Handover Management in Femtocell Networks

by

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Abstract

Radio communication has come a long way from 1G Advanced Mobile Phone Systems (Amps) voice to Evolved 3G Enhanced Voice Data Optimized (EVDO), High Speed Packet Access plus (HSPA+) and 4G Long Term Evolution (LTE) now. Spectrum is a scarce resource. While this remains a constant with limited number of frequency bands available, the overall performance of the network is expected to rise many folds. Every instant the need to accommodate more number of users, devices and better quality services increase on the network. Many new technologies help support this ever growing need. Recent advancements in the development of Multiple Input Multiple Output (MIMO), sensitive, directive antennas, modulation schemes like Orthogonal Frequency Division Multiplexing (OFDM), interference mitigation methods like Successive Interference Cancellation (SIC) are good contributions. A technology that holds promise to provide the next leap in performance is a femtocell.

Femtocell technology brings the network closer to the user by adding smaller cells, which provide the benefit of higher quality links and more spatial reuse. The benefit of deploying femtocells within cellular networks is established considering the wide acceptance for these networks from several service providers. To fully exploit this diversity realized at the physical layer some challenging issues have to be addressed, smart decision making algorithms need to be implemented. Making a handover decision is one such issue where the user has various power levels available from Macro Base Station (MBS) and Femto Base Station (FBS). From a Base Station's (BS) perspective, there may be many users with close Signal to Noise plus Interference ratio (SINR) values needing service but all users cannot be accommodated due to bandwidth limitation. To make these decisions, appropriate handover mechanisms need to be adapted to fully exploit the advantages of these networks in various deployment scenarios.

The area covered by a femtocell is a few tens of meters and hence mobility and speed analysis are important in deciding a favorable FBS for handover. In the work presented, an extensive study of methods to optimize handover decisions under the open access scheme of operation, maintaining Quality of Service (QoS) thresholds to maximize overall network capacity such that fairness among users is maintained as well. Also, a list of the available parameters and algorithms for making efficient handover decisions are noted and related work by others is mentioned. Two proposed models are introduced namely counter based and stability based; to block temporary requests and to utilize service rate respectively as the methods main theme. The decisions are influenced by a combination factor resulting from SINR. The core contribution in this thesis is the development of algorithms with sound mathematical support and concurrent analysis of their benefits. A detailed description of which parameters are combined and how these are prioritized along with the state models that decide a users choice of FBSs is presented. Finally we evaluate the performance of the methods.

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Chapter 1

Introduction

1.1 Femto Base Station

FBS is a low-cost, low-power and short range BS, which is client installed and shares the same spectrum by communicating with cellular network over a broadband backhaul. Fig. 1.1 shows femto hardware devices which are used and whose deployment would increase at least a 100 fold of the present value. These devices typically operate at a power of 20mW and up to a distance of 10 meters. These devices look very similar to WiFi access points (AP). The distinguished differences are the presence of a timing slot for synchronization by 1588 server or Global Positioning System (GPS) input and the wide range of frequencies they can operate in lincensed, unlicensed and sometimes dual bands. There is enough randomness while planning femtocell networks which is due to the fact that FBS is deployed by the user and not the service provider leading to an unorganized or a distributed set.

1.2 Femtocell Network

A typical femtocell network is show in Fig. 1.2 with a few FBSs under a MBS's coverage area synchronized over internet backhaul. Unlike the MBSs which are installed and maintained by service providers, it becomes difficult to keep track of FBSs because of issues like hidden nodes and maintenance of neighboring cell lists. Yet, femtocell networks are a good choice in comparison to more conventional methods of relaying and directive antennas which increase the overall cost for the operators [1]. Spatial diversity achieved through small cell technology is known to alleviate the ill effects of channel fading in wireless channels and maximize overall spectrum efficiency of the network. The issue of handovers in femto/macro

Figure 1.1: Commercial Devices [*Source*: [18] [19] [20] [21]]

network which was raised in [1], along with a lot of insight into the pro and cons in deploying femtocells in [2]. Due to the reduced distance of wireless transmission, femtocell is shown effective in conserving transmit power, improving network capacity, and thus enhancing the quality of user experience. QoS for each user in a multicast for video streaming in femtocells is of prime importance [3].

Depending on the control present with the femtocell device, we have open and closed mode of operation. When network resources and services like calls, messages and data surfing are available to all users with equal priority, the network is set to be operating in open mode. Though this method may give efficient power and bandwidth utilization, the required level of quality may not be available to all users i.e., a user may not connect to the network even after repeated attempts because the network is busy. This scenario may work best with high load for maximum utilization but making a handover decision becomes highly computational.

