involves the determination of the radius of CCR2 and this can easily be done by determining the instantaneous channel capacity of the HUE units at the inner edge of the CCR2 that borders the CCR1. The reduction in interference contributed by the MeNB to the HeNB as the position of the latter approaches the edge region of the cell is also estimated. The difference can then be compensated for by increasing the unit size ( $\alpha$ ) of the allocated sub-channel to the HUE at the CER.

Lastly, the buffer zone can also be implemented in schemes such as the FFR-6 and the SFR. These two schemes are similar to the traditional FFR-3 schemes and they will both experience cross boundary interference from the centre MeNB to the HUE present at the border region of the centre region and the edge region. The Hybrid frequency usage concept can also be used to determine the size and area of the CER based on similar assumptions made in this work.

### 6.4 Chapter Summary

This chapter has given a brief overview of the analysis carried out in this dissertation and the recorded improvement by the adoption of the proposed scheme was briefly given. Future analyses that can be done on the proposed scheme were also presented and other interference mitigation schemes (based on frequency reuse) that can adopt the buffer zone to improve their performance were discussed in this chapter.

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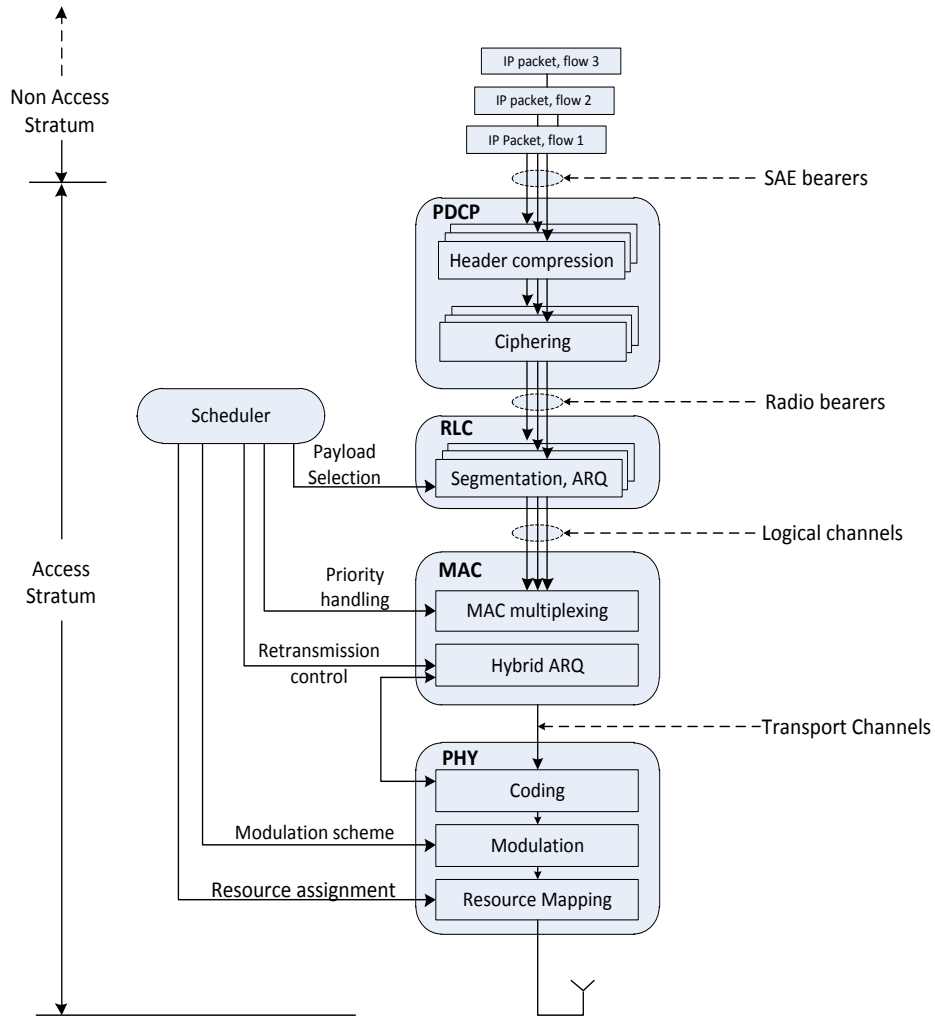
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## **Appendix A**

This appendix gives a brief overview of the OSI reference model as related to Femto-cells in 4G networks. The aim of this appendix is to briefly establish the relationship between inter layer services and protocols in LTE multi-tier networks. The relationship between the layers in the context of interference mitigation in Macro-cell and Femto-cell will be emphasized.

