PROVISIONING QOS GUARANTEES FOR HANDOVER CONTROL IN INTEGRATED FEMTOCELL-MACROCELL NETWORKS

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BONAFIDE CERTIFICATE

Certified that this project report titled **PROVISIONING QOS GUARANTEES FOR HANDOVER CONTROL IN INTEGRATED FEMTOCELL-MACROCELL NETWORKS** is the *bonafide* work of **APARNA S (2011103002)**, **SHALOMI GRACE J (2011103021)** and **HARINI U (2011103512)** who carried out the project work under my supervision, for the fulfillment of the requirements for the award of the degree of Bachelor of Engineering in Computer Science and Engineering. Certified further that to the best of my knowledge, the work reported herein does not form part of any other thesis or dissertation on the basis of which a degree or an award was conferred on an earlier occasion on these or any other candidates.

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ABSTRACT

Predictions show that most of the data traffic in the future will originate from indoor environments. Using the current macrocellular cover in environments with high traffic is difficult and expensive. Femtocells are low-power cellular base stations that provide an alternate method of expanding coverage with increased data rates. An integrated femtocell-macrocell network offers improved coverage, Quality of Service (QoS), reduces cost and helps in power saving.

The provision of QoS in an integrated network needs to consider the large number of Femtocell Access Points (FAPs) and interference between macrocells and femtocells. Procedures like resource allocation, interference management and handover control influence QoS. A key element for guaranteeing QoS is seamless handover between the macrocell and femtocell networks. Handovers may occur frequently due to the small size of femtocells. Therefore, efficient decision algorithms for handover between femtocells and macrocells are necessary.

The proposed system comprises of two algorithms: macrocell-to-femtocell and femtocell-to-macrocell handover decision, in which the velocity of the User Equipment (UE), Received Signal Strength (RSS) and several other factors are inspected. The algorithms aim to enhance QoS parameters like throughput and spectral efficiency and reduce packet loss ratio, handover latency and packet delay. The efficiency of the handover strategy is tested with respect to various QoS parameters.

ABSTRACT

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LIST OF ABBREVIATIONS

AP	Access Point
ARP	Allocation and Retention Priority
BW	Bandwidth
BS	Base Station
BE	Best Effort application
CAC	Call Admission Control
CSG	Closed Subscriber Group
CRRM	Cognitive Radio Resource Management
CBR	Constant Bit Rate application
CN	Core Network
HeNB	Femtocell
FAP	Femtocell Access Point
FGW	Femtocell GateWay
GBR	Guaranteed Bit Rate
HO	Handover
IP	Internet Protocol
IMS	IP Multimedia Subsystem
LTE	Long-Term Evolution
eNB	Macrocell
MAC	Media Access Control
PSR	Packet Success Rate
QCI	QoS Class Identifier
QoS	Quality of Service

RNC	Radio Network Controller
RSS	Received Signal Strength
SLA	Service Level Agreement
TCP	Transmission Control Protocol
UE	User Equipment
VoIP	Voice Over Internet Protocol application

CHAPTER 1

INTRODUCTION

Femtocells are low-power cellular base stations that provide an alternate method of expanding coverage with increased data rates. Integrated femtocell-macrocell networks are used to expand the coverage area with increased data rates and better QoS. However, mobile network topology changes when mobile nodes move from one place to another. One key element is to ensure that seamless cover is perceived by the user when moving onto or off a femtocell.

1.1 PROBLEM DOMAIN

The focus of the research is on enhancing QoS during handover in integrated femtocell-macrocell networks.

1.2 PROBLEM DESCRIPTION

Handover in integrated networks may occur in three ways. Inbound transfer is a handover from the macrocell (standard cellular network) to a femtocell. Outbound handover takes place from a femtocell to a macrocell. The third kind of handover occurs from one femtocell to one of its neighboring femtocells. Handovers to and from femtocells are more challenging as the backhaul network is different and there is little possibility of direct communication between the femtocell and the macrocell.

QoS parameters include handover latency, packet loss, jitter, location update cost, end-to-end packet delay, bit rate, QCI (QoS Class Identifier), packet error ratio, synchronization, Allocation and Retention Priority (ARP) and out of order delivery. Handovers may have adverse effects on the QoS provided to the user. It is essential to perform handover without compromising the offered QoS.

Conventional algorithms for femtocell-macrocell handover do not take a comprehensive set of QoS parameters into account, which may lead to inefficient usage of bandwidth and ping-pong effect.

1.3 SCOPE

The project concentrates on handover strategies available in integrated femtocell-macrocell networks. A handover decision algorithm that maintains a fairly constant level of QoS in the network is proposed. A comparative analysis of the efficiency of the proposed and conventional systems is done.

1.4 CONTRIBUTIONS

The proposed system is designed to provide optimized QoS-aware handover methods in integrated femtocell-macrocell networks. Algorithms for hand-in and hand-out which aim to minimize handover latency, increase throughput, provide optimal packet success rate (PSR), minimize handovers and ensure a reasonably constant service type to mobile users are proposed. Modules of the project will include implementation of various entities in the network and the handover decision algorithm taking into account various QoS parameters and predicted motion of the user devices.

1.5 ORGANIZATION OF THE THESIS

The remainder of the thesis is organized as follows. A comprehensive study of related research ideas is presented in Chapter 2. The merits and limitations of each approach are summarized. An analysis of the requirements for the proposed research is detailed in Chapter 3. Chapter 4 outlines the design principles and constraints of the system to be developed. Chapter 5 describes the algorithms proposed. The results obtained from simulations of the proposed system are analyzed in Chapter 6. A summary of the findings and limitations of the system is given in Chapter 7.

CHAPTER 2

RELATED WORK

An integrated femtocell-macrocell network can be viewed as a two-tier hierarchical network where macrocells form the upper tier and femtocells form the lower tier. Although this configuration reduces the load of the macrocell, many technical issues relating to radio resource management, end-to-end QoS support for network architecture, handover control and mobility management arise because the two networks co-exist.

2.1 QOS CONSIDERATIONS IN INTEGRATED FEMTOCELL-MACROCELL NETWORKS

Saba Al-Rubaye et al. (2011) [1] highlighted the potential of cognitive femtocells to allow for higher capacity and intelligent coverage, with guaranteed quality of service for future indoor services. The main idea was to achieve the requested QoS for users in indoor environments. The available white holes in the spectrum are used to either transmit or buffer data according to the time slot available.

Chowdhury et al. (2013) [2] proposed an evolutionary path from a macrocell network to an integrated femtocell-macrocell network architecture and suggested solutions to the QoS provisions of such a network. A mechanism that involves sharing frequency bands between femtocells and macrocells was presented to solve the issue of Frequency and Interference Management. An SLA framework ensuring QoS and a basic architecture of handover procedures were also proposed.

A modified handover procedure between macrocell and femtocell networks was proposed by Kim et al. (2010) [3] which handles voice call services. Unnecessary handover in hybrid access is reduced through Call Admission Control (CAC).

2.2 MOBILITY-BASED HANDOVER PROCEDURE IN INTEGRATED NETWORKS

Direct communication between femtocells and macrocells does not exist. Algorithms for handover from a macrocell to a femtocell, as proposed by Chowdhury et al. (2010) [4], require mechanisms that send signals to the Femtocell Gateways (FGW) connected through the Radio Network Controller (RNC) and the Core Network (CN). The macrocell interacts with a registration database which maintains an authorized neighbor Femtocell Access Point (FAP) list to select the appropriate femtocell to which handover should occur.

Several algorithms for optimized handover between femtocells and macrocells exist. One such algorithm (Rath et al. 2012)[5] factors the speed of the User Equipment (UE) into the handover decision function. A mobile UE may be in one of two modes based on its speed- the Swift mode or the Free mode. A UE is in the Swift mode if it moves at a speed higher than the threshold; it is in the Free mode otherwise. Swift mode does not allow a handover to occur from one femtocell to another femtocell. Handover between femtocells is possible only when the UE is in the Free mode.

The speed of the UE can also be used to determine if handover occurs between femtocells or between a femtocell and a macrocell, as proposed by Shih Jung Wu (2011) [6]. Two threshold velocities v1 and v2 are fixed, such that v1 $>$ v2. The velocity of the UE is checked against the threshold velocities and handover occurs based on available bandwidth and whether the service is for a real-time application or not. Handover decisions vary for Closed Subscriber Group (CSG) and non-CSG equipments.

Challenges of mobility management in integrated networks with emphasis on cell identification and search, access control and cell selection were detailed by Xenakis et al. (2014) [7]. Depending on the handover decision criteria, existing HO decision algorithms were classified and a comparative summary of the main decision parameters was obtained.

2.3 RADIO RESOURCE AND INTERFERENCE MANAGEMENT IN INTEGRATED NETWORKS

In a femtocell-macrocell network, additional parameters need to be considered to ensure that interference caused during a handover is minimal. Several approaches exist to reduce interference in such integrated networks.

Saquib et al. (2012) [8] proposed a few interference management approaches which include cooperation among macrocell base stations, clustering femtocells, and accessing the spectrum intelligently. A power-control approach was highlighted and a quantitative comparison between the different interference management approaches was included. With efficient interference management techniques, femtocells can be used to increase network capacity and coverage so that both subscribers and providers are satisfied.

An LTE-based MAC scheduling algorithm was devised by Zaki et al. (2011) which assigns the radio resources between the priority users by differentiating between different QoS classes. User channel conditions were also considered by the scheduler to establish QoS guarantees.

Shao-Yu Lien et al. (2010) [9] proposed a cognitive radio resource management (CRRM) scheme where the femtocell can autonomously sense the radio resource usage of the macrocell so as to mitigate interference. By analytical deriving the effective capacity of the CRRM that specifies the QoS guarantee capability of the system, the optimum sensing period and radio resource allocation are proposed for the CRRM to achieve a fully radio resource utilization while statistically guaranteeing the QoS of the femtocell.

Chandrasekhar et al. (2008) [10] highlight the technical challenges that arise when we consider femtocell networks. Radio frequency interference occurs between femtocells and macrocells due to near-far effects and low transmit power. The challenge of allocating spectrum in the presence of interference and providing timing synchronization in femtocells is addressed here. For physical and medium access layers, cross-tier interference can be eliminated by allocating different frequency bands.

2.4 QOS-AWARE HANDOVER STRATEGIES IN MOBILE IP NETWORKS

Sroka et al. (2003) [11] evaluates QoS-conditionalized Binding Update approach for handover scenarios in mobile IP networks with several parameters such as handover latency, packet success rate and binding updates per successful handover. In cellular networks, such handover takes place with the help of routers, called QoS entities as they are responsible for maintenance of QoS resources. If a handover request is sent, resource availability in the desired Access Point (AP) is checked. The handover takes place only if the resources are available, which is indicated by a positive feedback. A negative feedback is sent otherwise. In such a case, handover can occur through a different path, with a lower QoS level or the handover request can be rejected.

Yutu Liu et al. (2004) [12] proposed an open, fair, dynamic and secure framework to evaluate the QoS of a vast number of web services in order to enable quality-driven web service selection. It is modeled in such a way that the web services that meet requesters functional requirements is able to locate and bound dynamically from a large and constantly changing number of service providers based on their Quality of Service (QoS).

2.5 OBSERVATIONS OF THE SURVEY

It is evident that research has been carried out for optimizing handover in integrated femtocell-macrocell networks. However, an absence of QoS-aware handover mechanisms in integrated networks is recognized. Thus, there is a pressing need for efficient handover decision algorithms that take QoS requirements into account.

