On Improving Performance of Victim Macrocell Users in LTE HetNets with Closed Access Femtocells

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Declaration

I declare that this written submission represents my ideas in my own words, and where ideas or words of others have been included, I have adequately cited and referenced the original sources. I also declare that I have adhered to all principles of academic honesty and integrity and have not misrepresented or fabricated or falsified any idea/data/fact/source in my submission. I understand that any violation of the above will be a cause for disciplinary action by the Institute and can also evoke penal action from the sources that have thus not been properly cited, or from whom proper permission has not been taken when needed.

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Approval Sheet

This Thesis entitled On Improving Performance of Victim Macro Users in LTE HetNets with Closed Access Femto cells by Deepa Martolia is approved for the degree of Master of Technology from IIT Hyderabad

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Dedication

To Dr. Bheemarjuna Reddy Tamma, Dr. Antony Franklin A, Vanlin Sathya and Anil Kumar Rangisetti for their guidance, support, and encouragement.

Abstract

Todays wireless and cellular networks demand a minimum data rate requirements for its users, as the users have apparently become dependent on mobile networks with the advent smartphones, tablets, and other wireless gadgets. These high expectations from users have given rise in traffic demand. Cellular operators are also looking for solutions to eradicate the network issues like call drops, choppy videos, and slow downloads. All of these trends will continue and have fuelled the interest of researchers in wireless and cellular networks. In order to attain the high data demand from users, operators are deploying new solutions in a coverage prone and highly populated cell areas. 3rd Generation Partnership Project (3GPP) introduced Heterogeneous networks (HetNets) in LTE-Advanced (Long Term Evolution - Advanced) for improving the experience of mobile users. The HetNets launched new network topologies, which are cost-effective and also improves the data rate of mobile users. However, dense deployment of these new network nodes can also bring a lot of challenges *i.e.,* interference control and management of new network nodes. Hence, 3GPP specified various interference mitigation technologies, which includes ICIC (Intercell interference coordination), Enhanced Intercell interference coordination (eICIC), and Further Enhanced Intercell interference coordination (feICIC). In this thesis, we focus on the cross-tier interference between Macrocell and Femtocell, and the performance enhancement of Victim Macrocell users. We also proposed a centralized algorithm, which provides coordination between interfering Femtocell (Closed Access Mode) and Macrocell, and offer a joint Almost Blank Subframe (ABSF) and power control scheme for Femtocell muting. The two prime metric discussed in our thesis are; **a)** attuning the transmission power during ABSF for Femtocell and then calculating the number of ABSF required, and **b)** determining appropriate subframes for muting an arbitrary Femtocell. Centralized algorithm tracks the state of Macrocell users. A Macrocell user is referred as Victim Macrocell user if the signal-to-interference-plus-noise ratio (SINR) value of Macrocell user degrades from the required threshold value. In this work, we performed only Femtocell muting to show the effect of dense deployment of Femtocells on Macrocell users. During ABSF muting Femtocell automatically adjusts its transmission power depending upon the level of interference suffered by Victim Macrocell users, which also minimizes the unnecessary degradation in Femtocell users performance. In order to increase the favorable chances of scheduling Victim Macrocell users during ABSF by its serving Macrocell, the centralized algorithm mutes Femtocells in a round robin fashion and eradicates unnecessary Femtocell muting. Our proposed scheme, RrMute compared with various other schemes and the simulation results show that RrMute enhances the performance of Victim Macrocell users, while simultaneously not jeopardizing the performance of Femtocell users.

Contents

Chapter 1

Introduction

A massive growth in mobile data traffic, smart devices, and bandwidth-consuming application are putting a strain on mobile operators Figure 1.1. As a result, mobile operators are opting network densification to attain the high traffic demand from user equipments (UEs). In the last decade, cellular networks have witnessed a phenomenal growth in mobile data traffic from indoor UEs. A recent survey by Cisco [1] [2] shows that 80% of the mobile data traffic consumption is because of indoor UEs, which is expected to grow even more in future. In an indoor scenario, electromagnetic signals from the outdoor base station have to penetrate through walls and floor of the buildings, which makes electromagnetic signals more vulnerable and indoor UEs will receive weak signal quality.

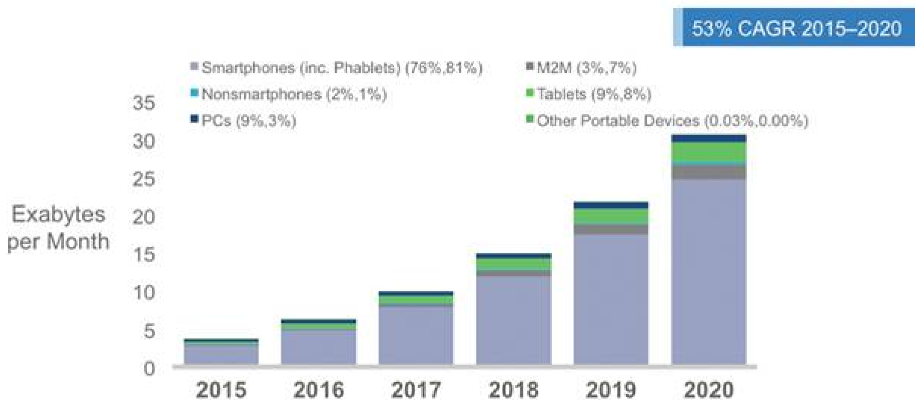

Figure 1.1: Mobile Traffic Growth Globally Source [1]

In order to address these challenges in the LTE standard, the new technology implemented, referred as LTE-Advanced and focus on increasing the system capacity through cell-splitting and frequency reuse. To accomplish these goals 3GPP introduced new low power nodes (*i.e.* Femtocell, Picocells) in the LTE network. Heterogeneous networks (HetNets) refers to the use of multiple varieties of low power access nodes in a mobile network/wireless network. These low transmit power nodes also known as small cells can significantly enhance the performance of UEs even in a densely populated area or in the coverage holes of the traditional Macrocell. 3rd Generation Partnership Project (3GPP) also introduced Femtocells to improve the coverage in home and office buildings, as fading and path loss can severely degrade the performance of indoor UEs. Dense Femtocell deployment is attracting too many mobile operators since the studies [1] [2] shows that most of the data consumption is because of indoor UEs. However, the dense deployment of the small cells brings bigger challenges like interference.

1.1 LTE Network

LTE stands for Long Term Evolution. Telecommunications organization 3GPP designed 4G wireless communications standard in LTE in 2008 to support high data rate around ten times of 3G networks for mobile devices like smartphones, netbooks, etc. The primary objective for LTE is to provide a high data rate, low latency, supporting flexible bandwidth deployments and its network architecture has been designed with the goal to facilitate UEs with seamless mobility and excellent quality of service.

Subframe Format and Downlink Transmission: In LTE, frame duration is of 10ms and each frame splits into ten subframes. Furthermore, each subframe contains two slots of duration 0.5ms; each slot carries 7 or 6 OFDM symbols, and the scheduler allocates RB on every subframe basis or TTI. Reader can refer [4] for more details.

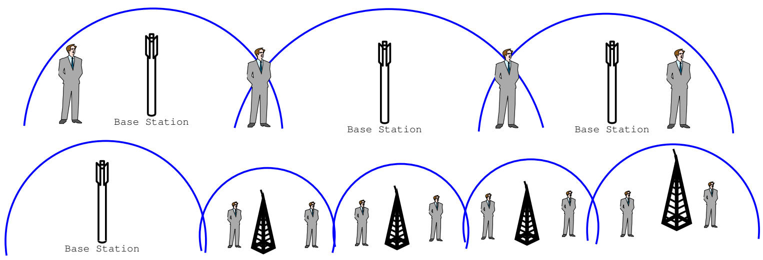

Figure 1.2: An Example of Cell Splitting

1.2 LTE HetNets

Cell spitting has emerged as a promising solution to improve the capacity of cellular/mobile networks. Cell spitting subdivides the cell region into smaller coverage chunk and serves those small coverage areas with low transmit power nodes, so that the coverage holes can be eradicated from the network Figure 1.2. LTE HetNets have a high potential to enhance the spectral efficiency and spatial reuse. The reason behind a huge success of LTE HetNets is the ever growing demand for high data rate services, which is a by-product of increasing myriad of smart devices and mobile applications. Mobile operators are opting for the dense deployment of small cells to relish the high data rate. However, a lack of planning, while deploying a multitude of small cells may cause severe interference (especially when small cell share the spectrum with Macrocell) and resulting in a reduced system capacity Figure 1.3.

In this chapter, we will provide a detail description of LTE Network Architecture. Challenges involved in LTE network, followed by the advent of LTE HetNets, and discussion about various interference scenarios in LTE HetNets.