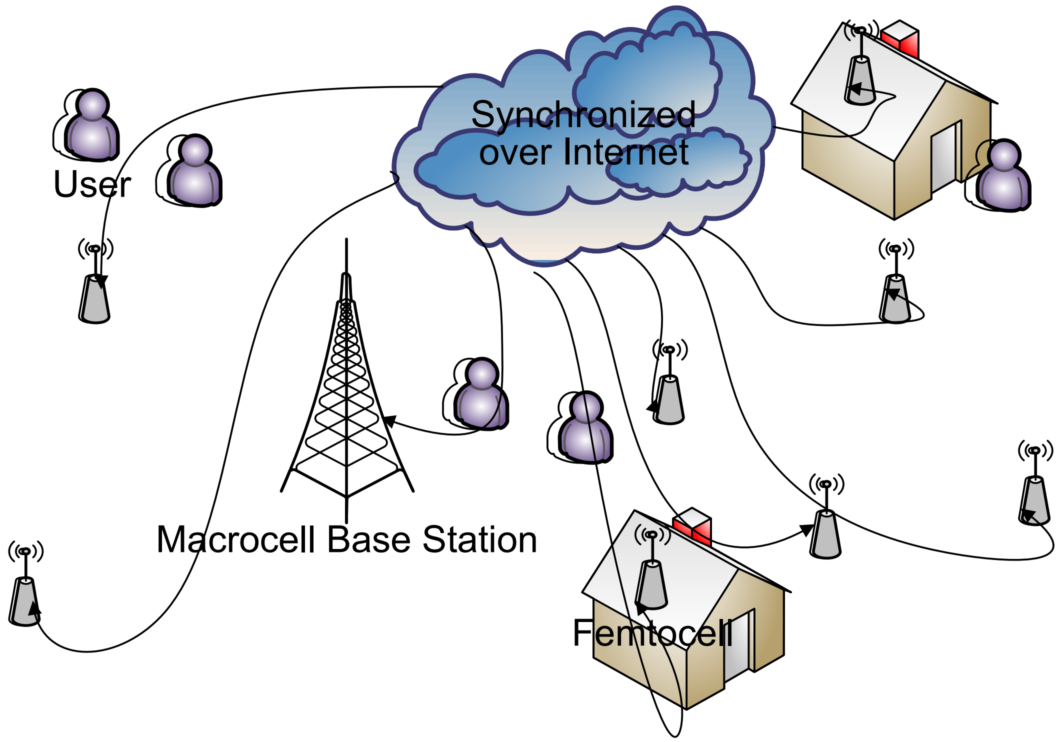

Figure 1.2: An example of a femtocell-based cellular network

The number of handovers in a group of femtocells is more owing to the ping pong effect, it is necessary to ensure the effectiveness of cell selection method which is usually a measure of channel capacity, received signal strength (RSS), load on neighboring cells, etc. We come across cell *selection* among femtocells in open mode as opposed to closed mode which is due to the large, variable number of users requiring services in open access contrasted to fixed, registered users in closed access. Before we concentrate on discussing handovers in these networks, other issues are dealt by previous work. There is always interference present and is handled through the method like SIC [4]. Fairness, grouping users based on SINR is a method for cell association with users while blocking weak requests [5]. Delay aware networks with a focus on mobility management is the essence of the work presented in [7].

In this thesis, we introduce two handover schemes for femtocell networks. And compare them with similar models to note the advantages of individual changes to the algorithm [5].

We then propose an improved scheme to further reduce the number of unnecessary handovers in femtocell networks. The aim is to develop low-complexity algorithms involving conventional parameters like RSS, throughput, connection time, dwell time before handing off a macrocell user to a nearby femtocell and vice-versa. The two handover algorithms are suggestively named counter and stability based schemes. *Stability* based scheme concentrates on the connection time dependent handovers, in a dense FBS distributed network. Few of the issues with handovers like velocity thresholds, maintaining FBS lists are presented under this scheme. Because the coverage radius of a FBS is less, users with high velocities cross the area more frequently. This leads to multiple handovers in every few meters and hence just signal-to-noise ratio (SNR) based analysis is not robust. In this work, we utilize connection time as an additional parameter to form a combination factor with SNR for handover decision making. A mathematical model for calculating connection times of each user with a FBS is then presented based on the user's present location. Connection time is valid for users within the coverage area of a particular FBS otherwise a value of zero for our consideration.

When the number of users in the network is few in comparison to the available FBSs, we observe better performance in reducing unnecessary handovers through the *counter* based scheme. This algorithm considers the QoS for each user by maintaining different thresholds for FBS and MBS, handover is based on SNR and dwell time. Fairness to all users in network is maintained by providing equal importance for every service request. A counter for each BS is maintained so that the capacity of the entire network is not compromised due to unnecessary requests when the BSs are saturated.

Chapter 2

Cellular Networks

One of the distinguishing feature of FBS is a requirement to operate on cellular frequencies apart from the other bands. Cellular frequencies are lower bands compared to unlicensed 2.4, 5 Ghz frequencies making them more penetrable and travel longer distances. With Internet Protocol (IP) transforming all traffic to datagrams over the networks, FBS act as good data offloading and coverage systems under LTE. Even circuit switched data like voice and SMS services are delivered through circuit switched fall back (CSFB) technology in voice over LTE (VoLTE) long term networks.