### **A.1 The Access Stratum of the OSI reference Model and Protocols in LTE.**

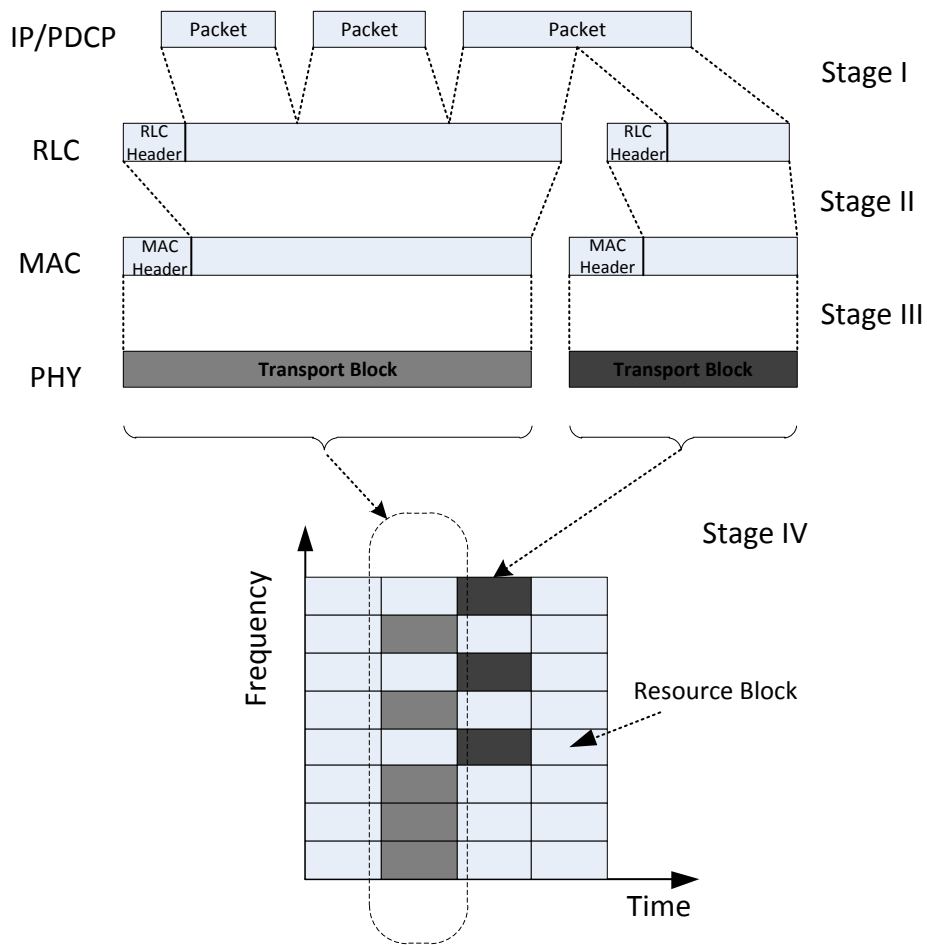
Out of the seven layers of the popular OSI model, the physical layer and the data link layer (PDCP, MAC and RLC) are more directly involved in interference mitigation and control. They are associated with the radio access portion of the network, hence they constitute the Access stratum (AS) while the upper layers, which perform more core network (CN) related signalling and data transfer constitute the Non Access Stratum (NAS). The logical representation of the LTE protocol stack is given in Fig. A.1.



**Figure A.1: The LTE Protocol Stack [50]**

LTE is an all-IP based system and data packets travel through the layers and sub-layers as illustrated in the Fig. A.1 before they are transmitted over the air interface. Generally, an upper layer encapsulates data into protocol data units (PDUs) and sends the PDUs to the adjacent lower layer. The lower layer receives the PDU from the upper layer as a Service data Unit (SDU), provides a service and then outputs another PDU to the next lower layer or sub-layer in the protocol stack.

The general flow of transmission processes and functionalities present at each layer/sub-layer and offered to the adjacent layers/sub-layers from the Data link layer to the Physical layer of LTE is depicted in Fig. A.2.