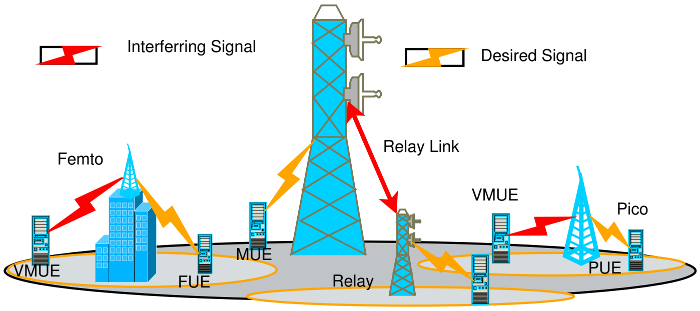

Figure 1.3: An Example of HetNets

1.3 Small Cells

In HetNets a variety of base stations exist such as Macrocell, low power nodes *i.e.,* Femtocell, Picocell, Relay nodes, and Remote Radio Head (RRH). These nodes vary in terms of their transmission power, coverage range, and access permission. Small cells are mainly integrated with the cellular network to improve the channel quality of indoor UEs, cell edge UEs and UEs served by a highly loaded cell. Small cell offload traffic from a Macrocell-only network to facilitate a UE, which is left deprived by a Macrocell and brings less congestion in the network. The inclusion of small cell in cellular network brings transmitter closer to a UE, which in turn enhances the spectral efficiency. Thus, HetNets will play a significant role in the future mobile networks.

1.4 Interference Mitigation in LTE HetNets

Despite all advantages discussed above for dense small cell deployment still, there are some challenges like co-tier and cross-tier interference are there. 3GPP specified Inter-Cell Interference Coordination (ICIC) in LTE release 8 and with the advent of LTE-Advanced (LTE-A) released Enhanced Inter-Cell Interference Coordination (eICIC). In this section first, we will discuss ICIC then followed by eICIC.

ICIC introduced to HetNets in 3GPP Release 8 and proposed a various solution for dealing with interference, some of the prime contributions [5] [6]. We will list down here.

Fractional Frequency Reuse: In this scheme, the spectrum is divided into two part one for cell-center UEs and other for cell edge UEs. Cell-center UEs will apply reuse one, and cell edge UEs will be using different reuse factor. The cell edge UEs will not use the same frequency used by another cell. Thus, the interference will get reduced. refer Figure 1.4 for better understanding.

Selective Power Reuse: In the downlink, the neighboring cell will use low transmit power for the cell-center UEs, and higher power for the edge UEs. Adjacent base stations will exchange RNTP (relative narrowband transmit power) messages over the X2 interface. RNTP contain information about, which resources limited by transmitting power, and adjacent base stations will avoid scheduling on those resources.

Cell Range Expansion: Typically in cellular networks, whenever a UE receives a signal strength from a base station better its current serving base station then it handovers its traffic to another base stations. The transmission power of the small cell (*i.e.,* pico cell is one example, pico cell are open access and usually deployed in an outdoor scenario) is lower than a Macrocell,

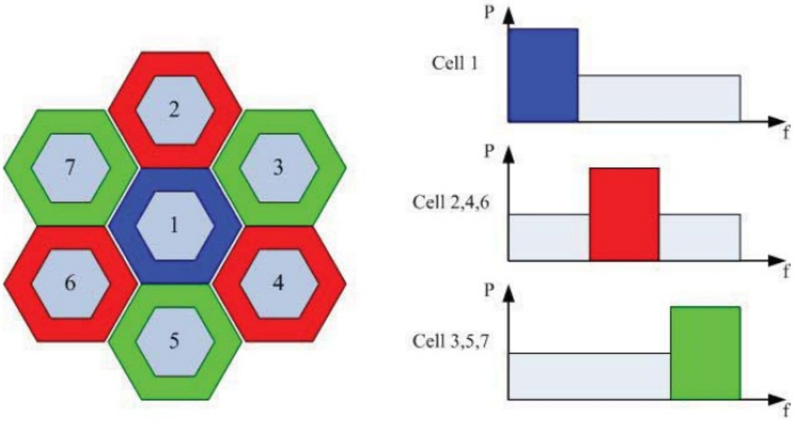

Figure 1.4: An Example of Fractional Frequency Reuse taken from [7]

which means it covers less cell area than a typical Macrocell. However, operators want to offload the data traffic from the Macrocell as much as possible to gain from the benefits of using small cells. In such a scenario, if a UE near to the pico cell but receives less signal strength from the pico cell as compared to the Macrocell then it tend to connect to the Macrocell, in such situation pico cells becomes underutilized. A positive cell bias value added to pico cells to ensure then that the UE will connect to pico cell even after receiving a less signal strength. This positive offset value takes care that the pico cell will not become underutilized and also improves Macrocell performance by offloading traffic from the Macrocell. Refer Figure 1.5 for better understanding.

Interference Overload Indication: In uplink, coordination between adjacent base station is achieved by exchanging X2 messages. Two X2 messages are defined, First is; High Interference Indicator (HII), second is; overload indication (OI). HII contains a bitmap, which indicates scheduling of cell edge UEs to reduce interference. OI reports when cell edge UEs suffers high interference and then whichever base station receives this messages it takes appropriate actions like reducing the transmission power.

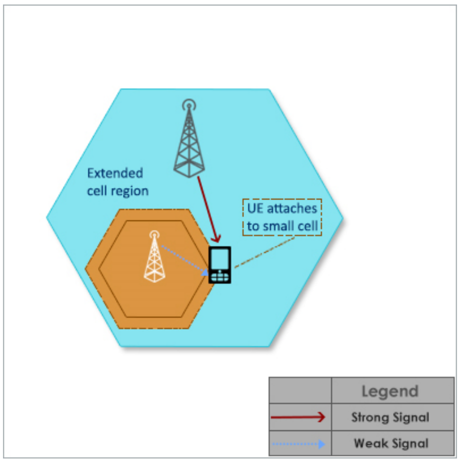

Figure 1.5: An Example of CRE for UE taken from [8]

3GPP specified new acronyms eICIC for handling interference in HetNets. The eICIC scheme added a new time domain solution for interference mitigation also referred to as ABSF. 3GPP added various specification in LTE to resolve the interference issues present in the HetNets.

ABSF: 3GPP introduced ABSF in LTE Release 10, as a time domain eICIC mechanism for interference mitigation in LTE HetNets. In order to assist the downlink transmissions of one the interfering tier, one interfering tier will mute some of its subframes also known as ABSF (*i.e.,* contain only control and cell reference symbols). During ABSF non-muted interfering tier will schedule its interfering UEs, then interfering UEs of a non-muting tier will suffer less interference and receive a better channel quality. These muted subframes are referred as almost blank because base station transmits only control and cell reference symbols over these subframes. Since these control and cell reference symbols occupy only a small fraction of all the OFDM symbols. Thus, the overall interference experienced by UEs of the non-muted base station will be much less during ABSF, and can achieve a significant performance improvement during ABSF, for more details please refer [8].

Interference scnenario with Femtocell: 3GPP specified Femtocells in LTE Release 9 to cope with coverage holes and high data demand of the indoor UEs. Typically, Femtocells are deployed on three distinct operating modes *i.e.,* Open Access (OA), Closed Access (CA), and Hybrid Access (HA). In OA mode, any UE in the cell range of Femtocell can get attached to it, but in CA mode, only a registered set of UEs (Closed Subscriber Group (CSG)) in Femtocell coverage range get access to it. HA mode; a combination of OA and CA, a limited set of radio resources reserved for non-CSG UEs. However, the unplanned and dense deployment of Femtocell may cause a significant decrease in SINR value of indoor UEs because of the cross-tier interference and a reduced electromagnetic signals in the presence of buildings. Hence, dense Femtocell deployment can satisfy the higher data rate requirement of UEs. But if deployed in an unplanned manner, it may cause severe degradation in overall network performance of outdoor-UEs or visiting-UEs.

Interference scenario with Picocell: Unlike Femtocells deployment Picocells are primarily deployed by operators. Picocells introduced in the cellular network for serving the UEs, which left deprived by macrocells and also to serve the cell region (highly loaded like malls, coverage holes like in skyscrapers). Picocells transmit power typically range from 23 to 30 dBm, which covers the cell region up to 300m depending upon the path loss received by UEs. Picocells are open access, which means any UE which receives a high signal strength from Picocell can get attached to it. The eICIC Proposal attracted the much attention for mitigating interference in HetNets like in Macrocell and Picocell interference. The eICIC proposal facilitates UEs for time sharing the spectrum for downlink, which provides UE a freedom to associate to a Picocell.