CHAPTER 3

REQUIREMENTS ANALYSIS

The integrated femtocell-macrocell network architecture is depicted in Figure 3.1. The environment comprises of a macrocell base station (eNB), a femtocell gateway (FGW), several femtocells (HeNB) and user equipments (UE). The UEs may be in the femtocell or macrocell network.

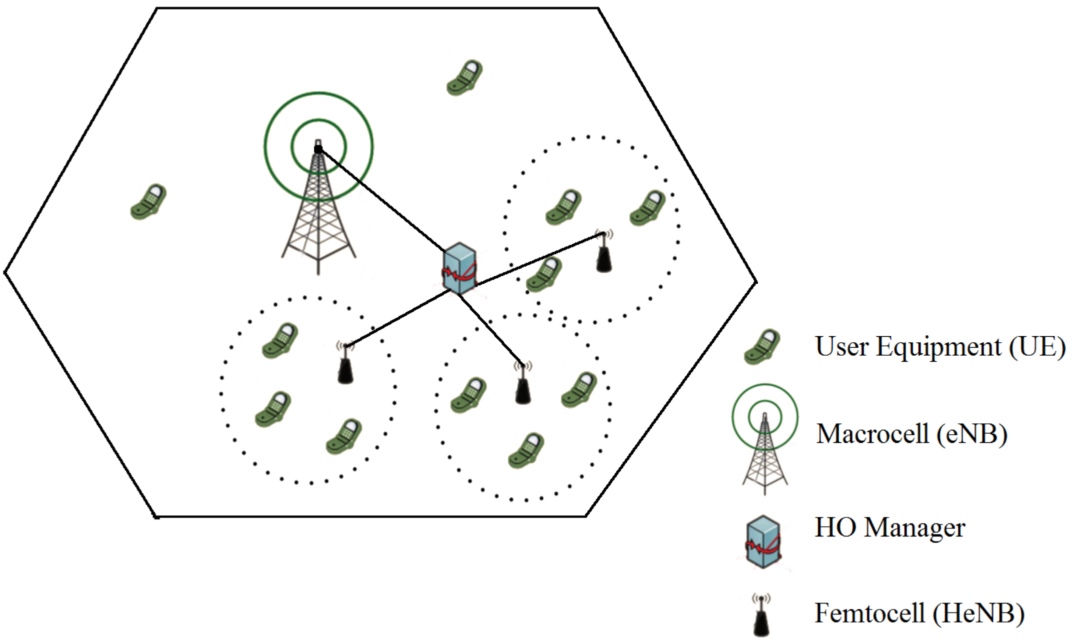


Figure 3.1: Network Architecture

3.1 HARDWARE AND SOFTWARE REQUIREMENTS

The system is implemented using the LTE-Sim network simulator and works well in a Linux-based environment.

3.2 FUNCTIONAL REQUIREMENTS

The system is required to enhance QoS during handover in integrated networks.

3.2.1 Use Case

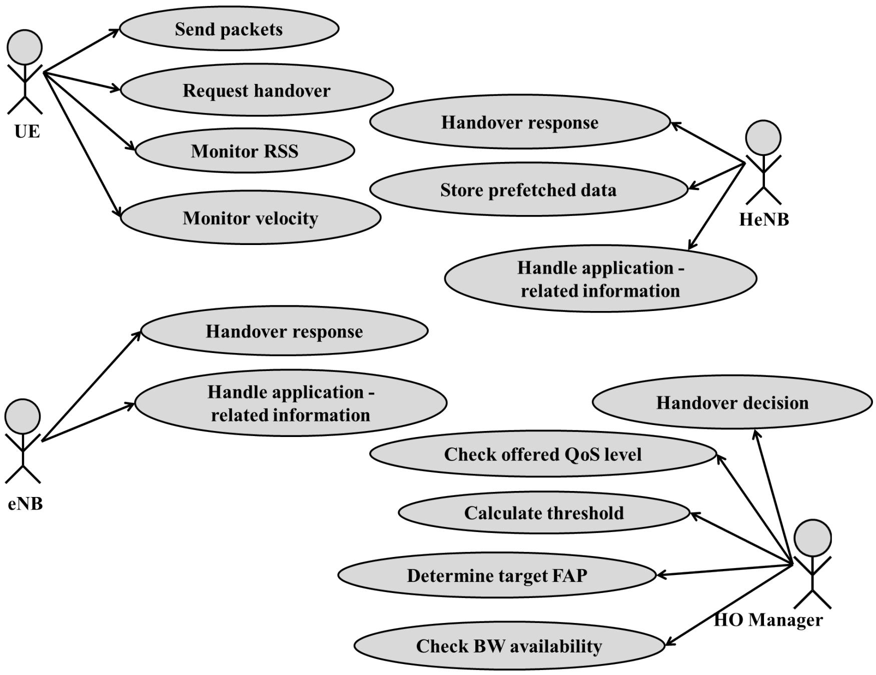


Figure 3.2: Use case specification

Figure 3.2 illustrates the functions performed by the different entities in the integrated environment.

3.3 NON-FUNCTIONAL REQUIREMENTS

The system executes the handover decision algorithm in the HO Manager. To ensure that QoS is not compromised during handovers, it is necessary to fix appropriate threshold values, taking into account the QoS parameters and the type of service requested by the user. We also propose a motion prediction algorithm that helps in choosing an optimal target cell after the handover decision is made.

3.3.1 Hand-in Sequence

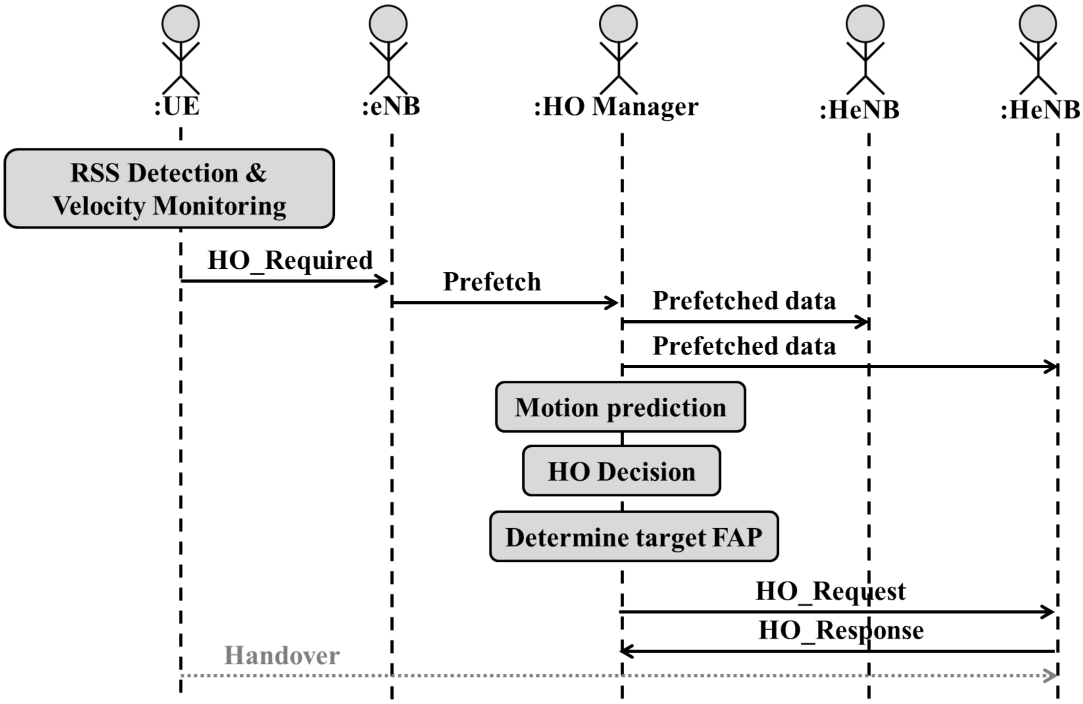


Figure 3.3: Hand-in Sequence

Hand-in occurs when a UE moves from a macrocell to a femtocell. Prefetching data to neighboring femtocells helps reduce handover latency. Handover is then executed to the most favorable femtocell access point. Figure 3.3 summarizes the hand-in sequence.

3.3.2 Hand-out Sequence

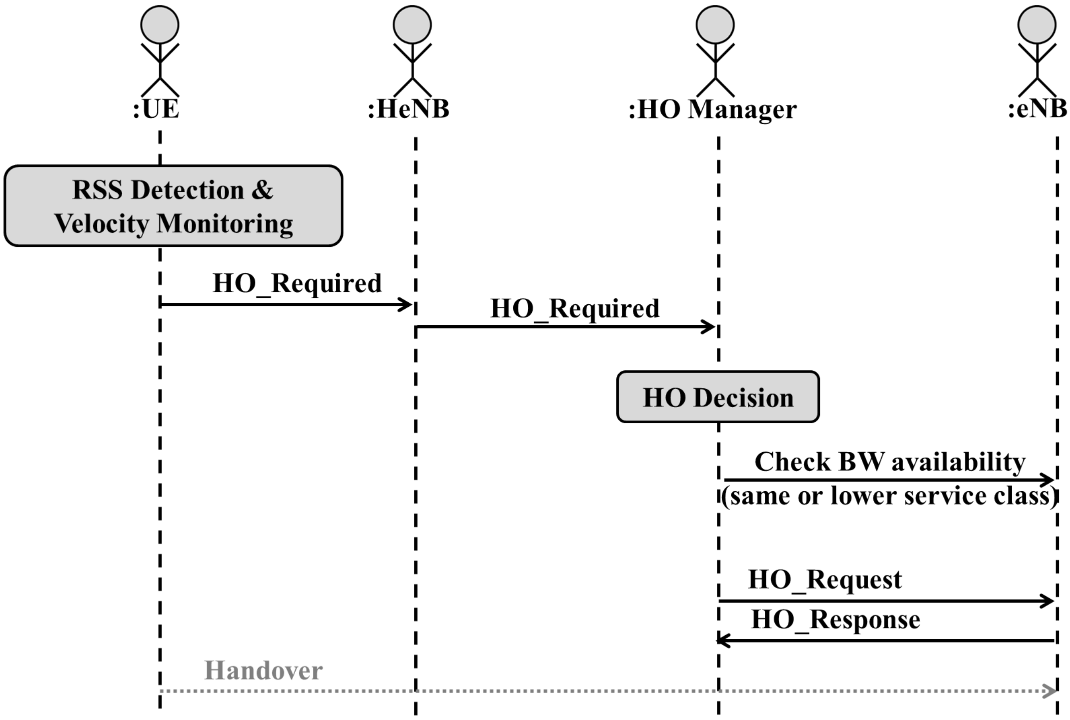


Figure 3.4: Hand-out Sequence

A handover to a macrocell when a UE moves out of a femtocell is termed hand-out. The hand-out sequence is detailed in Figure 3.4. If the available bandwidth is insufficient, handover is done using a lower service class.

CHAPTER 4

SYSTEM DESIGN

In accordance with the functional and non-functional requirements of the system, a handover decision algorithm is proposed. The network architecture consists of macrocells, femtocell access points and UEs. Communication between the macrocell base station and the femtocells is not possible directly. The femtocell gateway acts as an intermediate entity that facilitates communication between them.