**Figure A.2: Data flow and resource mapping in LTE**

### **A.1.1 The Data-Link Layer**

The Packet Data Convergence protocol (PDCP) is the topmost sub-layer of the data-link layer (layer 2) and is responsible for the compression and ciphering of IP headers received from the Network layer (Layer 3). These compressed packets are forwarded to the Radio Link Control (RLC) protocol.

The RLC layer performs segmentation and concatenation of packets received from the PDCP into RLC Protocol Data Units (PDUs). It also enhances the radio bearer with Automatic Retransmission on Request (ARQ). The retransmission is triggered with the use of sequence

numbered data frames and status reports. The size of the RLC PDUs depends on the resource allocation offered by the MAC layer (illustrated in stage II of Fig. A.2).

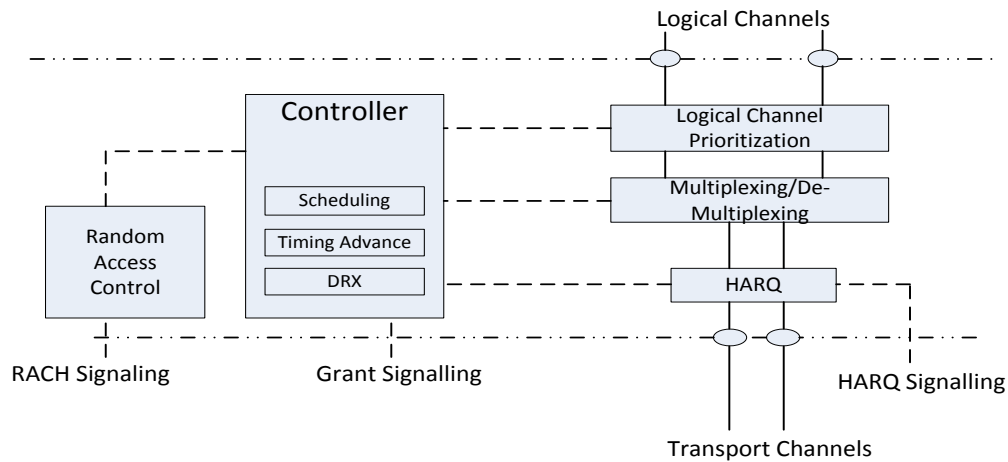
The MAC sub-layer on the other hand performs resource allocation and scheduling. The MAC sub-layer is the lowest sub-layer in layer 2 of the LTE radio protocol stack and it plays a crucial role of coordinating how the upper layers access the wireless physical medium. It connects to the physical layer below it through the transport channels and to the RLC above it through logical channels. It therefore performs multiplexing and de-multiplexing between the logical channels and transport channels.

The Logical channels used by the MAC sub-layer in providing data transfer services for the RLC sub-layer can further be divided into Control logical channels (used for signalling transfer purposes on the control plane) and Traffic logical channels (used for actual user data transfer on the data plane). The logical channels used on the control plane includes the following; Broadcast Control Channel (BCCH), Paging Control Channel (PCCH), Common Control Channel (CCCH), Multicast Control Channel (MCCH) and Dedicated Control Channel (DCCH). The traffic logical channels include the Dedicated Traffic Channel (DTCH) and the Multicast Traffic Channel (MTCH) [47].

For the MAC sub-layer and Physical layer interaction, the transport channels are used for data exchange. Data is multiplexed onto the transport channels depending on how it is transmitted over the air interface(see Fig. A.1 and A.2 (stages III and IV)). The transport channels are further categorised as Broadcast channel (BCH), Downlink Shared Channel (DL-SCH), Paging Channel (PCH), Multicast channel (MCH), Uplink Shared Channel (UL-SCH) and Random Access Channel (RACH). Additional information about the functionalities associated with each of these channels can be found in [47].

The MAC layer performs the scheduling of users onto the physical transport channels offered to it by the Physical layer. It consists of a HARQ entity, a multiplexing/de-multiplexing entity, a logical channel prioritization entity, a controller which performs various control functions and a random access control entity. A logical architecture of a LTE MAC sub-layer is given in Fig. A.3.

The HARQ entity performs transmit and receive HARQ (combination of forward error control (FEC) technique and traditional ARQ) operations for error mitigation purposes. In an adaptive HARQ scheme, variations in the channel condition together with transmission resource allocation in the frequency domain are taken into consideration and used for the selection of modulation and coding scheme at each retransmission.