1.5 Problem Statement

The inclusion of small cell in traditional network significantly improves the data rate and excel the broadband experience of UEs irrespective of UE's location with low cost since spectrum reused in multiple areas in the network. However, the deployment of these small cells will also bring a lot of challenges since the bandwidth reused among base stations, which may cause interference with these base stations. Hence, an advanced Interference control and management techniques are required for these networks. In order to mitigate interference in such HetNets scenario, 3GPP introduced enhanced intercell interference coordination (eICIC).

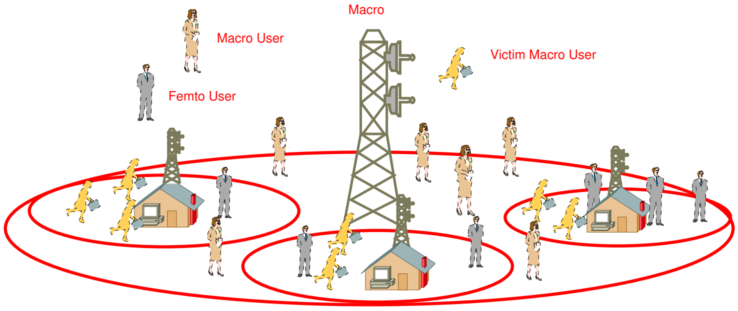

Figure 1.6: Cross-tier Interference between Macrocell and Femtocell

The eICIC revolves around two mechanisms, which includes CRE (Cell Range Expansion) realized through cell bias or cell association rules and ABSF (Almost Blank Subframe) achieved through muting certain subframes of base stations to assist the UEs of other interfering base stations. In eICIC, some of the subframes of interfering base stations are muted also known as ABSF (i.e., contain only control and cell reference symbols), and another interfering tier will schedule its interfering UEs during those muted subframes. Interfering UEs of a non-muting tier will suffer less interference and receive a better channel quality. Residential UEs prefer Femtocell in a closed access (*i.e.* only a registered set of UEs will able to get access to Femtocell) mode. Femtocells also share the spectrum with Macrocells, which causes cross-tier interference with the Macrocell and co-tier interference with other conflicting Femtocells. If a Femtocell configured in a closed access mode, then only Closed subscribers Group (CSG) UEs will be served by the Femtocell, which may create a severe interference scenario for conflicting Macrocell UEs (MUEs) or Victim Macrocell UEs (VMUEs) Figure 1.6. VMUEs will not be able to connect to the Femtocell, even after receiving a high signal strength and creates a more vulnerable interference than in the case of open access mode (*i.e.* no CSG defined any UE can get attached to the base station) interference scenario [3]. The mobile traffic demand of indoor UEs is increasing tremendously so does the number of Femtocells, which in turn triggers the growth of VMUEs. The application of ABSF enhances the channel quality of VMUEs. But at the cost of degrading the performance of the Femtocell (as Femtocell does not send any data during ABSF which becomes a prime cause of throughput degradation).

1.6 Organization of Thesis

In sections, we provided a brief description of each chapter, and the thesis organized as follows:

Chapter 2 - Related Work and Proposed Method: This section will go through various research done in the field of interference mitigation and considering different interference scenarios. This section also introduces to our proposed work and also explains every process that is incorporated and implemented in our proposed work. Problem formulation also covered in this chapter.

Chapter 3 - NS-3 Overview and ABSF Implementation Methodology: This chapter, enlightens your knowledge about the powerful network simulator NS-3 then we will also go through the main project of NS-3 LENA (as it used in our thesis work). We will also review the implementation details about ABSF in NS-3, then we analyze the simulation results considering various scenarios.

Chapter 4 -Conclusion and Future Work: Finally we will conclude the thesis with the conclusion and future work.

Chapter 2

Related Work and Proposed Algorithm

In this chapter, we provide an overview of research papers related to ABSF and power control for improving the performance of VMUEs. First, we will provide a detailed overview of research papers related to ABSF and some of the derivatives of ABSF as well that share a similar idea. Then we will also review papers related to Macrocell muting and issues related to those papers. Finally, we will discuss our proposed algorithm and how it tackles with the interference.

2.1 Related Work

In this section, we will provide a detailed description of research papers in corresponding to different eICIC solutions *i.e.* ABSF, power control, and frequency domain.

ABSF solution for improving VMUE's channel quality: The eICIC scheme proposed in LTE HetNets for cross-tier interference mitigation. In [9], authors proposed ABSF solution for enhancing the throughput of VMUEs and activates the ABSF mode at an interfering Femtocell via sending information using X2 interface. This work significantly improves the throughput of VMUEs but at the cost of severe degradation in Femtocell performance. The authors proposed a fixed ABSF patterns, which clearly does not consider the dynamic scenario. Furthermore, the ABSF pattern chosen are unable to differentiate between path-loss MUEs and VMUEs.

Derivatives of ABSF for improving VMUE's channel quality: Researchers have proposed various variants of ABSF, which requires the amendment in the standard ABSF. In [13], Macrocell reserves some resource blocks (RBs) for interfering UEs during ABSF then Macrocell scheduler allocates these reserved RBs to interfering UEs, which minimizes of throughput degradation at the Macrocell during ABSF as the Macrocell does not give all of its RBs but their proposed work does not consider the interference experienced by interfering UEs.

Power control and placement of Femtocell: The other domain explored is power control as power control can significantly reduce the interference among conflicting base station if managed properly. In [10], authors addressed the problem of VMUE's poor channel quality by combining the frequency allocation and power control techniques. They proposed an interference map, which used by a central entity for identifying the level of interference between Femtocells and UEs. The centralized entity provides information about all interfering scenarios. Authors claim that by limiting resource sharing among far neighbors, better throughput for VMUEs can be achieved. In another work [11], authors proposed a method for enhancing the performance of VMUEs via placement of Femtocells and dynamic adjustment in the transmission power of Femtocell. The author provides an algorithm for placement of Femtocells which one of influential paradigm and also provides power control technique for handling interfering UEs. Although power control can help in reducing interference among conflicting base station but can cause degradation at the cell site if applied for a longer duration.

Macrocell muting and eradicating unnecessary muting: In literature, there are some papers which address the issue of performance degradation at the Macrocell via ABSF application. In ABSF muted base station does not transmit any data during the period of ABSF which causes severe degradation at Macrocell site as it serves more UEs. In [12], authors propose the multitone muting for Macrocell, which states that instead of completely muting Macrocell during ABSF reduce the transmission power level during those muted subframes. Their work reduces the Macrocell throughput degradation during ABSF and also shows improvements in spectrum utilization. However, the transmission power level chosen during ABSF does not consider the degree of interference suffered by interfering UEs.

2.2 Proposed Algorithm

This chapter will introduce our proposed method RrMute and also gives a detail description of problem formulation and pseudo code used.

We considered LTE HetNets, where MUEs are categorized into two categories non-VMUEs and VMUEs. VMUEs distributed over the entire Femtocell coverage region and the interference suffered by VMUEs is proportional to the proximity of VMUE from its conflicting Femtocell. In RrMute, we sectorized the Femtocell coverage region into different cell area (refer Figure 2.2) according to Channel State Information (CSI) values received from VMUEs. By sectorization of Femtocell transmission region, a precise transmission power level can be chosen during ABSF (*i.e.,* higher interference suffered by VMUEs more reduction in transmission power of Femtocell required during ABSF and vice-versa). Note that a Macrocell is allowed to transmit to its UEs during non-ABSF periods as we are considering only Femtocell muting, which could lead to a good-enough performance to UEs very close to the Femtocell.

2.3 Detailed Discription

(a) **Global Information Center (GIC) :** RrMute proposes coordination among Femtocell and Macrocell for providing global information about all channels and interference scenarios. GIC (refer Figure 2.1) has a matrix ζ (Channel State Matrix). ζ is a 2D matrix, between UEs $\mathcal{U}$ and base stations ($\mathcal{F} \cup \mathcal{M}$) and used for tracking the channel conditions of MUEs then identifying VMUEs. ζ_x^i denotes RSRQ received by MUE x from an interfering Femtocell i, same applies for ζ_x^j as well. In our case, we are considering the indoor scenario and our algorithm uses the existing LTE CSI for constructing ζ. One major challenge comes with the centralized approach