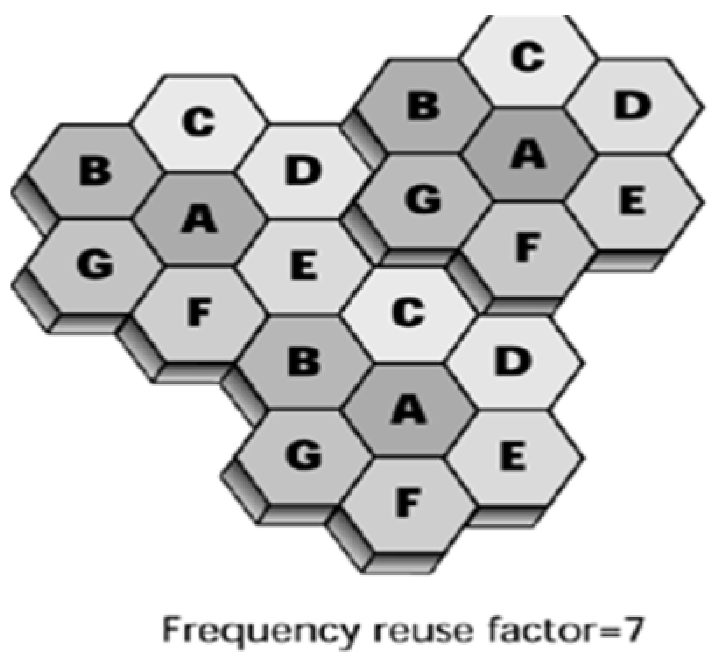

Figure 2.1: Efficient Spectrum Utilization Technique [*Source*: [32]]

2.1 Spectrum Utilization

The lower cellular frequencies make communications truly mobile by covering larger areas and less dead zones. These bands are a scarce resource though, Internet Service Providers (ISP) or operators bid for gaining permission to use it commercially. Hence proper utilization of this spectrum is important. Many bandwidth efficient technologies are presently used and are being researched.

Directional antennas are allowed to transmit higher powers in comparison to omni-directional antennas. Higher power antennas reach greater distances and cater to more users in a high traffic area. Because directional antennas are transmitting according to a plan, the interferences are also handled properly. Directional antennas are priced higher than regular antennas as expected.

Cellular networks derive their name from *cell*. A geographic region is divided into cells during planning of radio resources and BS setup. All the available frequencies with an operator are divided into groups and each cell utilizes a group of frequencies. The same group of frequencies are spatially separated to be used in a different cell. This is an important concept for cellular networks called frequency reuse. Fig. 2.1 shows an area divided into 3 clusters of 7 cells each. This means that the total bandwidth available divided into 7 sets which can be replicated multiple times. The spatial separation helps with co-channel and adjacent channel interference mitigation. Sectorization, Small cell or femtocell technology are few of the frequency re-use methods. Sectorization is a concept which is realized by directional antennas which radiate in beams of 60, 90, 120 degrees to provide 6, 4, 3 sectors respectively. Small cell as the name indicates has small BSs in a larger cell, hence the spectral efficiency.

2.2 Access Network

There are several channel access or multiple access schemes Time Division Multiple Access (TDMA), Frequency Division Multiple Access (FDMA), Code Division Multiple Access (CDMA); newer schemes like Wavelength Division Multiple Access (WDMA), Space Division Multiple Access (SDMA) and Orthogonal Frequency Division Multiple Access (OFDMA) are also in use.

2.2.1 Line of Sight

As the name suggests LOS propagation does not have obstacles between the transmitting and receiving parties. This mode of propagation can naturally achieve higher throughput with less power radiation in comparison to having obstacles in the path. Setting up of BSs in this mode is quite straight forward. All radio transmission technologies can be used to transfer in LOS. High capacity microwave links can be utilized in this scenario.