4.1 TOP LEVEL BLOCK DIAGRAM

The Received Signal Strength (RSS) and the velocity of the UE are continuously monitored. If HO (Handover) is required, an HO-Required signal is sent to the entity that initiates the handover process. If the UE is currently in the macrocell network, the signal is sent to the macrocell Base Station (BS). The signal is sent to the HO Manager if the UE is currently in the femtocell network. The top level block diagram for the system is shown in Figure 4.1.

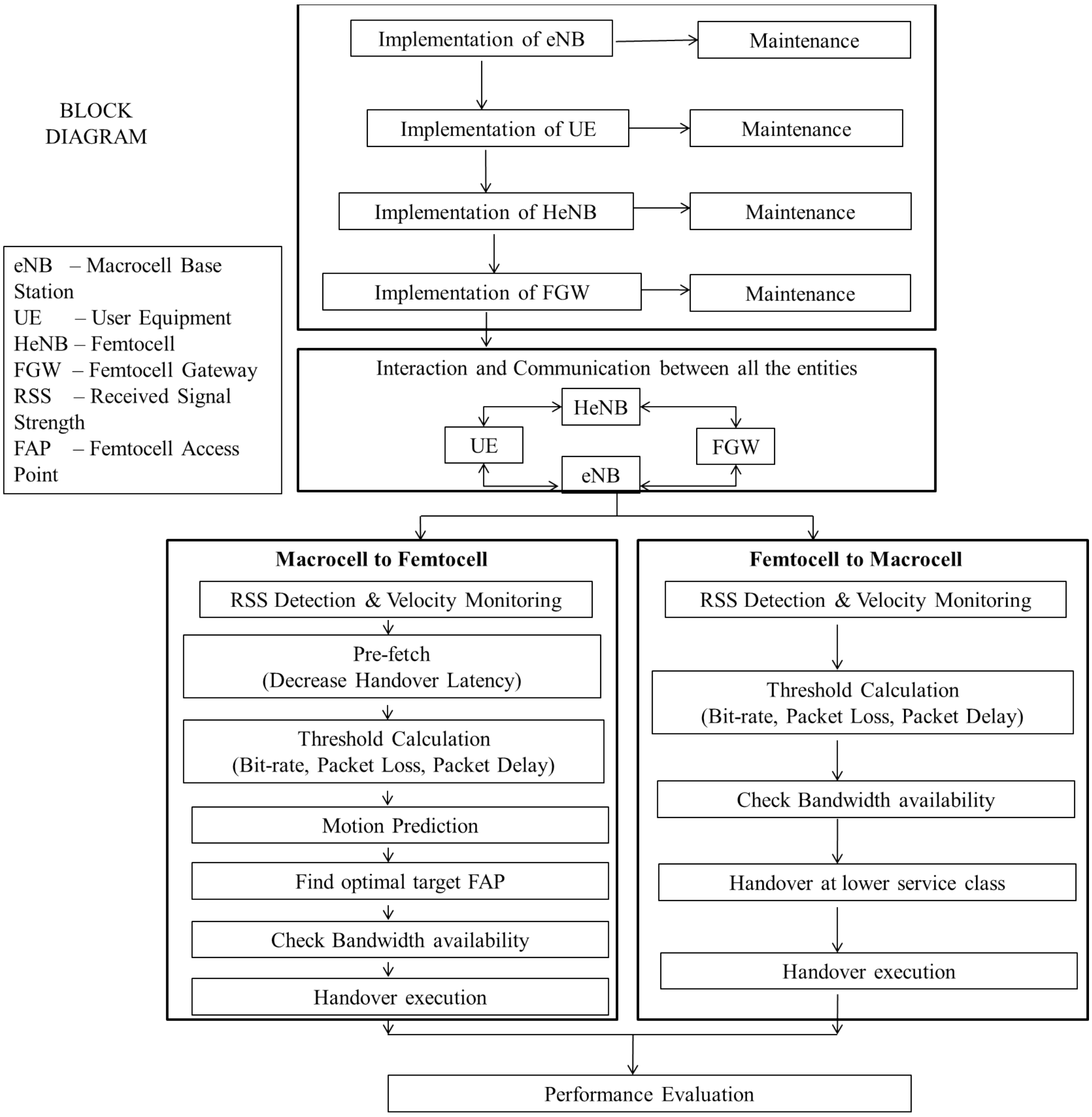


Figure 4.1: Top Level Block Diagram

4.2 HANDOVER DECISION ALGORITHM

The handover decision algorithm in Figure 4.2 inspects the RSS and velocity of the UE.

When the UE is in the macrocell network and the RSS is diminishing, data is prefetched to the neighboring femtocells to reduce handover latency. The threshold value is calculated using the service class and the type of application in use.

The velocity of the UE is compared against the threshold value. Optimal target FAPs are found using the motion prediction algorithm.

Handover is executed when the velocity is less than the threshold value.

For handovers from a femtocell to other cells, a similar procedure is used to compute the threshold value. Frequent inter-femtocell handovers are reduced by shifting UEs that are moving very fast to the macrocell. Handover at lower service class is possible from a femtocell to a macrocell, if bandwidth is insufficient.

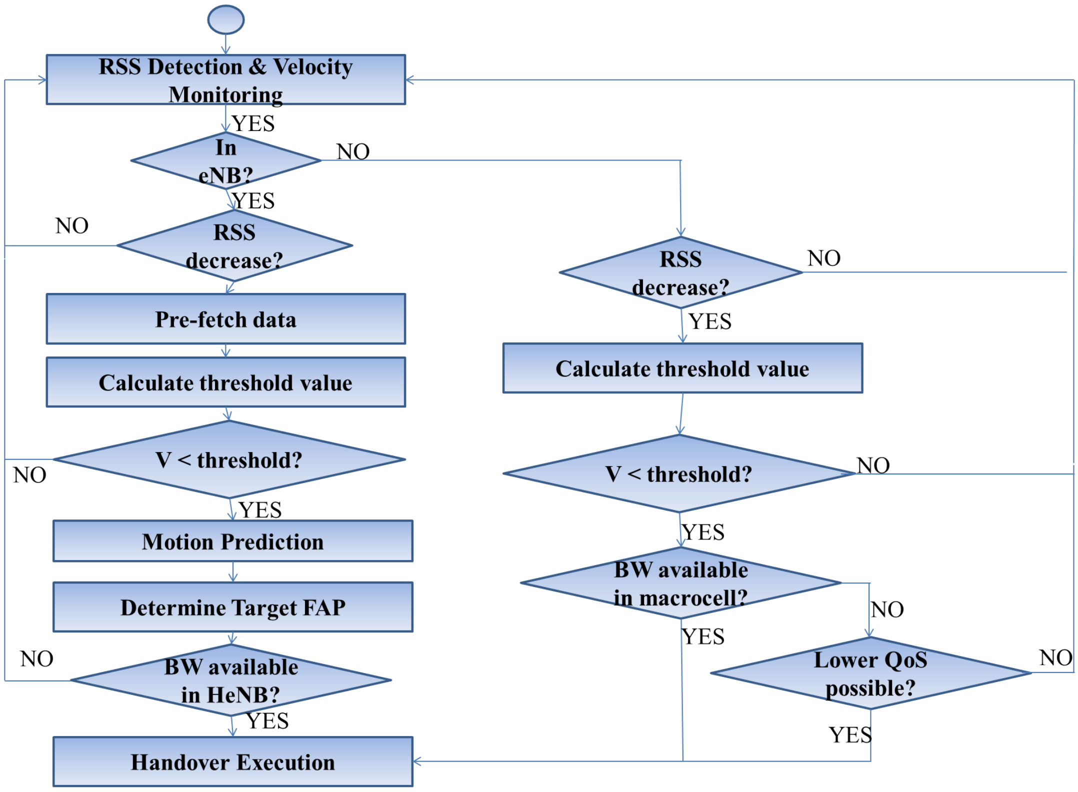


Figure 4.2: Handover Decision Algorithm

4.2.1 Hand-in

When a hand-in (macrocell to femtocell handover) occurs, the handover procedure is segregated to prefetch data to all the femtocells in the proximity of the UE. Prefetch takes place in the neighborhood of the UE and the actual handover occurs only when the UE moves into the target femtocell.

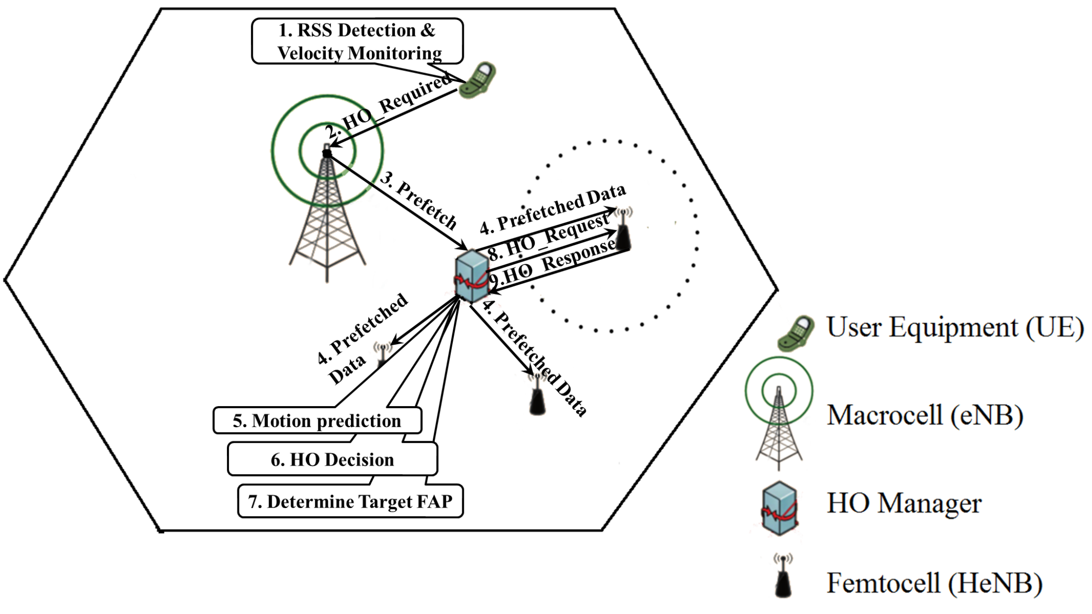


Figure 4.3: Macrocell to femtocell handover

The RSS and the velocity of the UE are compared with the threshold values to determine if a handover should take place. The threshold values are calculated using the average handover speed of the network, size of the femtocell and the expected utility of the time spent by the UE in the cell. Figure 4.3 depicts the hand-in sequence.

4.2.2 Hand-out

Hand-out (femtocell to macrocell handover) starts with the UE sending the HO-Required signal to the HO Manager, which then executes the handover decision algorithm. When the velocity of the UE is less than the threshold value, handover to the macrocell occurs. Figure 4.4 depicts the hand-out sequence. If bandwidth is unavailable, a lower service class is used.