Table 2.1: Notation and Abbreviation

Notation	Interpretation
$\mathcal{M}$, $\mathcal{F}$	Set of Macrocell, Femtocell and $i \in \mathcal{F}$, $j \in \mathcal{M}$
$\mathcal{U}$, x	Set of UEs, $x \in \mathcal{U}$, and $b \in (\mathcal{M} \cup \mathcal{F})$
x_i, x_j	An arbitrary UE x connected to Femtocell i and Macrocell j, respectively
$\mathcal{I}_{x_i}$, $\mathcal{I}_{x_j}$	Interference received by UE x_i, x_j
f, $f^{'}$	Number of Femtocells interfering with UE x_i and x_j, respectively
$\mathcal{G}_{i,x_i}$, $\mathcal{G}_{j,x_j}$	Channel gain between Femtocell i and UE x_i, Macrocell j and UE x_j, respectively
Phi_i, Phi_j	Maximum transmit power for Femtocell i and Macrocell j, respectively
$\mathcal{N}$, $\mathcal{R}_A$	Number of subframes and RBs per TTI
$\mathcal{FR}_d$, $\mathcal{SB}_d$	Frame duration, subframe duration
c_{x_b}	1 if UE x is connected to base station b, 0 otherwise
v	Number of VMUE in territory of an arbitrary Femtocell i
ϕ	Minimum interference bound denoting poor channel condition
ψ	Maximum interference tolerance bound
N_0, $\mathcal{C}_0$	Background noise and Constant 126
β	If β value is 4, then 4x4 MIMO antenna
$\mathcal{N}_{AB,i}$	Number of ABSF calculated per periodic run of algorithm respective to Femtocell i
$\mathcal{N}_{MAX_i}$	Maximum number of subframes allocated by Femtocell i
$\mathcal{M}_{ix}$	Throughput of VMUE x territory of Femtocell i
$\mathcal{D}_{min_f}$, $\mathcal{D}_{min_m}$	Minimum bit rate required for Femtocell UE (FUE) and MUE, respectively
$\mathcal{RB}_{x_j}$	RBs required by VMUE x connected to Macrocell j
$\mathcal{R}_{av,i}$	Average RB requirement per Femtocell i
$\mathcal{R}_{MAX,i}$	Maximum RBs given per TTI by Femtocell i
$\mathcal{D}_{ar_i}$	Bit rate per Femtocell i after application of ABSF.

is the delay, signaling overhead during communication with the base stations, and a strict time synchronization required by ABSF. As the core component of our algorithm, GIC placed with each Macrocell. Thus, delay and overhead can significantly be reduced.

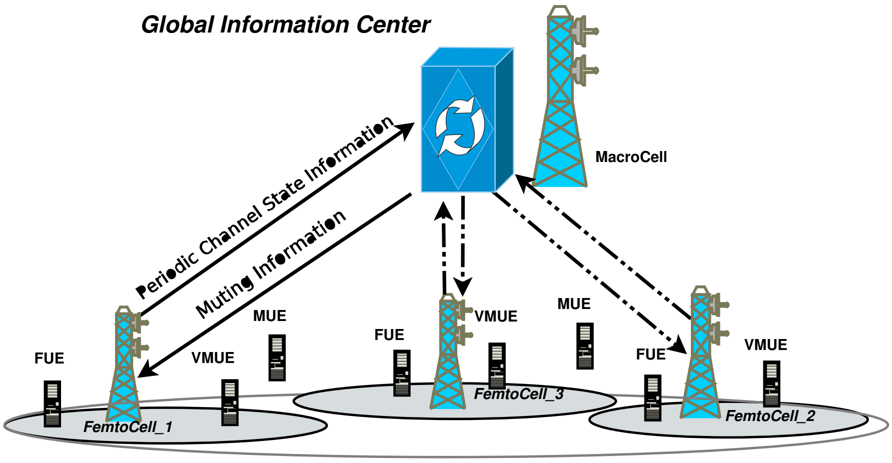

Figure 2.1: Interaction Between Femtocell/Macrocell and Global Information Center

(b) **Transmission Power :** ζ used for categorization of VMUEs in various groups. For each Femtocell, a category of its VMUEs determined by ζ. According to the class of VMUEs, a unique transmission power will be chosen. As in RrMute Algorithm, Femtocells are transmitting throughout the frame. Furthermore, Femtocell transmission power during ABSF is proportional to interference experienced by its VMUEs. Transmission power for the Femtocell i is $\rho(i)$, where $\rho(i) \in \mathcal{P}$ and $\mathcal{P} = \rho_1, \ldots, \rho_k$, k is interference category available and

$\psi \in \psi_1, \ldots, \psi_{k-1}$ represents interference bounds. If we consider $k = 4$ and $\psi_1, \ldots, \psi_{4-1}$ denote interference bounds, then transmission power chosen for the Femtocell i is given below.

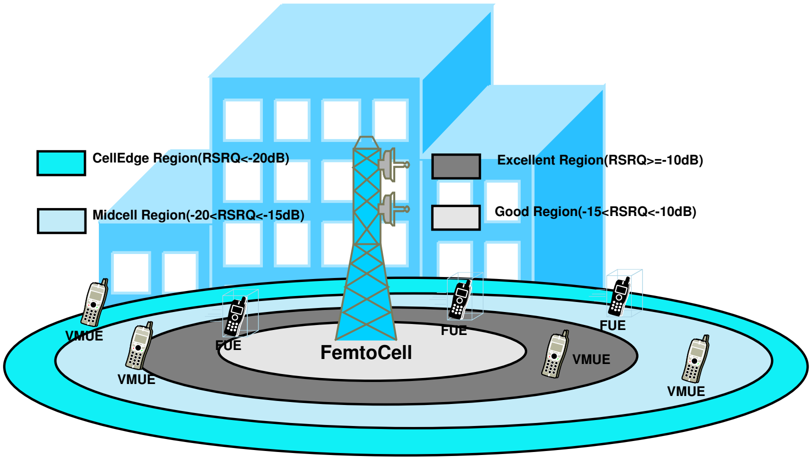

Figure 2.2: Categorization of UEs into four different Femtocell regions based on CSI

Round Robin Femtocell Muting: Consider a scenario as in Figure 2.3, where three Femtocells deployed in the cell region of one Macrocell and causing interference to MUEs. For each Femtocell subframe demand is calculated based on the number of VMUEs. Hence, the more VMUEs in the territory of Femtocells higher the subframe demand will be and vice-versa, refer Figure 2.4 for visualizations (**Figure 3.4, lines are not aligned properly**). The centralized algorithm defined Algorithm 1 first calculates the transmission power level and the number of ABSF for interfering Femtocell then Algorithm 2 finds the appropriates subframes for Femtocell muting. An example of round robin Femtocell muting shown Figure 2.4.

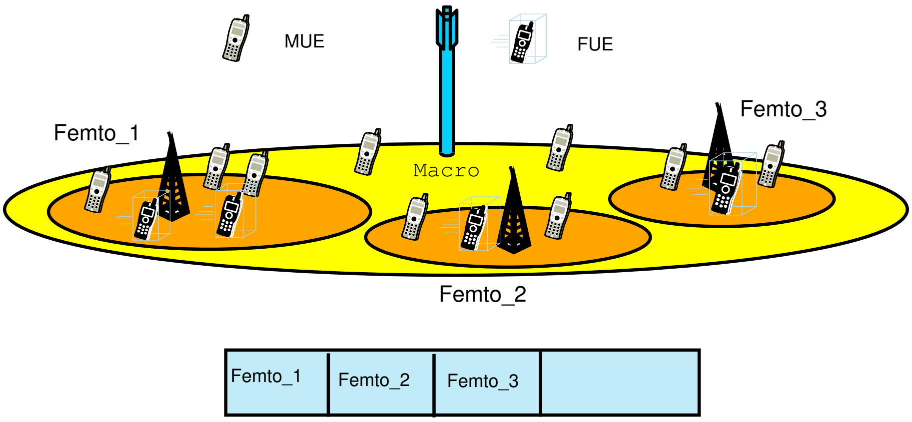

Figure 2.3: Round Robin Femtocell Muting

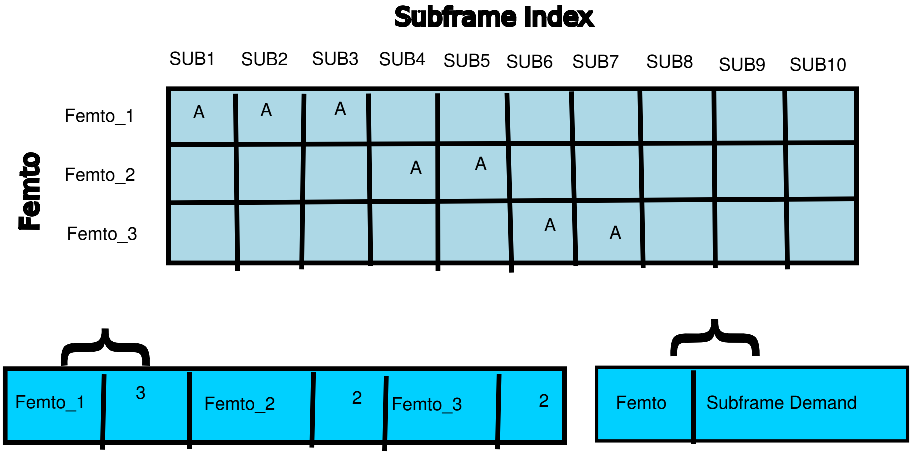

Figure 2.4: An Example of Subframe Allocation

$$\rho(i) = \begin{cases} \rho_1 & \zeta_x^i \leq \psi_1 \\ \rho_2 & \psi_1 \leq \zeta_x^i \leq \psi_2 \\ \rho_3 & \psi_2 \leq \zeta_x^i \leq \psi_3 \\ \rho_4 & \psi_3 \leq \zeta_x^i \end{cases} \tag{2.1}$$

$$\mathcal{I}_{x_i} = \begin{cases} Phi_j \times \mathcal{G}_{j,x_i} + \sum_{f'=1}^{f'} p(f') \times \mathcal{G}_{f',x_i}, & ABSF \\ Phi_j \times \mathcal{G}_{j,x_i} + \sum_{f'=1}^{f'} Phi_{f'} \times \mathcal{G}_{f',x_i}, & non\text{-}ABSF \end{cases} \tag{2.2}$$

$$\mathcal{I}_{x_j} = \begin{cases} \sum_{f=1}^{f} p(f) \times \mathcal{G}_{f,x_j}, & ABSF \\ \sum_{f=1}^{f} Phi_f \times \mathcal{G}_{f,x_j}, & non\text{-}ABSF \end{cases} \tag{2.3}$$