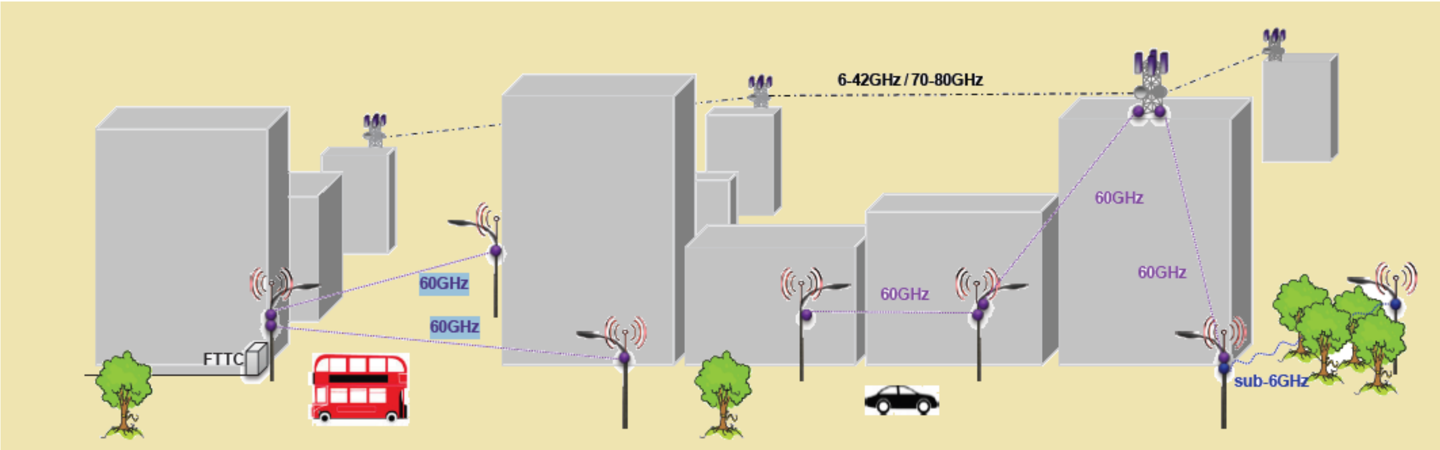

Figure 2.2: Use case illustration for 60 GHz and 70-80 GHz technologies [$Source$: [22]]

2.2.2 Near/Non-Line of Sight

When there are obstacles in the path of destination receiver, communications still happen by the different modes of transmission like reflection, refraction, diffraction or a combination of these. When there is no LOS but is not clear or has mildly penetrable bstacles around which radio waves can bend, like the sub 6 GHz carrier is called near LOS. Non LOS is when there are rigid obstacles in the path. If link budget permits, we can divide a NLOS path in to few smaller LOS paths.

Fig. 2.2 from Small Cell Forum release 2, document 049.02.01 on backhaul technologies for small cells shows an urban environment with a concentration on 60 GHz links. This summarizes the various scenarios we encounter LOS, n/NLOS links. Access mechanism vary in deployment use cases like metro, rural and suburban area with large buildings contrasted to more open spaces.

2.3 Core Network

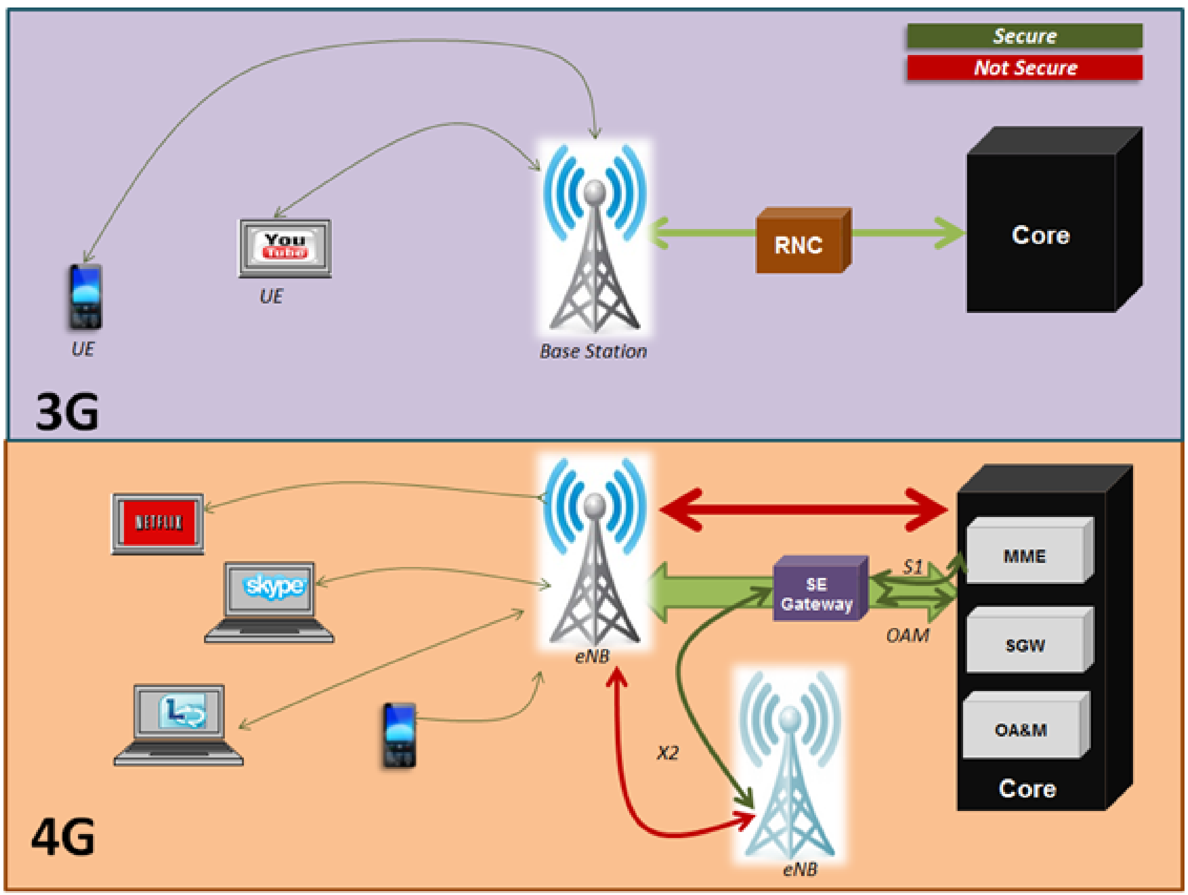

Figure 2.3: Access and Core Networks

From Fig. 2.3 access network is the part where the user connects to an AP, data from multiple APs are aggregated and transferred over various backhauls. Core network does the authentication, aggregation, mobility management, pricing and channel monitoring.