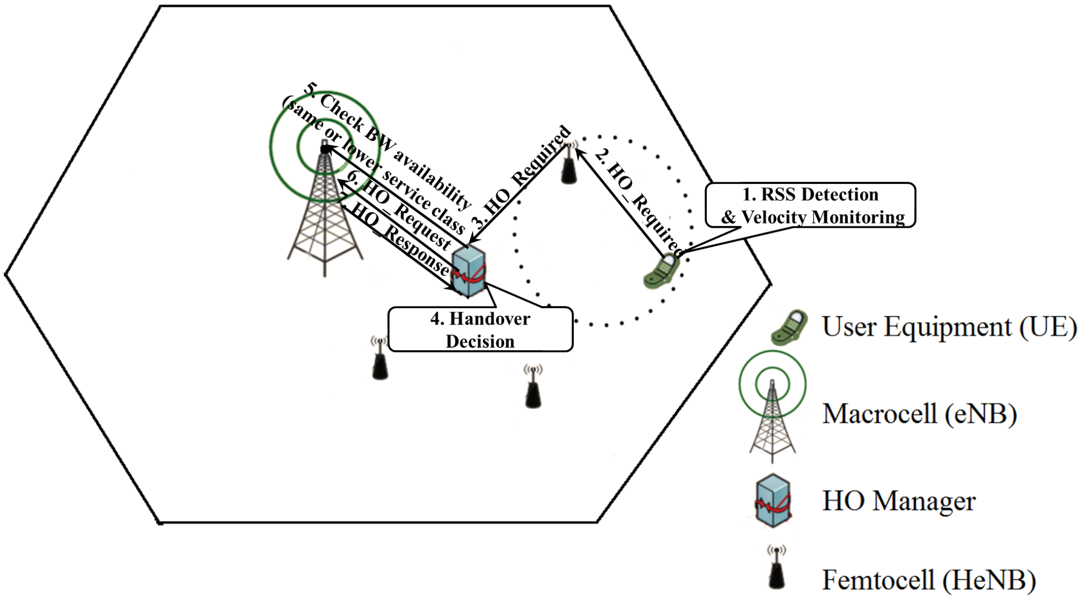


Figure 4.4: Femtocell to macrocell handover

4.3 MODULE DESIGN

4.3.1 Network Architecture

User Equipment (UE)

User Equipments are responsible for initiating the handover process. The UEs adopt the Random Waypoint mobility model and continuously send mobility related information to the corresponding cell. Received Signal Strength and velocity are continuously estimated and this information is used to determine if a handover is necessary.

Macrocell (eNB)

Macrocells provide extensive network cover and are responsible for prefetching data into the neighboring femtocells, thus reducing handover latency.

Femtocell (HeNB)

Femtocells extends the macrocell network coverage to the UEs that are connected to it through the FGW. They also store the prefetched data transferred during hand-ins.

HO Manager

The HO Manager is the entity which checks the need for handover based on the position of the UE. Estimation of threshold and QoS maintainence during handover is performed. The macrocell bandwidth availability is checked before performing a hand-out. If the requested class of service is unavailable then HO Manager offers a lower service class.

Femtocell Gateway (FGW)

Femtocell Gateway acts as the intermediate entity for all communication between the macrocell and femtocells.

4.3.2 RSS Detection

The signal strength received by the User Equipment is continuously monitored. This is done by taking into account the capacity of the macrocell or the femtocell access point that the UE is connected to. The time complexity for computing RSS is O(1).

4.3.3 Velocity Monitoring

The position of the UE is closely monitored and the velocity is determined. UEs that move swiftly may give rise to the ping-pong effect, which is a sequence of unnecessary handovers. The velocity of the UE can be determined in O(1) time.

4.3.4 Determination of Neighbors List and Target FAP

Macrocells determine the neighbors list by calculating the distance between the mobile UE and the femtocells in the proximity of the UE. This serves as a base for prefetching to take place. The time complexity is $O(n^2)$, where n is the total number of cells in the network.

4.3.5 Prefetch

The data required for the handover process are prefetched to the neighboring femtocells. This reduces handover latency as the data will be present in the neighboring femtocells to which handover may occur. The time complexity is $O(n)$, where n is the number of femtocells in the neighbors list.

4.3.6 Threshold Determination

The velocity of the UE is compared with a threshold value T, which is calculated using the following parameters - size of the femtocell, average speed for handover execution in the network and the time the UE is expected to spend in the cell. The threshold value can be calculated using a linear regression. The determination of threshold can be done in O(1) time.

$$T_i = \alpha X_{i_1} + \beta X_{i_2} + \gamma X_{i_3} + \varepsilon_i \tag{4.1}$$

where i = 0,1,2 . . .

T_i = threshold value

X_{i_1} = average speed for handover execution

X_{i_2} = time spent by the UE in the cell

X_{i_3} = size of the femtocell

ε = random error variable that adds noise to the linear relationship

α, β, γ are the regression coefficients

The regression coefficients are estimated based on the type of service initiated by the user.

QCI	Type	Priority	Packet Delay	Packet Error Loss Rate	Service
1	GBR	2	100ms	10^{-2}	Conversational Voice
2	GBR	4	150ms	10^{-3}	Conversational Video
3	GBR	3	50ms	10^{-3}	Real Time Gaming
4	GBR	5	300ms	10^{-6}	Non-Conversational Video
5	non-GBR	1	100ms	10^{-6}	IMS Signaling
6	non-GBR	6	300ms	10^{-6}	Video (Buffered Streaming)
7	non-GBR	7	100ms	10^{-3}	Voice, Video, Interactive Gaming
8	non-GBR	8	300ms	10^{-6}	Video (Buffered Streaming), TCP
9	non-GBR	9	300ms	10^{-6}	Video (Buffered Streaming), TCP

Table 4.1: QoS Class Identifier : QCI

The classification of the allowed services and the corresponding QoS parameters is given in Table 4.1 [13].

4.3.7 Motion Prediction Algorithm

The current position and the direction in which the UE moves can be factored into the handover decision algorithm and can be used in all handover scenarios. By estimating the next position of the UE, the appropriate target femtocell can be chosen. We assume that the UE can periodically update its position to the macrocell base station or the femtocell access point. We also assume that the serving cell keeps a record of all the possible targets to which handover might be performed. The probability of moving to a cell may be approximated as a Markov process as follows.

$$p_n = [p] \times [P_{n-1}] = [p_{n-1}] \times [P] \tag{4.2}$$

where p_n is denoted as the probability of UEs position after n transitions, p is the initial distribution matrix, P_{n-1} is denoted as current transition probability matrix, p_{n-1} is the initial distribution after n transitions and P is the original transition probability matrix. The motion prediction algorithm works in O(n) time, where n is the number of femtocells in the network.

4.3.8 Bandwidth Availability

The Bandwidth Manager is used to check the bandwidth availability in the macrocell for a hand-out process and in the target femtocell for a hand-in process.

4.3.9 Service Class

QoS parameters are fixed based on the type of the service requested by the user. Service classes include QoS parameters like bit rate, packet delivery latency, packet success rate and packet error rate.

4.3.10 Performance Evaluation

The system can be tested by comparing the performance with respect to QoS parameters like handover latency, packet loss ratio, packet delay, spectral efficiency and throughput.

CHAPTER 5

SYSTEM DEVELOPMENT

The design principles highlighted form the basic structure for the implementation of the proposed system. The project is implemented using the LTE-Sim network simulator.

5.1 HANDOVER DECISION

The handover decision algorithms for hand-in and hand-out are shown in Algorithm-1 and Algorithm-2 respectively.

Algorithm 1 : Hand-in Algorithm

procedure HAND-IN-DECISION
top:
    $RSS_i \leftarrow$ current RSS
    $velocity_i \leftarrow$ current velocity
    if $RSS_i < RSS_{i-1}$ **then**
        Prefetch higher layer data to neighboring FAPs
        Calculate threshold $T_i = \alpha X_{i_1} + \beta X_{i_2} + \gamma X_{i_3} + \epsilon_i$
        if $velocity_i < T_i$ **then**
            procedure MOTION-PREDICTION
            Determine target FAP
            if BW available in HeNB **then**
                Handover Execution
            else
                goto *top* //No Handover
        else
            goto *top* //No Handover
    else
        goto *top* //No Handover

Algorithm 2 : Hand-out Algorithm

procedure HAND-OUT-DECISION
top:
  $RSS_i \leftarrow$ current RSS
  $velocity_i \leftarrow$ current velocity
  if $RSS_i < RSS_{i-1}$ **then**
    Calculate threshold $T_i = \alpha X_{i_1} + \beta X_{i_2} + \gamma X_{i_3} + \epsilon_i$
    if $velocity_i < T_i$ **then**
      if BW available in eNB **then**
        Handover Execution
      else
        if lower Service Class possible **then**
          Handover Execution at lower Service Class
        else
          goto *top* //No Handover
    else
      goto *top* //No Handover
  else
    goto *top* //No Handover

5.2 RSS DETECTION

The received signal strength for a mobile UE can be estimated using the distance of the UE from the cell tower and the radius of the cell.

$$RSS = -113.0 - 40log_{10}(r/R) \tag{5.1}$$

where -113 is the minimum received power
40 is the average path loss per decade for mobile networks
r is the distance of the mobile device from the cell tower
R is the mean radius of the cell tower

5.3 MOTION PREDICTION

Based on the history of movement of the UE, an approximation can be made to estimate the position of the UE after *n* transitions. A Markov approximation can be utilized to predict how the UE is likely to move in the near future. The motion prediction algorithm is shown in Algorithm-3.

Algorithm 3 : Motion Prediction Algorithm

procedure MOTION-PREDICTION
    $P_{n-1} \leftarrow$ transition matrix
    Determine current position of UE (Cartesian coordinates)
    $p \leftarrow$ initial distribution matrix
    $p_n = [p] \times [P_{n-1}]$
    $region \leftarrow$ predicted region of UE in the next transition from p_n
    $listFemto \leftarrow$ list of femtocells with the corresponding position
    $probableTargetFAP \leftarrow$ NULL
    while listFemto has next femtocell **do**
        if femtocell is in $region$ **then**
            add femtocell to $probableTargetFAP$
    end while

Motion prediction is performed during the hand-in process as there may be a large number of neighboring femtocells. The algorithm returns a list of femtocells that are in closest proximity to the UE which requests handover. The target femtocell is chosen from this list.

The results obtained from the implementation are pictorially described.

5.4 SETTING UP THE NETWORK ARCHITECTURE

The creation of a macrocell is shown in Figure 5.1. The macrocell is placed at the origin of the Cartesian coordinate system. Bandwidth is allocated and split into uplink and downlink channels.

```
Created Cell, id 0, position: 0 0
Created Building, id 0, position: 443.28 427.737 and 1 floors and 3 femtocells
Created enb, id 0, cell id 0, position: 0 0, channels id 00
BandwidthManager: 0xab7f170
        operative sub band: 1
        m_dlBandwidth 5
        m_ulBandwidth 5
        m_dlOffsetBw 0
        m_ulOffsetBw 0
        DL channels: 2110 2110.18 2110.36 2110.54 2110.72 2110.9 2111.08 2111.26
2112.88 2113.06 2113.24 2113.42 2113.6 2113.78 2113.96 2114.14 2114.32
        UL channels: 1920 1920.18 1920.36 1920.54 1920.72 1920.9 1921.08 1921.26
1922.88 1923.06 1923.24 1923.42 1923.6 1923.78 1923.96 1924.14 1924.32
```