SINR calculation for FUEs:

$$SINR(x_i) = \begin{cases} \frac{p(i) \times \mathcal{G}_{i,x_i}}{\mathcal{I}_{x_i} + N_0}, & During\ ABSF \\ \frac{Phi_i \times \mathcal{G}_{i,x_i}}{\mathcal{I}_{x_i} + N_0}, & During\ non\text{-}ABSF \end{cases} \tag{2.4}$$

SINR calculation for MUEs:

$$SINR(x_j) = \begin{cases} \frac{Phi_j \times \mathcal{G}_{j,x_j}}{\mathcal{I}_{x_j} + N_0}, & During\ ABSF \\ \frac{Phi_j \times \mathcal{G}_{j,x_j}}{\mathcal{I}_{x_j} + N_0}, & During\ non\text{-}ABSF \end{cases} \tag{2.5}$$

As we considered the CA system, each UE (FUE or MUE) allowed to associate with only one base stations.

$$\sum_{b \in \mathcal{F} \cup \mathcal{M}} c_{x_b} = 1 \qquad \forall x \in \mathcal{U} \tag{2.6}$$

2.4 Problem Formulation

The objective function is to maximize the aggregate throughput of VMUEs, while maintaining the minimum bit rate requirement of FUEs as well as non-VMUEs.

$$\text{Maximize} \sum_{i=1}^{f} \sum_{x=1}^{v} \mathcal{M}_{ix} \tag{2.7}$$

$$\text{Subject to } \mathcal{D}_{ar_i} \geq \mathcal{D}_{min_f}, \quad i = 1, \ldots, f. \tag{2.8}$$

$$\mathcal{D}_{ar_x} \geq \mathcal{D}_{min_m}, \quad i = 1, \ldots, v. \tag{2.9}$$

Above constraints ensure, VMUE's throughput enhancement without degrading the performance of FUEs. However, according to [14], maximization of the aggregate performance of VMUE is an NP-Hard problem. Our Algorithm 1 considers the density of VMUEs inside the Femtocell coverage region and applies the power control on subframe level to achieve fair results in real time.

Algorithm formulates RB requirement according to the bit rate constraints of UEs.

$$\mathcal{RB}_{x_j} = \frac{\mathcal{D}_{min_m} * \mathcal{SB}_d}{\mathcal{C}_0 * MCS(SINR_{x_j}) * \beta} \tag{2.10}$$

$$\mathcal{RB}_{av,i} = \frac{\sum_{x=1}^{v} \mathcal{RB}_{x_j}}{v} \qquad \forall i \in \mathcal{F} \tag{2.11}$$

Femtocell bit rate requirement split into two different bit rates, during ABSF $\mathcal{D}_{AB,i}$ and during normal subframes $\mathcal{D}_{N,i}$ as an outcome of varying SINR.

$$\mathcal{D}_i = \begin{cases} \mathcal{D}_{AB,i}, & During\ ABSF \\ \mathcal{D}_{N,i}, & During\ non\text{-}ABSF \end{cases} \tag{2.12}$$

$$\mathcal{R}_{MAX,i} = \frac{\mathcal{D}_{min_f} * \mathcal{SB}_d}{\mathcal{C}_0 * MCS(SINR_{x_i}) * \beta} \tag{2.13}$$

$$\mathcal{N}_{AB,i} \leftarrow [min(\mathcal{RB}_{av,i} * v, (\mathcal{R}_A - \mathcal{R}_{MAX,i}))/\mathcal{R}_A] \tag{2.14}$$

$$\mathcal{D}_{ar_i} = \frac{\mathcal{D}_{AB,i} * (\mathcal{N}_{AB,i} * \mathcal{SB}_d) + \mathcal{D}_{N,i} * (\mathcal{N} - \mathcal{N}_{AB,i}) * \mathcal{SB}_d)}{\mathcal{FR}_D} \tag{2.15}$$

Algorithm 1 Algorithm for Finding Λ Map

Input : ζ_x^i, $x \in \mathcal{U}$, *and* $i \in \mathcal{F}$

Output : Λ,κ

Initialization : *Clear* Λ, κ, Γ

for each $x \in \mathcal{U}$ for j **do**
    if $\zeta_x^j \leq \phi$ **then**
        $flag \leftarrow false$
        for each $i \in \mathcal{F}$ **do**
            if $\zeta_x^i \neq \Upsilon$ and $\zeta_x^i \geq \psi$ **then**
                $\kappa_x.push(i)$
                $flag \leftarrow true$
                if $i \notin \Gamma$ **then**
                    $\Gamma.insert(i, \zeta_x^i)$
                else
                    if $\Gamma.find(i) < \zeta_x^i$ **then**
                        $\Gamma.insert(i, \zeta_x^i)$
                    end if
                end if
            else
                UEs x Interfering with Femtocell i
            end if
        end for
        if $flag \neq false$ **then**
            UE x Experiencing Interference
        else
            UE x Experiencing Pathloss
        end if
    else
        UE x Receiving Desired Signal Strength
    end if
end for
for $i \in \Gamma$ **do**
    Create a tuple for Λ_i
    $\Lambda_i.Power \leftarrow \rho(i)$ $\longrightarrow$ Equation (2.1)
    $\Lambda_i.MutedSub \leftarrow \mathcal{N}_{AB}$ $\longrightarrow$ Equation (2.14)
    $\Lambda.insert(i, \Lambda_i)$
end for

2.4.1 Algorithm for finding Λ map

Identification of VMUE of Femtocell i can be determined from ζ, considering the conditions $\zeta_x^j \leq \phi$, $\zeta_x^i \neq \Upsilon$ and $\zeta_x^i \geq \psi$. Algorithm 1 constructs Λ map, which maps Femtocell i with appropriate transmission power level (*i.e.,* equivalent to VMUEs interference level) and ABSF requirement (*i.e.,* proportional to the number of VMUE in the territory of i). Femtocells interfering with MUE x_j can be represented κ_{x_j}. Υ denotes no interference scenario between Femtocell and MUE. Λ_i indicates the value of optimal muting power during ABSF and pattern (*i.e.,* number required ABSF and their interval according to each Femtocell i) for i. Γ is an intermediate map, which used for getting actual Λ map. Γ_i contains a vector of ζ_x^i values according to each VMUE, which resides in the territory of a Femtocell i. Apart from VMUEs detection and non-uniform muting discussed above, UEs prioritization during scheduling done on the core principles of Proportional Fair Scheduling Algorithm [15]. p is a total number of UEs available. At the beginning of each subframe τ, each RB group r, and for each UE a priority metric gets calculated as follows:

$$\mathcal{PM}(\tau)_r = \underset{x=x_1,\ldots x_p}{\arg\max} \frac{\mathcal{AR}_x(r,\tau)}{\mathcal{TT}_x(\tau)} \tag{2.16}$$

$\mathcal{AR}_x(r,\tau)$ is maximum achievable rate in subframe τ, $\mathcal{TT}_x(\tau)$ total data transmitted in previous subframes. UE x_i with highest $\mathcal{PM}(\tau)_r$ value gets opportunity to get scheduled.

2.4.2 Algorithm for finding Ω queue

Algorithm 2 finds the Ω queue, which stores the information about interfering Femtocell and used to perform non-uniform ABSF muting. $\Omega_i.subD$ represents the number of subframes for which i needs to mute, $\Omega_i.timer$ number of ABSF, $\Omega_i.powL$ Optimal transmission power level during ABSF. In Algorithm 2 a round robin Ω queue for Femtocell muting form. Although, Algorithm 2 can be modified according to various other metrics like UEs priority, Femtocell muting constraints. In our algorithm, we chose a scenario where all UEs and Femtocells have equal priority.