Under System Architecture Evolution (SAE) which is an evolution of General packet radio service (GPRS) core network, the following functions like handling various gateways and their signaling, operations, administration and management (OAM) does all the monitoring and troubleshooting.

2.4 Mobility

Mobility Management Entity (MME) handles the access network nodes, user authentication through Home Subscriber Server (HSS). It is responsible for monitoring acknowledgements, retransmissions, tracking and paging services.

When a radio network is simulated, we need the nodes to be mobile. There are various mobility models which represent the nodes and the paths traversed, each has its merits based on its application to individual deployment scenarios. Few of the models are random waypoint, random walk, Manhattan, Markovian, Brownian models, etc. The mobility of the user in this work is not a constrained one, it is limited to θ_i which ranges from $[-90, 90]$ degrees. This implies that a user's next position cannot be backwards i.e., the maximum possible deviation from their present position is to the right or left. But the user can reach any point on the map depending on their present direction and the number of steps they can take.

Chapter 3

Handovers

In network communications, handover or handoff is the user's choice to select a new BS when the present connection is weak. It depends on the availability of other BSs which offer better QoS and how weak the present connections is. During network planning, it can be seen as a process involving a new BS taking over an existing BS serving a user. The question of why handover is defined by the various parameters and their thresholds. And the question of when is defined by the handover algorithm. Few of the parameters and handover algorithms are listed below.

3.1 Parameters

There are various parameters for handover decision making like distance between the i-th user and the j-th BS $d_{i,j}$, RSS, SNR, SINR which are all interrelated. There are other parameters which are combinations or interpretations in a different form.

3.1.1 Received Signal Strength Indicator

RSSI is the measured power at the receiver before signal amplification. It can be understood that a power level less than the sensitivity of the receiver is a weak signal.

3.1.2 Signal to Noise Ratio

As the name indicates, it is the ratio of the required information, signal to unwanted noise ratio. It is mathematically represented as a logarithmic value and measured in decibels (dB). It is implied that both the signal and noise measurements are taken at the same point in a system.

$$SNR = \frac{P_{signal}}{P_{noise}} \tag{3.1}$$

Equation 3.1 gives SNR and has no units.

$$SNR_{dB} = 10 \log_{10}(SNR) \tag{3.2}$$

Equation 3.2 is a measure in dB.

$Shannon-Hartley$ theorem equation 3.3 connects the channel capacity (C), bandwidth (B) and the SNR of a communication channel. It is an indicator of the maximum data rate possible within the given conditions.

$$C = B \log_2(1 + SNR) \tag{3.3}$$

Where C is the channel capacity, B is the bandwidth of a given radio channel. Remember the SNR in equation 3.3 has no units is not a logarithmic measure in dB.

3.1.3 Signal to Interference plus Noise Ratio

SINR is more theoretical and helps is planning the capacity requirements of a wireless system. It gives the upper bound of channel capacity considering a particular signal power (P), sum of all interferences in network (I) and noise (N) according to the equation 3.4. It is often represented in decibels.

$$SINR = \frac{P}{I + N} \tag{3.4}$$

3.1.4 Quality of Service

QoS required by each user has a threshold. Each algorithm or decision for determining a QoS threshold is dependent on the requirements. We can categorize the limits as opportunistic, pessimistic and moderate respectively as high quality availability, high load sharing and regular requirement.

3.1.5 Capacity

Capacity is the data rate or bulk of services that can be accommodated on a single BS or the overall network. It is a measure of number of users supported or the data rates achieved.

3.1.6 Coverage

This is the area representation of the threshold power for good QoS. The coverage of a BS increases with power it radiates, this might not always be a good option considering the interference or noise it introduces in adjacent cells or channels. Lossy medium, fading are the reasons for a n-th order diminishing power, where n is dependent on the deployment area.

3.1.7 Latency and Jitter

Latency is the delay in transmission from starting node to end node, i.e. the transmission delay. Congestion of the network, processing time at routers contribute to this delay. Voice is more sensitive to delays than data. Typical latencies are in the order of 100 millisecond.

Differential delays between packets, the order of arrival constitutes to jitter. Voice is more sensitive to jitter hence buffers, sequencing packets is usually used to deal with it.

3.1.8 LTE indicators

Received Signal Received Power (RSRP), Received Signal Received QoS (RSRQ) and the previously discussed GSM indicator RSSI are utilized as indicators at present. When we talked about RSSI, it was implied that the indicator was throughout the pass band. When we discuss RSRP, RSRQ a mention of subcarries and reference signals is encountered. The bandwidth is divided into subcarriers and few of the subcarries take up the role of reference signals. RSRP is an average over the subcarriers and gives a finer indication, RSRQ studies the quality of reference signals received by the present BS its connected to.