**Figure A.3: Logical layout of the MAC layer [47]**

The Femto-cells are structurally similar to the Macro-cells, hence they share the same layers and protocols of the OSI model. Interference (either cross-tier or co-tier) must be avoided on the transport channels as they cause poor decodability of both control and data plane signals at the receiver.

## **A.1.2 The Physical (PHY) layer**

The modulation, coding and actual resource mapping take place at the physical layer. Orthogonal Frequency Division Multiplexing (OFDM), a multicarrier technology is employed at the LTE physical layer. The system model of OFDM transmitter and receiver is depicted in Fig. A.4. Orthogonal Frequency Division Multiple Access (OFDMA) which is based on OFDM is the multiple user access scheme for LTE. The granularity with which physical channel resources can be allocated to users makes OFDMA an attractive scheme for interference avoidance schemes.

In Fig. A.4, the inverse Fast Fourier Transforms (IFFT) at the transmitter can be said to construct the OFDM signal in the frequency domain [14]. The  $N$ -sample output from the IFFT block is an OFDM symbol and it consists of the sequence given as

$$x[n] = \frac{1}{\sqrt{N}} \sum_{k=0}^{N-1} X[k] e^{j \frac{2\pi n k}{N}}, n = 0, \dots, N - 1 \dots\dots\dots A1.0$$

Each complex symbol  $X[k]$  is an OFDM subcarrier and they are arranged in an orthogonal manner relative to each other. Multicarrier schemes are suitable for combatting channel frequency selectivity as each subcarrier can be said to experience an almost flat frequency response. As a result of this, multi user diversity (MUD) can be achieved whereby users (either attached to the Macro-cell or Femto-cell) are assigned subcarriers on which they have the best channel gain.

Aggregation of the subcarrier in both time and frequency domains as explained in section 2.9.2 and Fig. 2.5 leads to the creation of resource blocks (RBs), which are then presented as the physical channels that the transport channels are mapped onto for the transmission of MAC PDUs illustrated in Fig. A.2 over the air interface.

In multi-tier networks, orthogonalisation of RBs and intelligent scheduling at the MAC layer are crucial to minimising cross-tier and co-channel interference. Therefore, efficient coordination between the MAC sub-layer and the PHY layer is very important.