Algorithm 2 Algorithm for Formation of Ω

Input : Λ , Ω, *and* $i \in \mathcal{F}$
Output : Ω

Use Λ *map to determine* Ω
for each $i \in \Lambda$ **do**
    if $i \notin \Omega$ **then**
        Create a tuple for a new i
        $\Omega_i.cellid \leftarrow \Lambda_i.cellid$
        $\Omega_i.subD \leftarrow \Lambda_i.MutedSub$
        $\Omega_i.timer \leftarrow \Lambda_i.MutedSub$
        $\Omega_i.powL \leftarrow \Lambda_i.Power$
        insert Ω_i *at the end of* Ω
    else
        Override the previous subframe demand for i
        $\Omega_i.subD \leftarrow \Lambda_i.MutedSub$
        $\Omega_i.timer \leftarrow \Lambda_i.MutedSub$
        remove Ω_i *from* Ω
        insert Ω_i *at the end of* Ω
    end if
end for
for each $i \in \Omega$ **do**
    if $i \notin \Lambda$ **then**
        Remove Tuple $\Omega_i \in \Omega$
    end if
end for

Chapter 3

NS-3 Overview and ABSF Implementation Methodology

In this chapter, we will get along with the powerful network simulator NS-3 used in this thesis. We will also discuss LENA-LTE/EPC project of NS-3 network simulator and various models included as part of LENA project. Followed by ABSF implementation in NS-3, then we will discuss the simulation results acquired from the different scenarios and analyze the simulation results.

3.1 Overview of NS-3 and LENA- LTE/EPC

The programming language used to build NS-3 includes c++ and python (which is available using Python bindings), and it is a discrete-event network simulator [16]. NS-3 primarily designed for research, development, and educational purposes, and it is also an open-source, GNU GPLv2 license software. However, a vast majority of researchers are focused on network simulations, which involve models like Wi-Fi, WiMAX, and LTE. Furthermore, NS-3 provides a framework for simulations, which are more realistic in nature and it's also backward compatible with NS-2. NS-3 developers or UEs do not have to write the code from scratch as they can also modify the existing models to fulfill their requirements.

LENA is an open source NS-3 project developed for mobile network simulations, and it provides researchers a test bed to design and validate the performance of their algorithms related with areas like HetNets, eICIC, etc. LENA is an open source project that why it benefited heavily from the open source community, and it also includes the various model, which are as follows.

∗ **Radio Propagation Models:** it includes, building models, path loss models, fast fading models, and antenna models. Building model used in our thesis for generating the indoor scenario.

∗ **Phy Model:** Only frequency division duplex (FDD) implemented, time granularity is per TTI basis, and frequency granularity is resource block (RB) basis. CQI feedback also included.

∗ **HARQ model:** It calculates the overall success probability of transmission taking into consideration the retransmission attempts also integrated with the PHY error model. HARQ managed by the scheduler.

* **MAC and Scheduler model:** In this model, RBs are allocated per TTI in the form of RB groups by default the size of RB group 3 RBs. LENA included propositional fair and round robin. Scheduler model also calculates the Modulation and Coding Schemes (MCS) from SINR received from the UE.

3.2 Implementation Details

During ABSF one of the interfering base station does not exploit the data channels, and another interfering base station will transmit. In this way, interfering UEs of non-muted base stations will receive less interference. The above procedure needs to identify some of the important points, which discussed as follows.

Identifying VMUEs: In order to exploit ABSF thoroughly, the algorithm requires to identify VMUEs in the territory of Femtocells. By analyzing UEs RSRQ values, the algorithm determines whether the less RSRQ is a by-product of interference or path loss. For differentiation between VMUEs and non-VMUEs, a map constructed between base stations and UEs. The identification process runs after every 120ms (in our implementation setup) in case static and less depending upon the VMUE's speed. Our algorithm is centralized and, many people have doubt about the centralized scheme with the delay and processing speed but as our centralized algorithm runs at each Macrocell, which results in less backhaul delay.

Scheduler enhancement: One of the main changes we have to make in the scheduler code is to ensure that the UEs of the Femtocell (as we are muting Femtocell in our work) will not get scheduled during ABSF. Thus, we made changes in the PfFfMacScheduler::DoSchedDlTriggerReq method of Proposition fair scheduler. We also ensured that VMUEs would get scheduled only during ABSF because during non-ABSF there received SINR is very less, which will unnecessarily waste the resource even if the Proposition fair scheduler allocates resource to VMUEs. During ABSF Femtocell transmits with reduced transmission power and only control and cell-specific signals transmission will take place, which can also be transmitted with lesser MCS values as the data needs to transfer is very less.

CQI calculation: CQI calculation is of paramount significance for implementing ABSF because if the scheduler does know about the improved CQI value of VMUEs during ABSF, then it will transmit data with less MCS value, which in turn constitutes in very less data rate received by VMUE.

3.3 Simulation Results

We considered an LTE HetNets (Femtocells (CA Mode)) scenario, where both Macrocell and Femtocell share the same radio spectrum. Implementation of our algorithm uses open-source LENA simulator NS-3.24 and for validation, we compared RrMute with three other different approaches. As discussed in previous sections, we simulate power level muting based on the degree of interference suffered by VMUEs and also need to ensure fairness among VMUEs and non-VMUEs. Thus, we modified the propositional fair scheduler code and physical layer files. In our work we have considered only downlink transmissions.

Table 3.1: Simulation Parameter

Parameters	Value
System	HetNet in LTE-A
Channel Bandwidth	10MHz
Number of Macrocells and Femtocells	1 and 4, respectively
Macrocell Transmission Power	46dBm
Femtocell Transmission Power	23dBm
Number of FUE per Femtocell	5
Minimum Distance between Macrocell and Femtocell	300m
Application	TCP bulkSendApplication
Antenna Type	Omnidirectional Antenna
Scheduler	Proportional Fair
Frequency Reuse	1
Path-Loss Model	OhBuildingsPropagationLossModel

3.3.1 Comparative eICIC scheme:

NoeICIC: VMUEs experience a poor signal quality as no eICIC mechanism applied.

OpTPowSub: OpTPowSub first calculates the number of ABSF and then attunes transmission power (refer Algorithm 1) for an interfering Femtocell. OpTPowSub implements uniform Femtocell muting or in other words, all interfering Femtocells in the entire system do not follow any pattern while muting. If we mute all interfering Femtocells at the same time or without following any Femtocell muting pattern, then the number of VMUEs to be scheduled at the Macrocell scheduler during ABSF will increase. Although scheduler will give preference to VMUEs over regular UEs, as it will assign resources to some of the VMUEs then those VMUEs, which does not get resources during ABSF, will unnecessarily degrade the performance of an interfering Femtocell. Therefore, the Macrocell scheduler is unable to perform efficiently.

RrMute: Non-uniform Femtocell muting is of paramount significance to make sure that VMUEs exploit the ABSF thoroughly, VMUEs needs to get scheduled during ABSF by its serving Macrocell. Unlike OpTPowSub, where interfering Femtocells while muting does not follow any pattern, RrMute mutes Femtocells in a round-robin fashion and VMUEs in the territory of muted Femtocell will get scheduled by its serving Macrocell, which eradicates the unnecessarily Femtocell muting. RrMute performs in a two-tier algorithmic scheme, first tier; OpTPowSub scheme will be responsible for assigning appropriate transmission power and number of ABSF, second tier; carries out a round-robin based Femtocell muting which ensures a guaranteed bit rate to all UEs (refer Algorithm 2). Hence, by performing two-layer algorithmic approach RrMute vanquishes all the flaws discussed above with OpTPowSub.

ABSF: Femtocell will only transmit the control and reference signal unlike OpTPowSub and RrMute, which is the prime cause of throughput degradation.