3.2 Classification

The actual handover between BS is a decision and the various schemes are classifed according to *who* decides, based on *which* parameter and *when* is it done. Most of the handover classifications here are parameter driven, so they make a decision based on the indicators we discussed in the previous section.

As shown in the Fig. 3.1, we encounter the various handovers situations between FBS and MBS. In a group of femtocells underlying a MBS, handover from a femtocell to macrocell is simpler as there are only few choices. Sufficient planning is required to transfer a user to one among a group femtocells especially when most of them can provide quality service and are available for resource allocation. In an open-access femtocell network, user may leave its serving MBS and switch to one of the FBSs. When large number of neighboring femtocells are available, a user has multiple choices for a new connection and some choices are better than others. Thus, it is required to investigate a method for cell selection during a handover procedure in order to maximize benefits of gained capacity and elimination of redundant handovers.

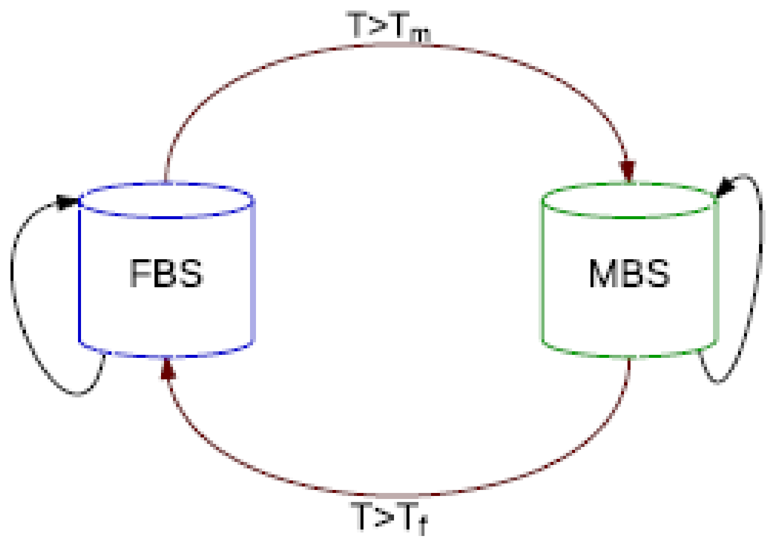

Figure 3.1: Handover Situations

3.2.1 Hard/Soft Handovers

Typically one imagines a switch of the user by connecting to the next BS after breaking its present BS. This is called a hard handover. Some services cannot afford an interruption between handovers. Soft handovers connect the user to the next BS before breaking the service from the present BS. Hence the user receives services from multiple BSs simultaneously.

3.2.2 Network/Mobile Controlled

The status of the present servicing channel needs to be continuously monitored. Almost all centralized networks have dedicated nodes to tap in information like congestion and bearer channels that carry control signals, synchronization sequences. These are network controlled handovers where the decision is based on the information by the network alone.

Sometimes user sends the status of the present BS's signal quality, other signals from neighbors or its position. This is more accurate because the information is real-time and location based than predictive. Although for gather this information, the UE needs to be smart and have processing capability. These kind of handovers are not exactly called mobile controlled because the operator has to still handle the transfer between BSs. We can classify them as mobile assisted handovers.

3.2.3 Predictive Rerouting

Although many parameters influence the quality of links, prediction is a strong resource for planning. The study of statistical information about handovers based on location, BS and studying for patterns helps make predictive handovers. Location based study could reveal some areas to have many users and multiple handovers. A strong BS handles more requests from users than a weaker BS. Even the study of routes taken frequently helps design congestion free networks. This is predictive rerouting.

Throughput based handovers (TBH) are one such example where some handovers to particular BSs have proven to repeatedly handle higher capacities or data rates. It is likely that BSs with higher capacities are given more weightage to serve a user. Dynamic rerouting strategies like TBH are possible.

3.2.4 RSSI based Handover Decision

From our previous discussion of LTE indicators, UE measurements based decision making is presently utilized in industry. RSSI, RSRP or a combination can be used to make a decision. As we can see, this type of handover scheme is mobile assisted, by providing the operator the bearer information.

3.2.5 Sojourn Time-based Handover Decision

If requests were measured in a systems where in the present requests are being handled and new requests are arriving, the sum of all transient (waiting) times is called the sojourn time. The application of stochastic process to the individual states of the number of users, total requests will give and average time for a BS to handle each request. Hence a decision based on the waiting time for a new request to a particular BS can be made.

3.2.6 Position based Handover Decision

During the implementation of a network, we plan it in blocks or map based. We observe the characteristics of a BS in different locations. This study based on location will show a repetitive behavior in signal quality BSs in similar environments. Hence many position based handover scheme are available. Consider few FBS with fixed area uniformly distributed on a map (no dead zones, an ideal case), a handover scheme defining a user to connect to the BS based on its location on the map is an example. This is overly simplified because lots of factors like fading, obstacles, hidden nodes are not being considered but there are models which do.

3.2.7 Heuristic Scheme

A heuristic is aimed at getting to algorithms at are near optimal, complete to the model we like to propose. These are particularly important when a head on solution cannot be obtained mathematically like NP-hard problem during load-balancing and optimization. We define a heuristic twice in the thesis to compare it with our proposed models.