Figure 5.1: Creation of Macrocell

The creation of femtocells is shown in Figure 5.2. Each building contains three femtocells. The femtocells are randomly placed inside the building and uplink and downlink channels are similarly allocated.

```
Created Home enb, id 1, cell id 1, position: 423.28 447.737, channels id 11
BandwidthManager: 0xab7f170
        operative sub band: 1
        m_dlBandwidth 5
        m_ulBandwidth 5
        m_dlOffsetBw 0
        m_ulOffsetBw 0
        DL channels: 2110 2110.18 2110.36 2110.54 2110.72 2110.9 2111.08 2111.26
2112.88 2113.06 2113.24 2113.42 2113.6 2113.78 2113.96 2114.14 2114.32
        UL channels: 1920 1920.18 1920.36 1920.54 1920.72 1920.9 1921.08 1921.26
1922.88 1923.06 1923.24 1923.42 1923.6 1923.78 1923.96 1924.14 1924.32
Created Home enb, id 2, cell id 2, position: 433.28 447.737, channels id 22
BandwidthManager: 0xab7f170
        operative sub band: 1
        m_dlBandwidth 5
        m_ulBandwidth 5
        m_dlOffsetBw 0
        m_ulOffsetBw 0
        DL channels: 2110 2110.18 2110.36 2110.54 2110.72 2110.9 2111.08 2111.26
2112.88 2113.06 2113.24 2113.42 2113.6 2113.78 2113.96 2114.14 2114.32
        UL channels: 1920 1920.18 1920.36 1920.54 1920.72 1920.9 1921.08 1921.26
1922.88 1923.06 1923.24 1923.42 1923.6 1923.78 1923.96 1924.14 1924.32
Created Home enb, id 3, cell id 3, position: 443.28 447.737, channels id 33
BandwidthManager: 0xab7f170
```

Figure 5.2: Creation of Femtocells

Figure 5.3 represents the creation of User Equipments. The UEs are distributed uniformly in the macrocell or the femtocell network. Each UE runs one type of application: BE, VoIP, Video or CBR.

```
Created UE - id 4 position 2777.2 489.442, cell 0, target enb 0
Created UE - id 5 position 1762.83 -1772.69, cell 0, target enb 0
Created UE - id 6 position -593.053 -729.307, cell 0, target enb 0
Created UE in femto-cell - id 7 position 418.019 441.71, cell 1, target HeNb 1
Created UE in femto-cell - id 8 position 433.355 442.738, cell 2, target HeNb 2
Created UE in femto-cell - id 9 position 448.469 443.038, cell 3, target HeNb 3
CREATED BE APPLICATION, ID 0
CREATED BE APPLICATION, ID 1
CREATED BE APPLICATION, ID 2
CREATED BE APPLICATION, ID 3
CREATED BE APPLICATION, ID 4
CREATED BE APPLICATION, ID 5
```

Figure 5.3: Creation of UE and Applications

The UEs follow a Random Waypoint mobility model, where each device moves with a random velocity in a particular direction. The device may change the speed and direction or remain idle. Figure 5.4 shows the UE updating mobility information to the serving cell.

```
MOBILITY_DEBUG: User ID: 5
         Cell ID 0
         Initial Position (X): 1762.83
         Initial Position (Y): -1772.69
         Speed: 120
         Speed Direction: 1.20367
         Time Last Update: 0
         Time Interval: 0
51762.83 -1772.69 120 1.20367 0 0
```

Figure 5.4: Mobility for User Equipments

5.5 HANDOVER DECISION ALGORITHM

The velocity of the UE is tracked periodically. Figure 5.5 shows the calculated RSS and velocity information.

```
-----------------VELOCITY MONITORING--------------------
 ID : 26 Speed 120 in direction 5.00656
--------------------RSS DETECTION----------------------
RSS: 10.8764 ID: 26
ID: 26 New position: ( 659.44 , -276.712 )
RSS is decreasing.

         Final Position (X): 659.44
         Final Position (Y): -276.712
659.44 -276.712
```

Figure 5.5: Velocity Monitoring and RSS Detection

When the RSS detected by macro-UEs decreases, prefetch of data is done to the femtocells, which is depicted in Figure 5.6.

```
Prefetching: UE-17 to femtocell 5
Prefetching: UE-17 to femtocell 6
Prefetching: UE-17 to femtocell 7
Prefetching: UE-17 to femtocell 8
Prefetching: UE-17 to femtocell 9
Prefetching: UE-17 to femtocell 10
Prefetching: UE-17 to femtocell 11
Prefetching: UE-17 to femtocell 12
Prefetching: UE-17 to femtocell 13
Prefetching: UE-17 to femtocell 14
Prefetching: UE-17 to femtocell 15
```

Figure 5.6: Prefetch Data to Femtocells

Threshold value is calculated only when the RSS is found to be decreasing, as shown in Figure 5.7. The type of application in use by the mobile devices determines the service class and QoS parameters that are factored into the threshold calculation. The velocity of the UE is compared against the computed value. Handover is possible only when the velocity does not exceed the threshold value.

```
--------------------RSS DETECTION----------------------
RSS: 45.9467 ID: 19
ID: 19 New position: ( 34.2145 , -321.363 )
RSS is decreasing.

         Final Position (X): 34.2145
         Final Position (Y): -321.363
34.2145 -321.363
------------------------THRESHOLD CALCULATION--------------
----HTIME-TIME-RADIUS---- 4.99 0.0744791 10
APPs TYPE 2
THRESHOLD: 74.8907
NO HANDOVER since velocity 120 > threshold 74.8907
 ID: 20 is idle
------------------------THRESHOLD CALCULATION--------------
----HTIME-TIME-RADIUS---- 4.99 8 10
APPs TYPE 2
THRESHOLD: 74.97
POSSIBILITY OF HANDOVER since velocity 0 < threshold 74.97
```

Figure 5.7: Threshold Calculation

Figure 5.8 illustrates the outcome of the motion prediction algorithm. Using a Markov model for the movement of the UEs, we obtain the prediction matrix, which predicts the most likely position of the UE in the next transition. The femtocells that are in close proximity to the predicted position are added to the list of probable targets.

```
-------------------Motion Prediction---------
The prediction matrix is:
0.2 0.2 0.5 0.1
MOTION PREDICTION: ID: 17 PROBABLE TARGETS ARE:
Femtocell ID 1
Femtocell ID 2
Femtocell ID 3
Femtocell ID 4
Femtocell ID 5
Femtocell ID 6
Femtocell ID 15
List of targets:
1 2 3 4 5 6 15
```

Figure 5.8: Motion Prediction

Figure 5.9 depicts a scenario where handover execution takes place, since bandwidth is available in the target cell.

```
New Downlink channel available. Channel ID is 6
New Uplink channel available. Channel ID is 6
BANDWIDTH AVAILABLE.
ID 17: HO from 0 to 6 at time 0
** HO **         HandoverProcedure for user 17
user 17 starts HO
         old eNB = 0
         target eNB = 6
 ID: 18 is idle
Prefetching: UE-18 to femtocell 1
Prefetching: UE-18 to femtocell 2
```

Figure 5.9: Bandwidth Availability and Handover Execution

The applications in use by the mobile devices send and receive packets. A section of the packet flow trace is shown in Figure 5.10.

```
TX VOIP ID 3 B 6 SIZE 32 SRC -1 DST 7 T 0.1 0
TX VOIP ID 4 B 8 SIZE 32 SRC -1 DST 8 T 0.1 0
TX VOIP ID 5 B 10 SIZE 32 SRC -1 DST 9 T 0.1 0
TX VOIP ID 6 B 12 SIZE 32 SRC -1 DST 10 T 0.1 0
TX VOIP ID 7 B 14 SIZE 32 SRC -1 DST 11 T 0.1 0
TX VOIP ID 8 B 16 SIZE 32 SRC -1 DST 12 T 0.1 0
TX VOIP ID 9 B 18 SIZE 32 SRC -1 DST 13 T 0.1 0
TX VOIP ID 10 B 20 SIZE 32 SRC -1 DST 14 T 0.1 0
TX VOIP ID 11 B 22 SIZE 32 SRC -1 DST 15 T 0.1 0
TX VOIP ID 12 B 24 SIZE 32 SRC -1 DST 16 T 0.1 0
TX VOIP ID 13 B 26 SIZE 32 SRC -1 DST 17 T 0.1 0
TX VOIP ID 14 B 28 SIZE 32 SRC -1 DST 18 T 0.1 0
TX VOIP ID 15 B 30 SIZE 32 SRC -1 DST 19 T 0.1 1
TX VOIP ID 16 B 32 SIZE 32 SRC -1 DST 20 T 0.1 0
```

Figure 5.10: Packet Flow (Trace)

5.6 HANDOVER SUMMARY

The first section of Figure 5.11 summarizes the total number of handovers executed in one simulation. The second section shows the number of handovers between each cell pair. The final section specifies the number of hand-ins and hand-outs.

```
------Number of handovers------
53
------Number of handovers betweem each cell pair------
     15          old eNB = 0
      1          old eNB = 10
      1          old eNB = 11
      2          old eNB = 12
     12          old eNB = 13
      1          old eNB = 14
      1          old eNB = 15
      1          old eNB = 2
      1          old eNB = 3
     10          old eNB = 4
      6          old eNB = 5
      1          old eNB = 7
      1          old eNB = 8
     21          target eNB = 0
      1          target eNB = 10
      1          target eNB = 11
      2          target eNB = 12
     11          target eNB = 14
     10          target eNB = 4
      7          target eNB = 6
-------Number of macrocell-femtocell handovers--------
( Given that eNB id=0 is only macrocell )
     15          old eNB = 0
     21          target eNB = 0
```

Figure 5.11: Number of Successful Handovers

CHAPTER 6

RESULTS AND DISCUSSION

The proposed system is implemented in LTE-Sim. The number of macrocells in the scenario is fixed as one. The number of UEs in the macrocell is fixed as fifteen. The number of UEs in each femtocell is set as three. The type of application that runs in each UE is also specified as BE (Best Effort), VoIP (Voice over Internet Protocol), Video or CBR (Constant Bit Rate). Velocity and initial distribution of the UEs in the network are randomized.

The conventional handover algorithm does not consider QoS requirements of the applications in use by the UEs. The mechanism executes handover based on the distance of the UE from the serving cell. Performance evaluation is done by comparing the efficiency of the conventional system with the proposed system. Analysis is done by taking an average of the values obtained for QoS parameters for ten simulations.

6.1 HANDOVER SUMMARY

The average number of handovers executed for each type of application, for ten simulations with fifteen femtocells is shown in Figure 6.1. It can be observed that CBR applications have the maximum average number of handovers, followed by Video applications. Both these applications require high priority and the best possible QoS values.

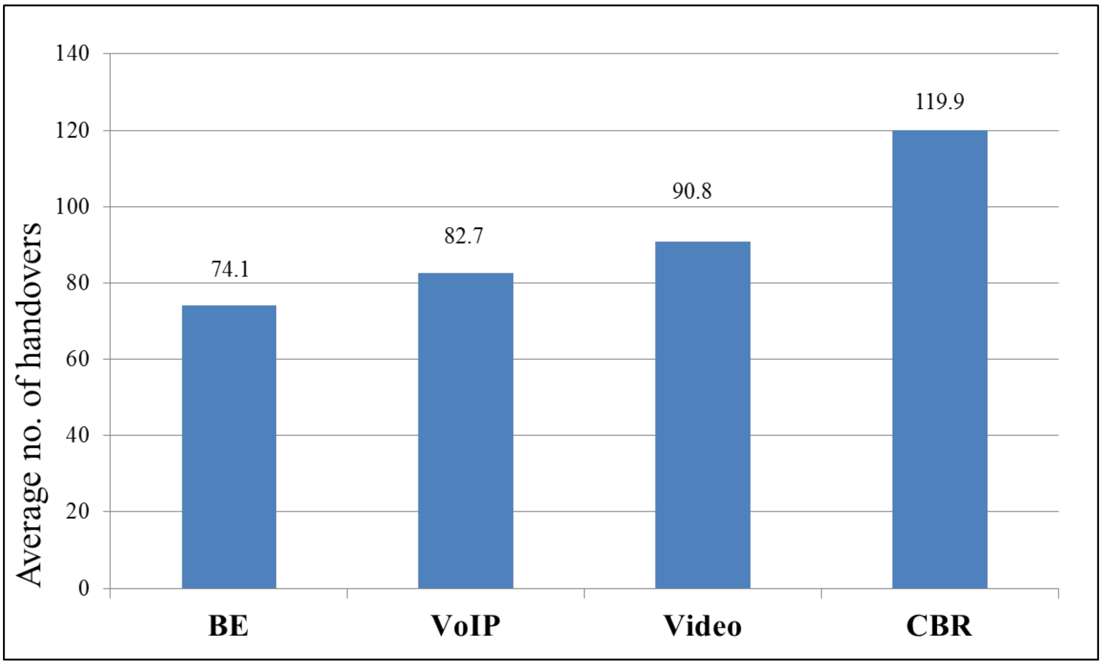


Figure 6.1: Average Number of Handovers for each Application

6.2 PACKET LOSS RATIO

Packet loss ratio can be computed as the total number of packets lost divided by the total number of packets sent through the network. A comparison of the packet loss ratio with respect to the different types of applications, for ten simulations with fifteen femtocells is shown in Figure 6.2. The proposed mechanism works best for BE and VoIP applications.