3.3.2 Simulation Results Discussion for Static Scenario

All UEs are static (including FUEs and MUEs), 20 non-VMUEs deployed in Macrocell coverage region. FUEs, VMUEs kept inside the building (*i.e.,* each building served by a Femtocell), and each Femtocell has 5 VMUEs trapped in its territory and total 4 Femtocells deployed in the macrocell

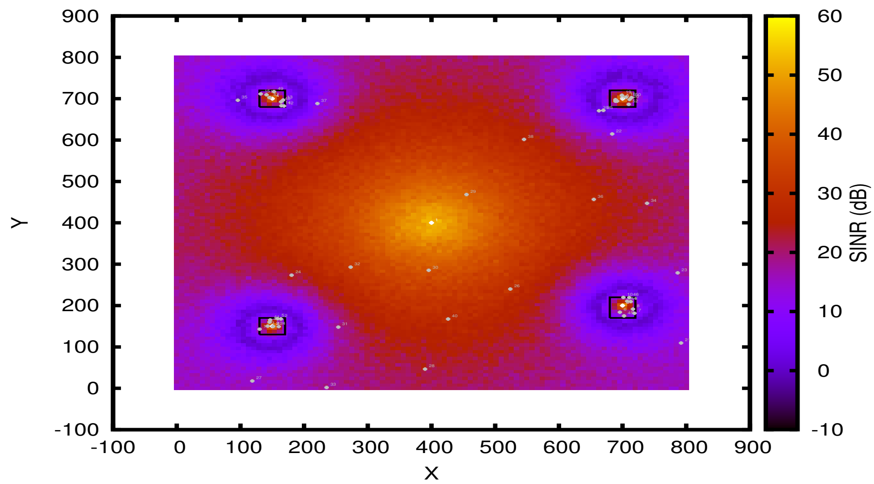

Figure 3.1: REM Acquired from Simulation Setup

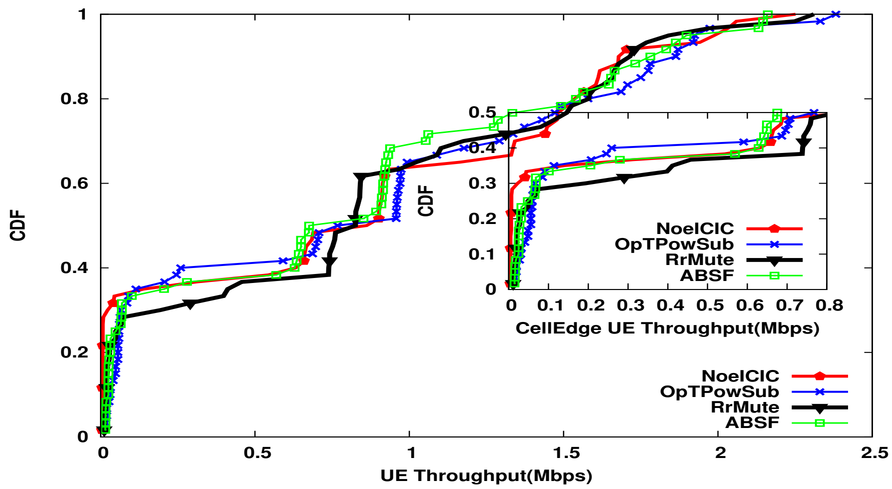

Figure 3.2: CDF Plot for all UEs and Inner CDF Plot Depicts Throughput Enhancement for Interference Experiencing VMUEs

coverage region. Refer Figure 3.1 for REM Plot. As seen in Figure 3.3, OpTPowSub, RrMute, ABSF significantly improves throughput of VMUEs. ABSF achieves a maximum enhancement in VMUE's performance (*i.e.,* no data transmission taking place while muting). In the case of OpTPowSub and RrMute, data transfer at a Femtocell is still taking place during ABSF but with reduced transmission power, which gives RrMute less degradation in Femtocell throughput and while enhancing the Macrocell throughput. The performance degradation minimized in OpTPowSub and RrMute Refer Figure 3.4. Femtocell throughput degradation minimized by of 12.9% (in the case of OpTPowSub and RrMute) as compared to ABSF while enhancing the Macrocell throughput by 4.6% and 11.9% times in case of OpTPowSub and RrMute respectively. Femtocell throughput degradation in OpTPowSub is almost same as RrMute. Whereas, RrMute gives more channel improvement to MUEs as compared to OpTPowSub (Refer Figure 3.5) by 7.3%. In Figure 3.2 shows that RrMute enhances throughput of 42% of UEs (Inner CDF plot) while maintaining the fairness among all UEs.

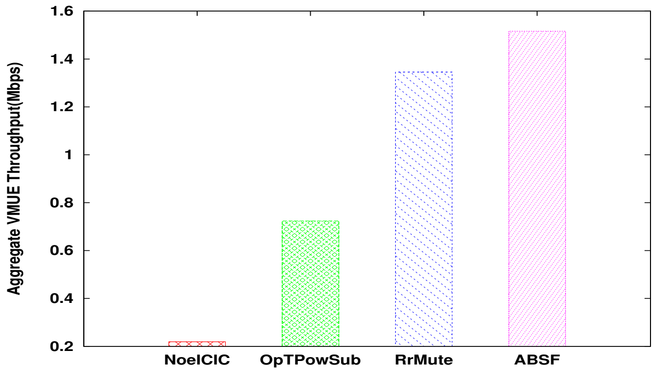

Figure 3.3: Aggregate VMUE Throughput

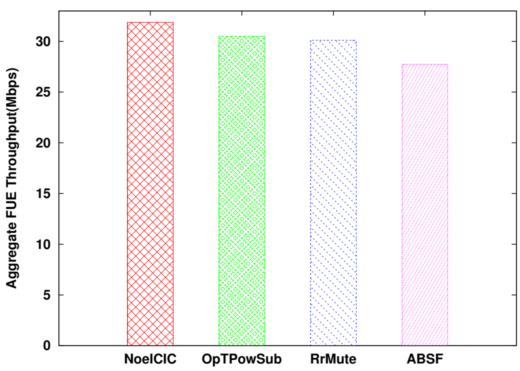

Figure 3.4: Aggregate FUE Throughput

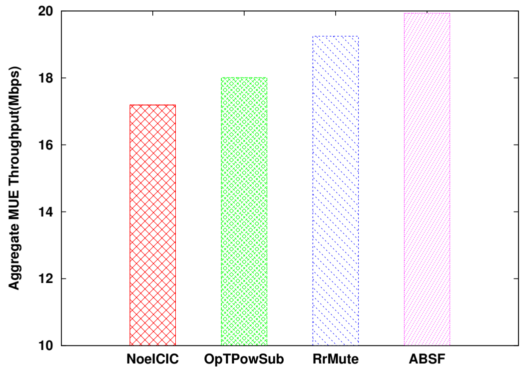

Figure 3.5: Aggregate MUE Throughput

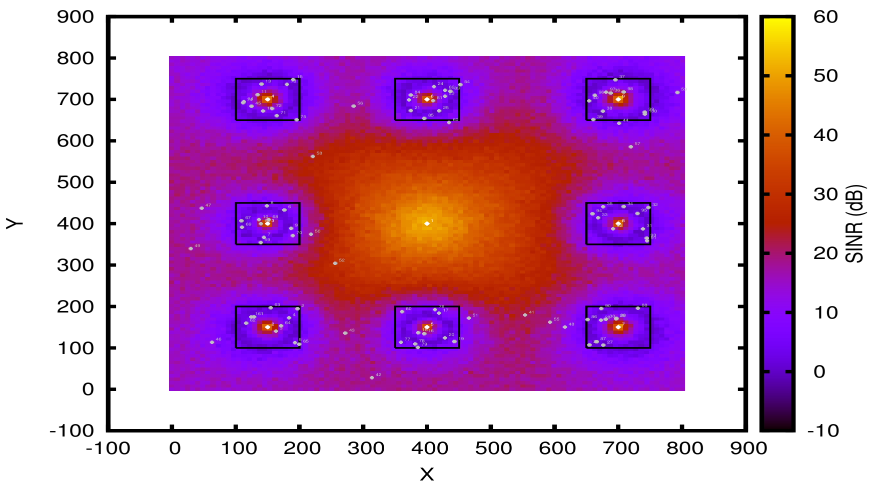

Figure 3.6: REM Acquired from Simulation Setup

3.3.3 Simulation Results Discussion for Dense Scenario

In this scenarios all UEs are static (*i.e.,* including MUE and FUE), 60 (to make the network dense we increased the number of UEs) non-VMUEs deployed in Macrocell coverage region. FUEs, VMUEs kept inside the building (*i.e.,* each building served by a Femtocell), and each Femtocell has 5 VMUEs

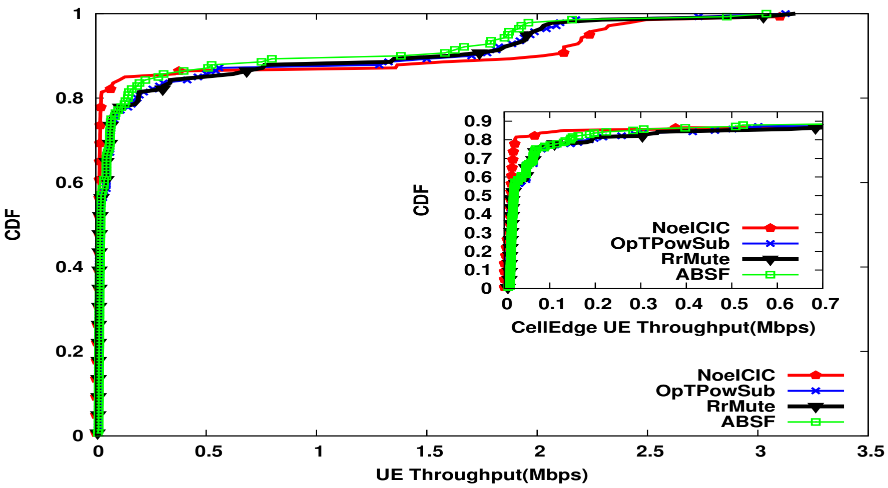

Figure 3.7: CDF Plot for all UEs and Inner CDF Plot Depicts Throughput Enhancement for Interference Experiencing VMUEs