There are other handovers like a scheme where requests are queued, reservation based schemes which prioritize service requests, handovers based on deployment scenario like metro, rural, sub-urban, indoor, outdoor, etc.

3.3 Related Work

In this section, we discuss earlier work aiming at efficient handover mechanisms which concentrated on various design issues like system latencies, ping pong effect, etc. In [26], a combination of received signal strengths from a serving MBS and a target FBS is considered as a parameter for efficient handover decision. This is a case when a handover decision is based on a combination factor and the critical weights are determined different for various situations. In [24], a mixture of mobility pattern and location prediction is taken as the measure to reduce the number of unnecessary handovers due to temporary femtocell visitors.

A new handover decision algorithm based on RSS and velocity were considered in [25]. A hybrid access scheme and a femtocell-initiated handover procedure with adaptive threshold were studied in [27].

When it comes to making a proper handover decision, delay time is critical. It is not a latency induced by the system but a guard time to check the reliability of a BS. In [15], a study about the effect of latency in voice over IP (VoIP), which is delay sensitive, is realized with a Time division duplex (TDD) Orthogonal frequency-division multiple access (OFDMA) system to maintain required capacity. Overall capacity and handling delay sensitive services are emphasized. For co-operative radio networks the use of delay prediction and violation to decide a link to be suitable for switching, for spectrum control is introduced in [14]. In [12], a discussion on the performance of various services for call admission control algorithms is presented to study the lag in queuing packets according to latest 3G/4G standards for Long-term evolution (LTE) systems. On the subject of control, call admission and access control is discussed widely in [12], [13]. Monitoring process times at application layer by maintaining sessions with promising mobility management is detailed in [7].

In [8] distance based handover decision algorithm is proposed and this is well suited for most situations considering the fact that SNR, SINR are all derived from it. Local neighbor cell list maintenance while looking for missing hidden nodes through a map is presented in [10]. An important aspect is the topology generation or knowing the entire map for the purpose of location based list updates. Other inclusions are a management server which maintains a list of correspondent to a BS relative to its neighbors. MOBIKE method is realized as a requirement for femtocell networks to support vertical handovers between legacy and flat mode to give uninterrupted, delay sensitive services like VoIP in [11]. A method involving femtocell access point and its role on maintaining sessions through IPSec and key exchange IKE2 to secure data communicated between verticals is presented. For table assisted handovers in femtocell networks based on future prediction with metrics like availability of femtocell, RSS at the desired location of service needs to be maintained or refreshed periodically. [16] suggests maintaining lists and prioritizing nodes for prediction. The study is about MANETs but weight assignment to cluster heads in Mobility Prediction based Weighted Clustering Algorithm (MPWCA) can be related for similar assignments. Decreased area under local cluster heads, solving of a minimizing problem though reduced number of hops has been of focus.

As our focus is on providing stable handovers wherein a user is associated with a single FBS for maximum possible time, the above contributions were noted. A map based analysis is needed to keep track of user association and number of connections to each BS. Suggestions for synchronization over internet between femtocells and macrocell are through global positioning system (GPS) among other methods. Choosing a factor for user assignment is important as most of the factors are interrelated and this may lead to redundancy and unnecessary computational complexity.

We finish up this chapter which noted the parameters that assist in handovers, the various classification or types of handovers and the related work in this area of research. We now introduce the proposed schemes of this thesis in the next two chapters.

Chapter 4

Counter based Handover Scheme

Consider the femtocell network in Fig. 4.1, with FBS's (indexed from 1 to $X-1$) deployed within the coverage area of the MBS (indexed X). We find three scenarios based on a FBS's distances from MBS as completely inside, partially inside and completely outside MBS's area. In case of a partially inside, we observe the user equipment (UE) to be out of range of MBS but available to FBS. We assume the MBS and $X-1$ FBS's are well synchronized over internet backhaul at any instant of time occupying the same spectrum to communicate with mobile users.