Packet loss ratio is marginally high in VoIP, Video and CBR applications because the packet contents arrive at a rate greater than it is possible to send through the network segment. For best-effort delivery, since the number of handovers is extensively reduced, the probability of packet drop is very low. This leads to a significant reduction in packet drop for BE applications.

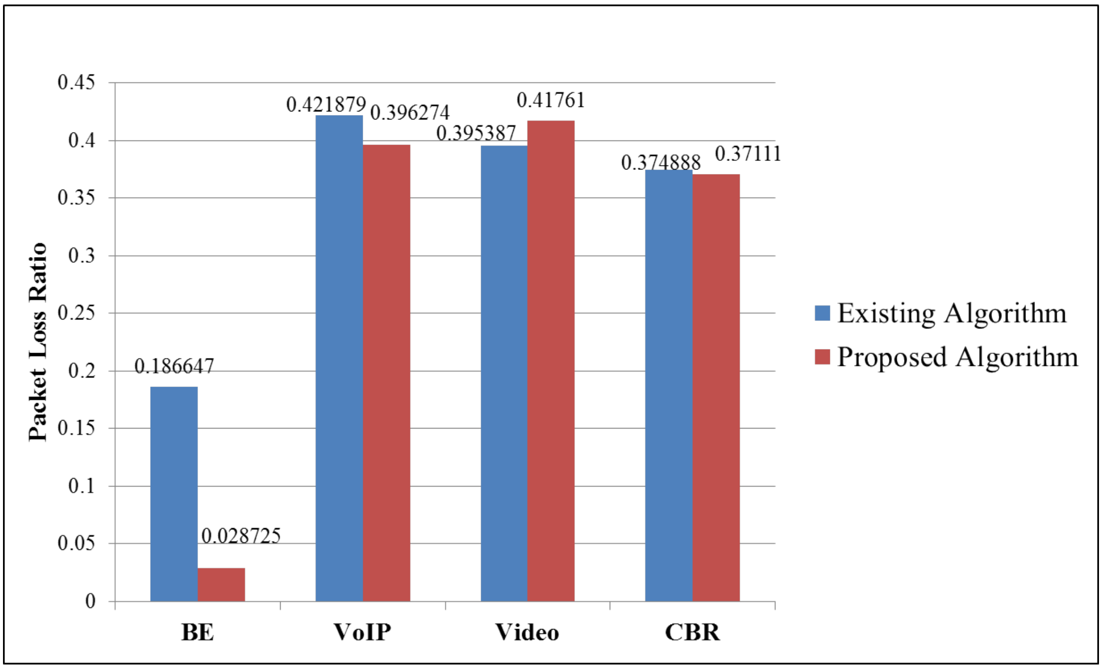
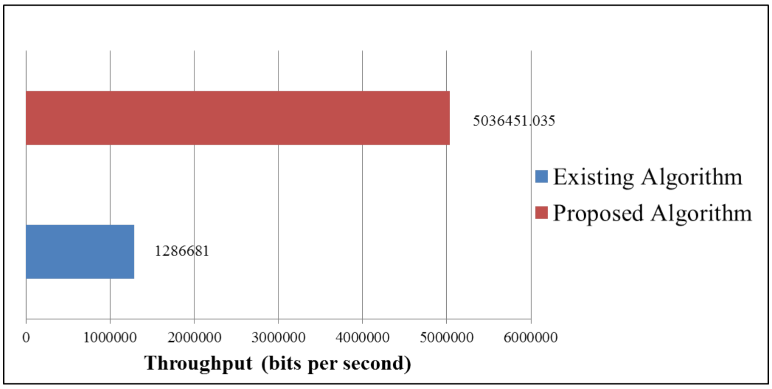


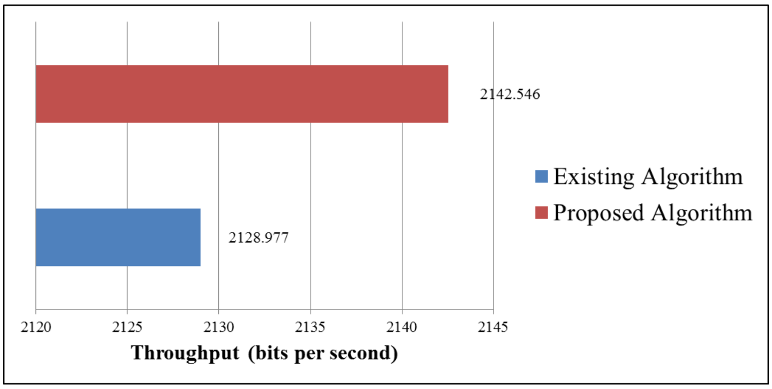
Figure 6.2: Packet Loss Ratio for each Application

6.3 THROUGHPUT

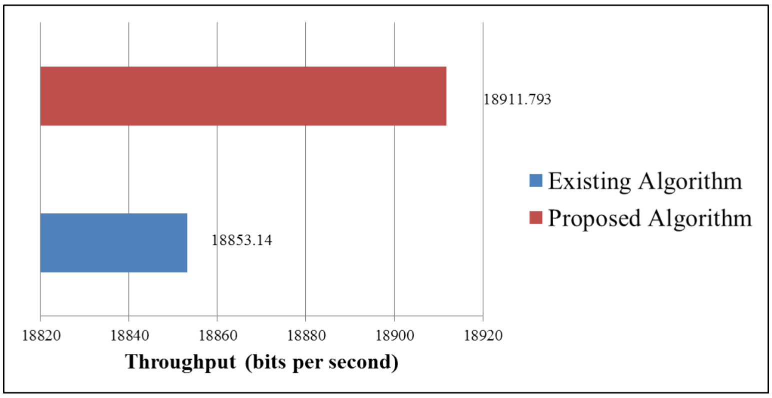
A comparison of the average throughput obtained for ten simulations with fifteen femtocells running BE, VoIP, Video and CBR applications is shown in Figure 6.3(a), Figure 6.3(b), Figure 6.3(c) and Figure 6.3(d) respectively. When handovers occur, there is a need for retransmission of packets sent to the UE. Frequent retransmission of packets decreases throughput. The proposed algorithm minimizes unnecessary handovers and thus increases throughput.



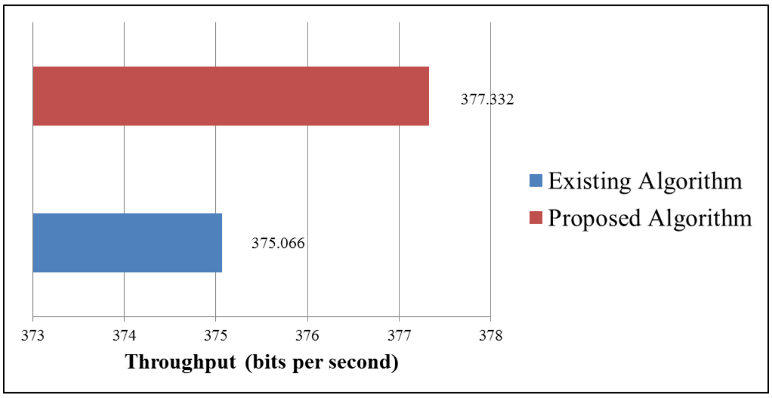
(a) Throughput for BE Application



(b) Throughput for VoIP Application



(c) Throughput for Video Application



(d) Throughput for CBR Application

Figure 6.3: Average Throughput for each Application

Figure 6.4 shows the throughput obtained for ten simulations of VoIP applications, while increasing the number of femtocells present in the integrated network. It is observed that the throughput increases with increase in the number of femtocells. Throughput obtained from the conventional and proposed handover strategies is almost the same when the number of femtocells is minimum. Improved service is possible only in small areas and the overall load on the macrocell increases. Throughput increases significantly when the number of femtocells in the network is in the optimal range.

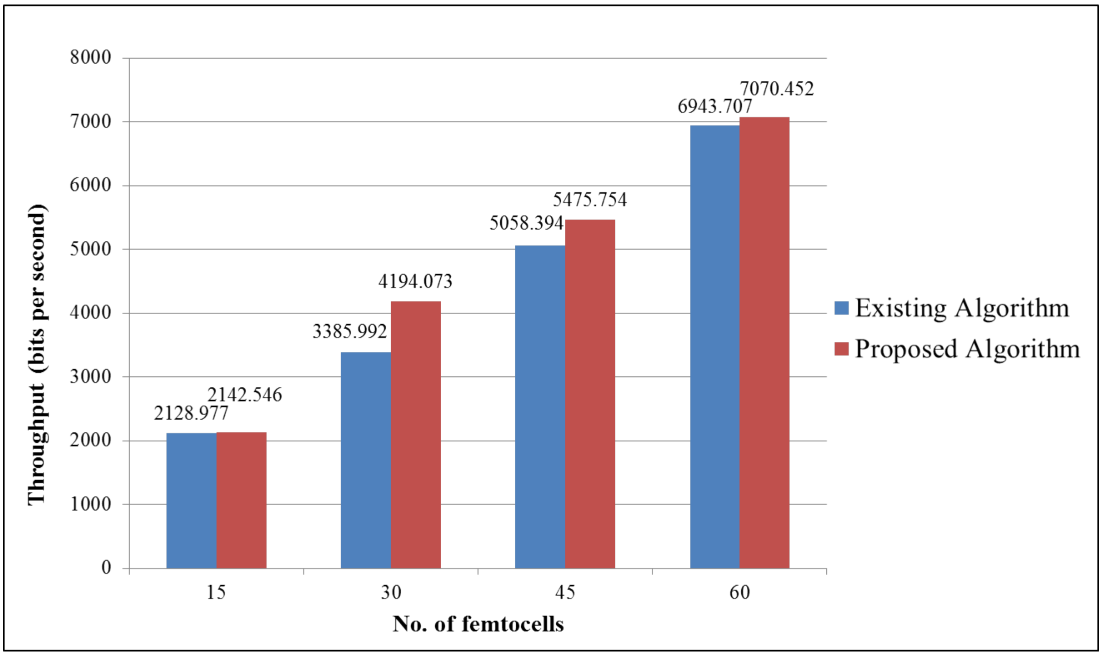


Figure 6.4: Variation of Throughput with Number of Femtocells

6.4 HANDOVER LATENCY

Figure 6.5 shows the variation of Handover Latency between the existing and proposed algorithm, for ten simulations with fifteen femtocells. An exceptional difference in the average latency is observed for all the four applications considered. This is because the proposed system prefetches data required for handover to the neighboring femtocells even before a handover decision is made. Therefore, the time taken for the handover execution is significantly reduced.