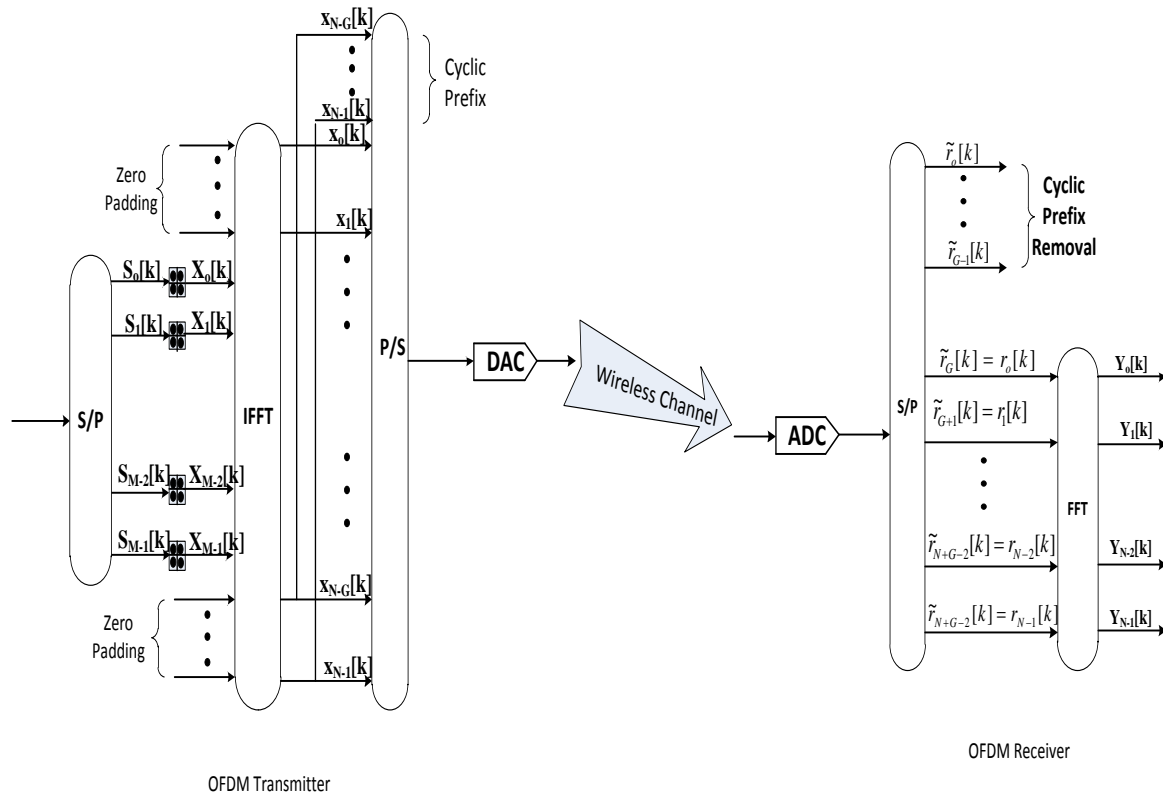


Figure A.4: OFDM System Model [47]

## Appendix B

This appendix presents the MATLAB codes used in evaluating the performance of the network prior to the deployment of Femto-cells and after Femto-cells have been overlaid on the Macro-cells in the network as explained in section 3.1 of chapter three.

The code was implemented in the Vienna LTE system level downlink Simulator which can be downloaded from [51]

```
close all force;
clc;
clear all
clear global;
clear classes;

simulation_type = 'tri_sector_tilted';
%simulation_type = 'tri_sector_plus_femtocells';

% Possible simulation types now:
% - 'tri_sector'
% - 'tri_sector_tilted', 'tri_sector_tilted_4x2', 'tri_sector_tilted_4x4'
% - 'tri_sector_plus_femtocells'
% - 'six_sector_tilted'
% - 'capesso_pathlossmaps'
% - 'omnidirectional_eNodeBs'

LTE_config = LTE_load_params(simulation_type);

%% If you want to modify something taking as a base the configuration file, do
it here: here an example is shown that changes the inter-eNodeB distances
based on the LTE_load_params_hex_grid_tilted config file.

% Some changes to the base configuration, in case you would need/want them
%LTE_config.show_network = 0;
LTE_config.show_network = 2;
LTE_config.frequency = 2000000000; %in Hz
LTE_config.bandwidth = 5e6;
LTE_config.nTX = 2;
LTE_config.nRX = 2;
LTE_config.tx_mode = 4;
LTE_config.scheduler = 'prop fair Sun'; % prop fair Sun %
round robin
LTE_config.shadow_fading_type = 'claussen';
LTE_config.compact_results_file = true;
LTE_config.delete_ff_trace_at_end = true;
LTE_config.UE_cache = true;
LTE_config.simulation_time_tti = 10; % in ms
LTE_config.UE_cache_file = 'auto';
LTE_config.adaptive_RI = 0;
LTE_config.keep_UEs_still = true;
LTE_config.UE_per_eNodeB = 2;
```

```
LTE_config.scheduler_params.av_window = 20;
LTE_config.map_resolution             = 10;
LTE_config.pregenerated_ff_file      = 'auto';
LTE_config.trace_version              = 'v1';    % 'v1' for pregenerated
precoding. 'v2' for run-time-applied precoding

output_results_file = LTE_sim_main(LTE_config);

simulation_data      = load(output_results_file);
GUI_handles.aggregate_results_GUI =
LTE_GUI_show_aggregate_results(simulation_data);
GUI_handles.positions_GUI      =
LTE_GUI_show_UEs_and_cells(simulation_data,GUI_handles.aggregate_results_GUI);
```

## Appendix C: List of Publications

The following conference presentation and paper have resulted from this dissertation:

1. Oluwadamilare D. Adeyemo and Mqhele E. Dlodlo, “An improved interference mitigation technique in LTE OFDMA Macro-cell-Femto-cell Networks,” A WIP presentation at “*South African telecommunication network and application conference (SATNAC)*”, August, 2014.
2. Oluwadamilare D. Adeyemo, Mqhele Dlodlo and Henry Ohize, “Mitigating Cross-tier Cross Boundary Interference in Fractional Frequency Reuse Scheme for Multi-tier Networks,” *IEEE symposium on Personal, Indoor and Mobile Radio Communications (PIMRC)*, Sept, 2015. (Submitted for review)