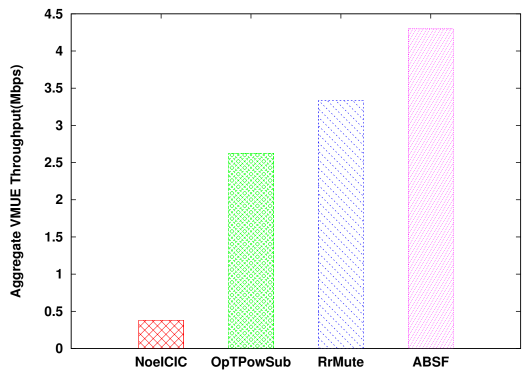

Figure 3.8: Aggregate VMUE Throughput

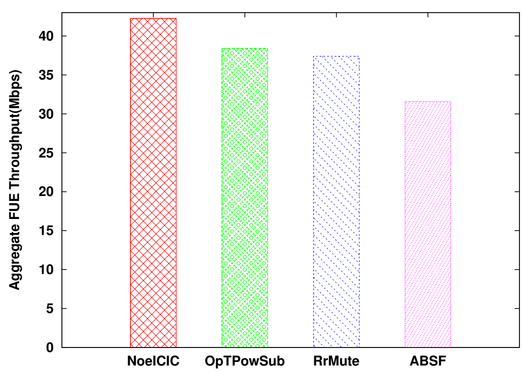

Figure 3.9: Aggregate FUE Throughput

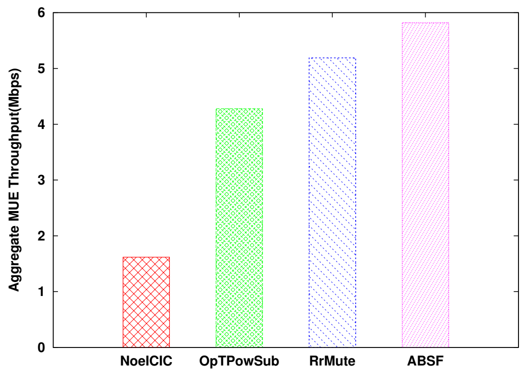

Figure 3.10: Aggregate MUE Throughput

trapped in its territory. Refer Figure 3.6 for REM Plot. As seen in Figure 3.8, OpTPowSub, RrMute, ABSF significantly improves throughput of VMUEs. ABSF achieves a maximum enhancement in VMUE's performance (*i.e.,* Femtocell transmitting only control and cell-specific reference signal resulting improvement in SINR for MUEs). In the case of OpTPowSub and RrMute, data transfer at a Femtocell is still taking place during ABSF but with reduced transmission power (Femtocell reduces its transmission power during ABSF results in improvement in SINR value received via MUEs), which gives RrMute less degradation in Femtocell throughput and while enhancing the Macrocell performance. The performance degradation minimized in OpTPowSub and RrMute Refer Figure ??. Femtocell throughput degradation minimized by of 16% (in the case of OpTPowSub and RrMute) as compared to ABSF while enhancing the Macrocell throughput by 2.6 times and 3.23 times in case of OpTPowSub and RrMute respectively. Femtocell throughput degradation in OpTPowSub is almost same as RrMute. Whereas, RrMute gives more channel improvement to MUEs as compared to OpTPowSub (Refer Figure 3.10) by 0.63 times. In Figure 3.7 shows that RrMute enhances throughput of cell edge UEs (Inner CDF plot) while maintaining the fairness among all UEs.

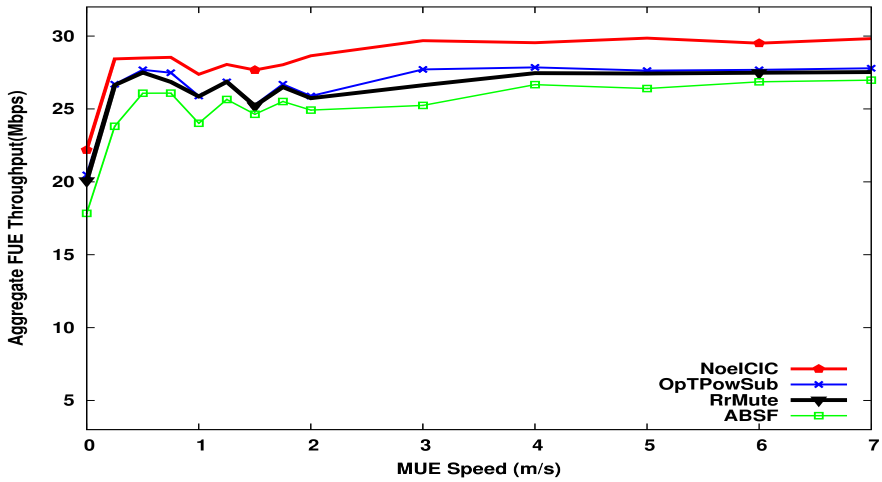

Figure 3.11: FUE Throughput

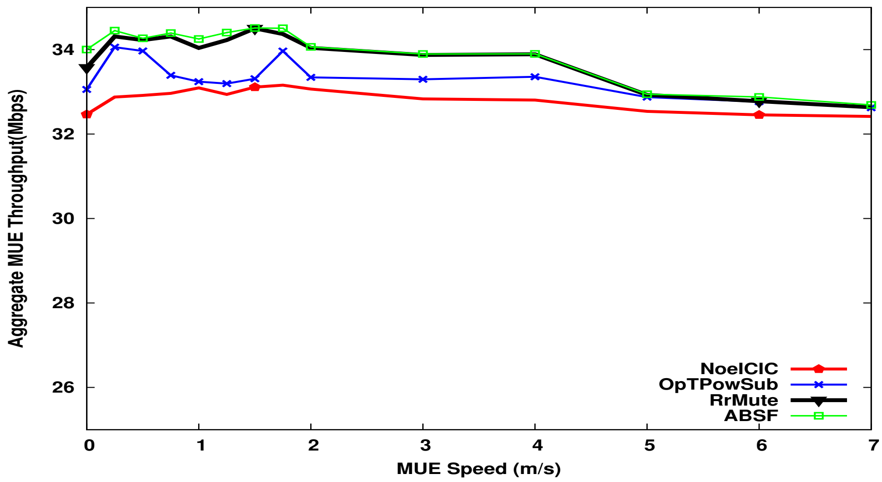

Figure 3.12: MUE Throughput

3.3.4 Simulation Results Discussion for Mobile Scenario

In this setup MUEs are moving with speed 0.25 m/s to 7 m/s uniformly across macrocell coverage region and FUEs are static (*i.e.,* deployed inside Femtocell coverage area). Refer Figure 3.1 for REM Plot. Simulation results (Figure 3.12) shows that an average Macrocell throughput enhancement in the case of OpTPowSub, RrMute, and ABSF is 1.48%, 3.05%, and 3.37% respectively, as compared to NoeICIC. On the other hand, the average degradation at Femtocell (Figure 3.11) is of 6.58%, 7.01%, and 13.20% in the case of OpTPowSub, RrMute, and ABSF respectively, as compared to NoeICIC. RrMute achieves an average of 6.19% less degradation in FUE's throughput as compared to ABSF and also enhances the performance of MUEs (Figure 3.12) by 3.05% and 1.57% as compared to NoeICIC and OpTPowSub respectively. Therefore, RrMute reduces the throughput degradation of FUEs during ABSF and simultaneously enhances the performance of MUEs. OpTPowSub starts deteriorating as the number of interfering Femtocell or VMUE increases. RrMute is amenable to dense setup as well as RrMute provides more favorable opportunities for scheduling MUEs or VMUEs during ABSF.

Chapter 4

Conclusions and Future Work

In this work, we have implemented three different eICIC mechanisms, ABSF, OpTPowSub and RrMute. Simulation Results show that RrMute enhances throughput of VMUEs and simultaneously minimizes the performance loss at a Femtocell during ABSF. In our simulation, we found that, if we place Femtocell very close to Macrocell then Femtocell signal starts deteriorating. Hence, the placement of Femtocells is also one of the influential paradigms on which one should focus. Another trend we found with UE's speed if UE's speed is higher, then the identification of VMUEs period should be shorter because if UEs moves with high speed, then there will more SINR variation for UE as compared to the static scenarios. In our future work, our focus will be on co-tier interference.

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