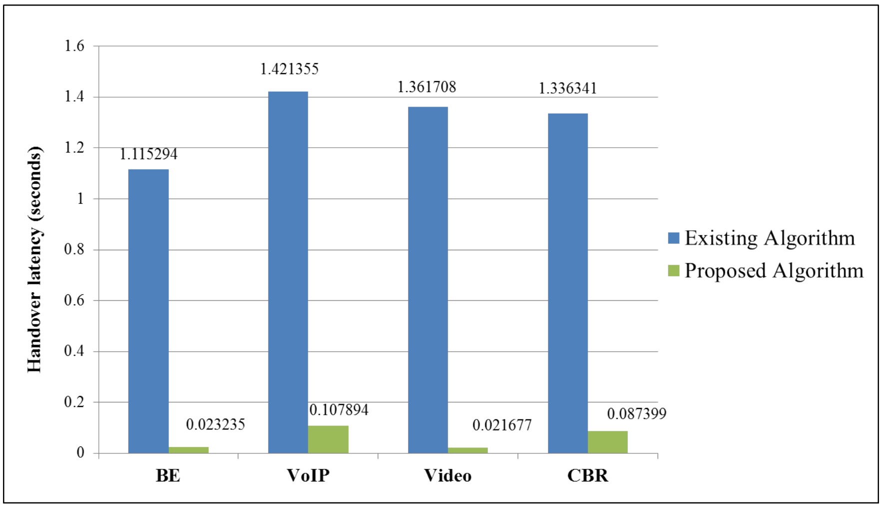


Figure 6.5: Handover Latency for each Application

An analysis of handover latency with varied number of femtocells is shown in Figure 6.6. Handover latency steadily increases up to a femtocell count of 45. The handover decision algorithm requires processing of all the possible target femtocells. As the number of femtocells increases, the probable target nodes increase and hence the steady increase in latency. However, it drops for the femtocell count 60 because the motion prediction algorithm used in the proposed system reduces the probable targets significantly.

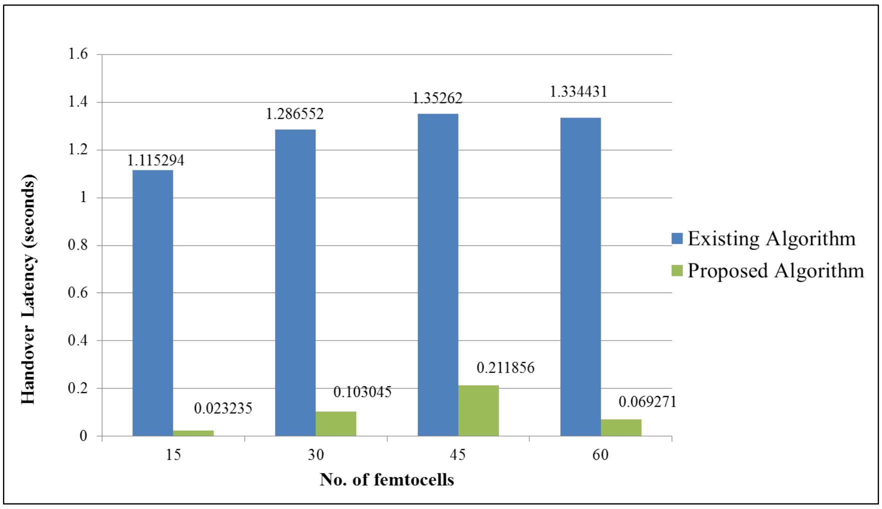


Figure 6.6: Variation of Handover Latency with Number of Femtocells

6.5 PACKET DELAY

The packet delay observed in the conventional and proposed handover algorithms for different application types are compared. Since unnecessary handovers are eliminated, the probability of packet loss is reduced, hence reducing the need for retransmission of packets. This reduces packet delay. Video applications tend to exhibit a greater packet delay as the packet size is considerably high. In the proposed algorithm, the packet delay for Video application is reduced which is shown in Figure 6.7.

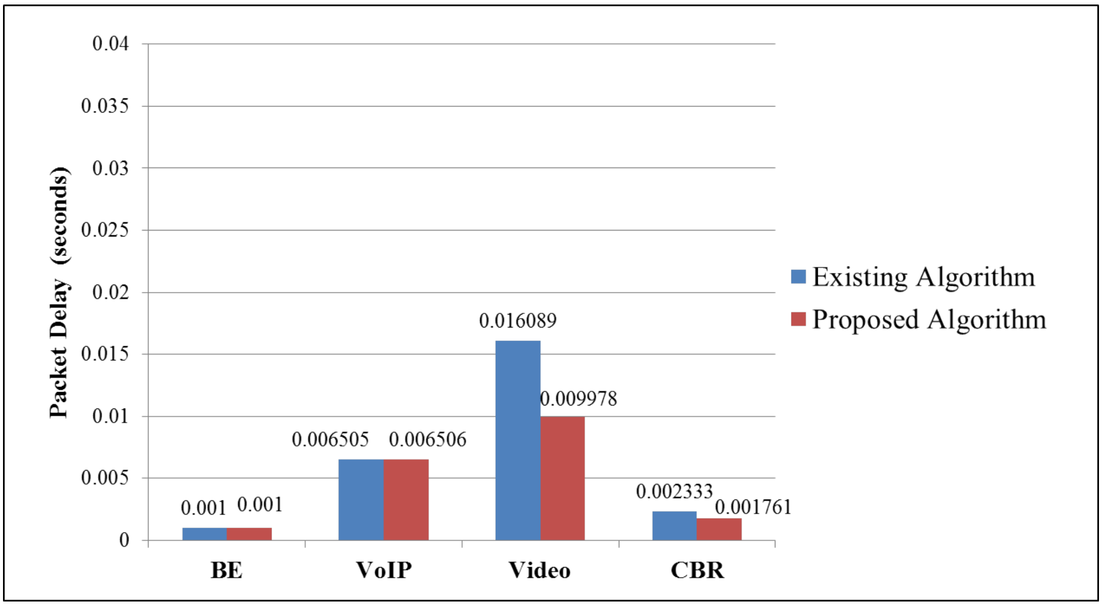


Figure 6.7: Packet Delay for each Application

6.6 SPECTRAL EFFICIENCY

Figure 6.8 implies that spectral efficiency increases proportionally with the number of femtocells in the integrated network. As the number of users per cell reduces with an increasing number of femtocells, there is an increase in spectral efficiency. Hand-in and hand-out efficiently occurs in the proposed system thereby causing a drastic improvement in usage of the spectrum.

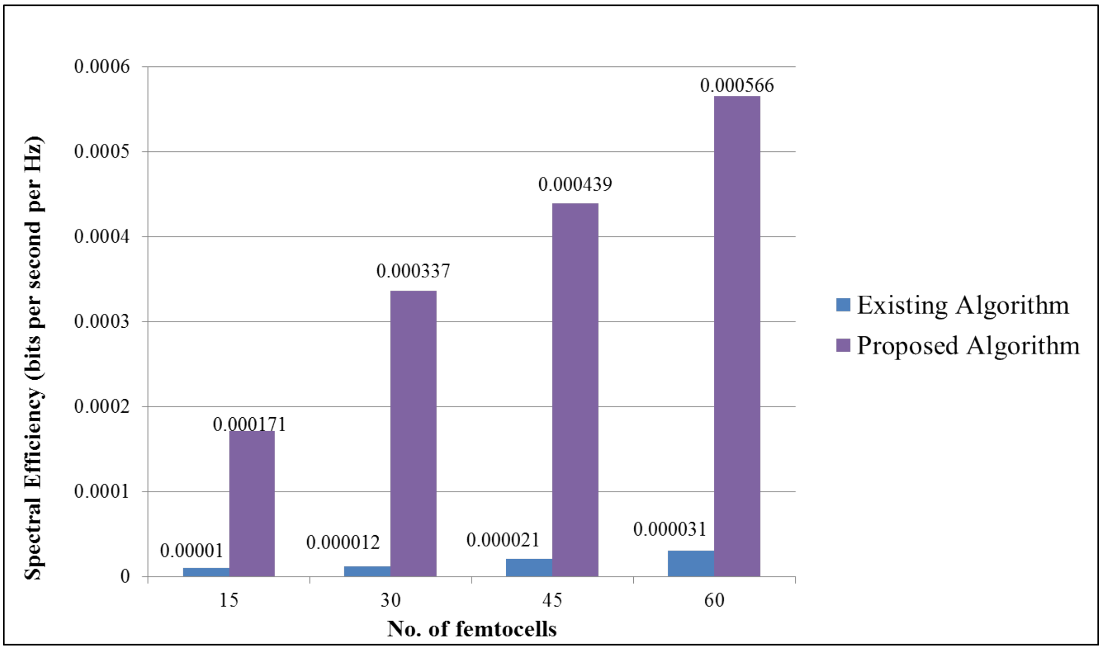


Figure 6.8: Spectral Efficiency for each Application

CHAPTER 7

CONCLUSION AND FUTURE WORK

A QoS-aware handover mechanism is proposed, which improves the performance of integrated femtocell-macrocell networks. Handover is executed between the femtocell and macrocell networks based on the signal strength received by the UE, the velocity of the UE and the QoS needed for the application in use. Load on the macrocell is reduced by distributing the mobile devices uniformly across the femtocell and macrocell networks.

The conclusions derived from the detailed analysis and inspection of the performance of the system are summarized.

7.1 SUMMARY

The proposed handover decision algorithm enhances throughput and spectral efficiency. The packet loss ratio is significantly reduced, while the packet delay does not increase. QoS parameters like handover latency and utility of the time spent in a cell are factored into the handover decision algorithm. A threshold value is computed to determine when a handover needs to be executed. Conventional handover strategies in integrated environments usually force a large number of unnecessary handovers to take place. This is a consequence of the small size of femtocells, which leads to the ping-pong effect. The proposed algorithm avoids executing unnecessary handovers between femtocells. Once a handover decision is made, the time taken to transfer data from the current serving cell to the target cell is considerably high. This latency is reduced in the proposed system by prefetching the data before a handover is initiated.

The algorithms proposed thus take into account a comprehensive set of QoS parameters and enhance the capabilities of integrated femtocell-macrocell networks.

7.2 FUTURE WORK

The handover strategy can be broadened to include other QoS parameters like jitter, location update cost and allocation and retention priority. Simulations of other types of traffic with different models to emulate mobility of UEs can be done.

APPENDIX A

DATASET : EVALUATION PARAMETERS

The values obtained for simulations of the system depend on the initial positions and velocities of the UEs, which are randomized.

A.1 HANDOVER LATENCY

The time taken to execute a handover is estimated as the time interval between a handover request and the handover response.

A.1.1 Variation of Handover Latency with Type of Application

Run	**Existing Algorithm**				**Proposed Algorithm**			
	BE	VoIP	Video	CBR	BE	VoIP	Video	CBR
1	1.795	1.720	0.553	1.113	0.020	0.016	0.035	0.046
2	0.671	1.408	1.960	1.244	0.023	0.012	0.021	0.013
3	0.937	2.332	2.328	0.914	0.025	0.026	0.021	0.036
4	0.836	0.973	0.572	0.884	0.020	0.006	0.011	0.039
5	1.529	0.736	1.285	1.637	0.037	0.226	0.032	0.037
6	0.870	1.150	1.564	1.281	0.019	0.015	0.009	0.011
7	1.676	1.227	1.117	1.397	0.011	0.704	0.037	0.026
8	0.984	2.045	0.730	1.741	0.044	0.017	0.013	0.024
9	0.839	1.107	2.253	2.017	0.005	0.028	0.010	0.594
10	1.010	1.511	1.249	1.130	0.024	0.024	0.023	0.045

Table A.1: Handover Latency for each Application

The values observed in ten simulations of the conventional and proposed handover decision algorithms are tabulated in Table A.1.

A.1.2 Variation of Handover Latency with Number of Femtocells

Handover latency for ten simulations of the system running VoIP applications is shown in Table A.2.

Run	**Existing Algorithm**				**Proposed Algorithm**			
No. femtocells	15	30	45	60	15	30	45	60
1	1.795	1.157	1.064	1.368	0.020	0.402	0.444	0.021
2	0.671	1.099	1.446	1.426	0.023	0.035	0.436	0.051
3	0.937	0.812	2.043	1.118	0.025	0.183	0.057	0.229
4	0.836	1.792	1.471	1.059	0.020	0.017	0.178	0.125
5	1.529	1.340	1.161	1.130	0.037	0.224	0.363	0.147
6	0.870	1.358	1.435	1.456	0.019	0.007	0.281	0.020
7	1.676	1.382	1.216	1.214	0.011	0.033	0.135	0.024
8	0.984	1.422	1.249	1.624	0.044	0.015	0.183	0.024
9	0.839	1.196	1.488	1.481	0.005	0.084	0.018	0.026
10	1.010	1.302	0.950	1.463	0.024	0.026	0.019	0.022

Table A.2: Variation of Handover Latency with number of femtocells

A.2 VARIATION OF PACKET DELAY WITH TYPE OF APPLICATION

The total delay that a packet experiences when it is stored and forwarded across the network is computed and shown in Table A.3.

Run	**Existing Algorithm**				**Proposed Algorithm**			
	BE	VoIP	Video	CBR	BE	VoIP	Video	CBR
1	0.001	0.006	0.018	0.003	0.001	0.008	0.012	0.001
2	0.001	0.007	0.016	0.002	0.001	0.006	0.010	0.001
3	0.001	0.004	0.015	0.002	0.001	0.007	0.010	0.002
4	0.001	0.006	0.015	0.002	0.001	0.005	0.015	0.001
5	0.001	0.009	0.016	0.003	0.001	0.006	0.007	0.001
6	0.001	0.006	0.010	0.003	0.001	0.006	0.006	0.001
7	0.001	0.008	0.024	0.002	0.001	0.010	0.008	0.001
8	0.001	0.008	0.016	0.002	0.001	0.005	0.007	0.001
9	0.001	0.005	0.012	0.002	0.001	0.005	0.014	0.001
10	0.001	0.005	0.018	0.003	0.001	0.006	0.010	0.002

Table A.3: Packet Delay for each Application

A.3 NUMBER OF HANDOVERS

Run	BE	VoIP	Video	CBR
1	53	94	82	186
2	83	44	77	75
3	70	141	151	122
4	75	31	41	150
5	125	49	78	75
6	45	47	61	67
7	28	31	247	95
8	118	151	40	53
9	20	130	48	90
10	124	109	83	286

Table A.4: Number of Handovers for each Application

The number of successfully executed handovers in ten simulations of the proposed algorithm is shown in Table A.4.

A.4 VARIATION OF PACKET LOSS RATIO WITH TYPE OF APPLICATION

The ratio of the total number of packets lost to the total number of packets sent in a network is tabulated in Table A.5.

Run	Existing Algorithm				Proposed Algorithm			
	BE	VoIP	Video	CBR	BE	VoIP	Video	CBR
1	0.090	0.367	0.235	0.513	0.043	0.438	0.284	0.327
2	0.127	0.358	0.607	0.531	0.004	0.337	0.170	0.381
3	0.252	0.640	0.367	0.308	0	0.489	0.356	0.351
4	0.195	0.485	0.427	0.409	0.035	0.472	0.507	0.338
5	0.186	0.269	0.423	0.353	0.011	0.297	0.302	0.174
6	0.280	0.347	0.428	0.218	0.123	0.438	0.500	0.333
7	0.139	0.511	0.368	0.374	0.041	0.465	0.610	0.272
8	0.109	0.370	0.346	0.460	0.010	0.471	0.333	0.443
9	0.194	0.407	0.300	0.373	0.019	0.340	0.560	0.544
10	0.293	0.465	0.454	0.209	0.001	0.217	0.553	0.547

Table A.5: Packet Loss Ratio for each Application

A.5 THROUGHPUT

A.5.1 Conventional Handover Algorithm

The throughput (bits per second) observed in ten simulations of the conventional handover algorithm is shown in Table A.6.

Run	BE	VoIP	Video	CBR
1	2266280.4	2395.13	23570.33	292
2	866932.47	2752.8	12027.07	281.33
3	825431.07	1356.67	19924.33	415.33
4	848536.73	1951.13	17605.07	354.67
5	1708946.13	2858.87	18156.93	388
6	967217.47	2155.87	17960.47	469.33
7	1557008	1953.6	19157.6	375.33
8	1441722.6	2005.4	20712.6	324
9	1709633.73	2109	22612.27	376
10	675101.4	1751.3	16804.73	474.67

Table A.6: Throughput - Conventional Handover Strategy

A.5.2 Proposed Handover Algorithm

Run	BE	VoIP	Video	CBR
1	4564783	2096.67	23086.6	404
2	6553659.5	2400.07	27097.4	371.33
3	8258930.6	1891.93	20909.53	389.33
4	3274358.13	1783.4	15479.07	397.33
5	5420551.53	2422.27	22741.2	495.33
6	3291453.93	1842.6	16334.4	400
7	4921662.3	2106.53	12804.2	436.67
8	5961613.26	1906.73	21779.2	334
9	3896812.8	2254.53	14210.53	273.33
10	4220685.3	2720.73	14675.8	272

Table A.7: Throughput - Proposed Handover Strategy

The throughput (bits per second) observed in ten simulations of the proposed handover algorithm is shown in Table A.7.

A.5.3 Conventional Handover Algorithm with Variation in Number of Femtocells

Throughput for ten simulations of the conventional system running VoIP applications is shown in Table A.8.

Run	**Femtocells**			
	15	30	45	60
1	2395.13	3357.13	3959	6817.87
2	2752.8	3256	5372.4	6914.07
3	1356.67	3416.33	4711.33	6674.8
4	1951.13	4329	5143	7089.2
5	2858.87	2641.8	4827.27	8226.33
6	2155.87	3342.33	5123.27	7678.73
7	1953.6	2582.6	5567.27	6921.87
8	2005.4	2849	4918.53	6457.73
9	2109	4666.93	5083.8	6171.6
10	1751.3	3418.8	5878.07	6484.87

Table A.8: Conventional Handover Strategy with Variation in Number of Femtocells

A.5.4 Proposed Handover Algorithm with Variation in Number of Femtocells

Throughput for ten simulations of the conventional system running VoIP applications is shown in Table A.9.

Run	**Femtocells**			
	15	30	45	60
1	2096.67	4040.4	4338.87	5929.87
2	2400.07	4215.53	6477.47	5907.67
3	1891.93	4158.8	6637.8	8095.6
4	1783.4	3189.4	4477	6487.33
5	2422.27	3317.67	4403	6938.73
6	1842.6	4131.67	5157.8	6583.53
7	2106.53	4689.13	6477.47	7190.33
8	1906.73	4353.67	5118.33	7977.2
9	2254.53	4370.93	5828.73	7412.33
10	2720.73	5473.53	5841.07	8181.93

Table A.9: Proposed Handover Strategy with Variation in Number of Femtocells

A.6 SPECTRAL EFFICIENCY

The rate of information transfer using a given bandwidth is termed as spectral efficiency.

A.6.1 Conventional Handover Algorithm

Table A.10 shows the spectral efficiency obtained from ten simulations of the conventional system.

Run	BE	VoIP	Video	CBR
1	0.00104	0.00001	0.00001	0
2	0.0008	0.00001	0	0
3	0.00075	0.00001	0.00001	0.00001
4	0.00071	0.00001	0.00001	0.00001
5	0.00081	0.00001	0.00001	0.00001
6	0.00067	0.00001	0.00001	0.00001
7	0.00076	0.00001	0.00001	0.00001
8	0.00078	0.00001	0.00001	0.00001
9	0.00084	0.00001	0.00001	0.00001
10	0.00065	0.00001	0.00001	0.00001

Table A.10: Spectral Efficiency - Conventional Handover Strategy

A.6.2 Proposed Handover Algorithm

Table A.11 shows the spectral efficiency obtained from ten simulations of the proposed system.

Run	BE	VoIP	Video	CBR
1	0.036518	0.00017	0.00185	0.00003
2	0.52429	0.00019	0.00217	0.00003
3	0.06226	0.00015	0.00167	0.00003
4	0.26195	0.00014	0.00124	0.00003
5	0.43364	0.00019	0.00182	0.00004
6	0.26332	0.00015	0.00131	0.00003
7	0.39373	0.00017	0.00102	0.00003
8	0.47693	0.00015	0.00174	0.00003
9	0.31175	0.00018	0.00114	0.00002
10	0.33765	0.00022	0.00117	0.00002

Table A.11: Spectral Efficiency - Proposed Handover Strategy

A.6.3 Conventional Handover Strategy with Variation in Number of Femtocells

The spectral efficiency obtained from ten simulations of the conventional strategy for VoIP applications is tabulated in Table A.12.

Run	Femtocells			
	15	30	45	60
1	0.00001	0.00001	0.00002	0.00003
2	0.00001	0.00001	0.00002	0.00003
3	0.00001	0.00001	0.00002	0.00003
4	0.00001	0.00002	0.00002	0.00003
5	0.00001	0.00001	0.00002	0.00004
6	0.00001	0.00001	0.00002	0.00003
7	0.00001	0.00001	0.00002	0.00003
8	0.00001	0.00001	0.00002	0.00003
9	0.00001	0.00002	0.00002	0.00003
10	0.00001	0.00001	0.00003	0.00003

Table A.12: Conventional Handover Strategy with Variation in Number of Femtocells

A.6.4 Proposed Handover Strategy with Variation in Number of Femtocells

The spectral efficiency obtained from ten simulations of the proposed strategy for VoIP applications is tabulated in Table A.13.

Run	Femtocells			
	15	30	45	60
1	0.00017	0.00032	0.00035	0.00047
2	0.00019	0.00034	0.00052	0.00047
3	0.00015	0.00033	0.00053	0.00065
4	0.00014	0.00026	0.00036	0.00052
5	0.00019	0.00027	0.00035	0.00056
6	0.00015	0.00033	0.00041	0.00053
7	0.00017	0.00038	0.00052	0.00058
8	0.00015	0.00035	0.00041	0.00064
9	0.00018	0.00035	0.00047	0.00059
10	0.00022	0.00044	0.00047	0.00065

Table A.13: Proposed Handover Strategy with Variation in Number of Femtocells

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