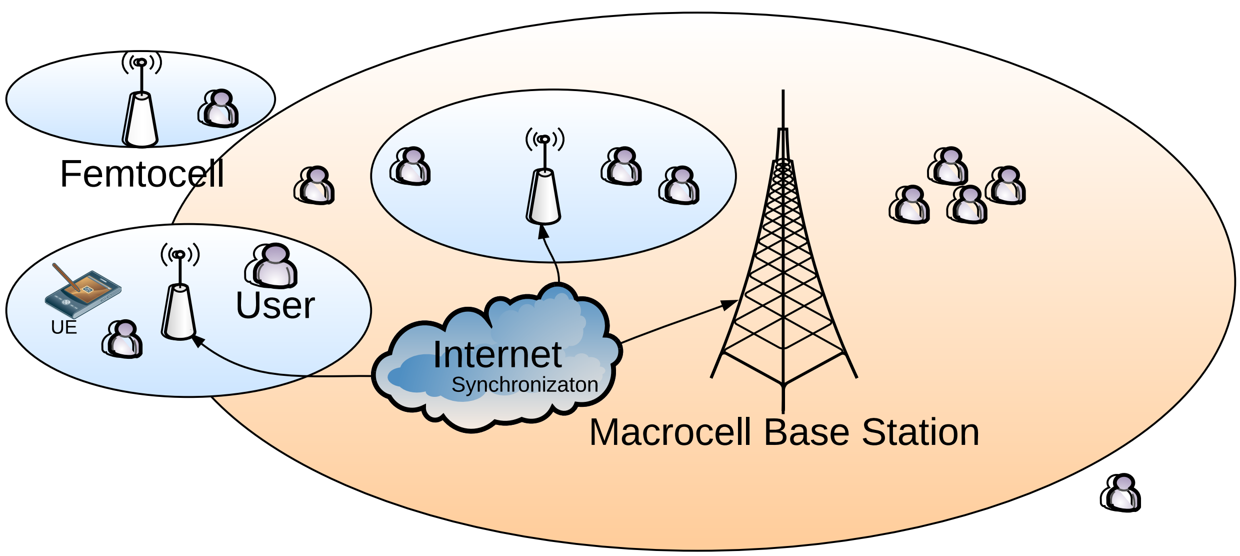

Figure 4.1: Femtocell Network

Three handover schemes are explained in the sub-sections which vary from each other based on the weightage given to parameters for making handover decision. The parameters utilized are SINR which is a combined measure of a wireless channel's quality, fairness as QoS which is related to the later and the guard or delay time for which a MBS or FBS maintains a threshold SINR before handover.

4.1 Heuristic Scheme: Opportunistic Users

This scheme serves as a base model to contrast our proposed schemes 1 and 2. When a user requests service, FBS with the best SINR value is chosen for handover. Priority for making a handover decision just based on SINR neither considers fairness to other users nor overall network performance. To consider the fairness among users, we assume the bandwidth is equally allocated to all users connected to the same FBS. Then, a heuristic solution is proposed that each user j chooses a FBS with the highest $\eta_{i,j}$ to connect. However, this approach does not address the QoS problem of each user, especially when all users are close to one FBS and connected to it. At a time interval if an FBS offers good SINR for users above the limiting values Y_{max}, we are presented with two issues. Opportunistic users tend to switch between FBSs even though the service provided by existing FBS is sufficient and secondly new users in the network who burden the already saturated FBS with increase in connections more than Y_{max} users, decreasing the overall network capacity.

4.2 Scheme 1: Grouping Users

User classification is the theme of this scheme where users with in a range of SINR values are grouped into levels. Scheme 1 addresses all the issues with Heuristic scheme adding a slight compromise in quality provided to each user and thereby increasing the total network capacity and user fairness. Blocking users with SINR values below λ_1 decreases the load on individual FBS's as these users try connecting unnecessarily. When it's time for a user to handover, we check for a list of FBS with best SINR that is FBS's on same level $\mathcal{L}$ and checking for its availability. With these small computations included in the algorithm, making a decision is bettered by reducing unnecessary handovers.

Table 4.1: Notations

Symbol	*Definition*
X	The number of femtocells
Y	The number of all users
P_0	Transmit power of the MBS
$G_{0,k}$	Channel gain from the MBS to the k-th user
P_i	Transmit power of the i-th FBS
$G_{i,k}$	Channel gain from the i-th FBS to the k-th user
C_k	The capacity at the k-th user
B	Network bandwidth
Y_i	The number of users served by the i-th BS
σ^2	Noise density
$I_{i,j}$	The interference at the j-th user from other BS's
I_j	The sum of desired power and interference at the j-th user
$\eta_{i,j}$	The percentage of desired power in I_j
U_i	The set of users connected to the i-th BS
$\mathcal{Q}$	QoS level matrix
$\mathcal{A}$	Assignment matrix
$\mathcal{F}$	The set of all BS's
$\mathcal{U}$	The set of all users

4.3 Scheme 2: Dwell Time

When the number of users is few and the serving FBS's are comparatively high, there is scope for unnecessary handovers. This scheme of operation addresses this issue by including a guard times T_f and T_m for FBS and MBS respectively. This time implies that a FBS is reliable enough to handover a user from MBS, this algorithm is discussed in detail below.

Cell association was introduced in the previous section where all users were not in motion. Now, we consider mobility in our system model. Since the coverage of femtocell is very small, it is essential to provide seamless handovers to and from femtocells within macrocell coverage. We assume both femto-to-macro and macro-to-femto handover requires multiple-times confirmation to prevent temporary visitors. We reduce the number of handovers by adopting two parameters T_m and T_f. The handover among BS's only takes place when the candidate BS has better connection for at least T_m (or T_f for femtocell) times. Our handover algorithm is described in table 4.2.

Table 4.2: Counter based Handover Algorithm

Initialize $T = 0$
While 1
  If user j is connected to the i-th FBS
    While $T < T_m$
      If $\eta_{0,j} > \min_{k \in U_0} \eta_{k,0}$ and $\eta_{0,j} > \eta_{i,j}$
        $T = T + 1$
      Else
        $T = 0$
      End if
      Wait for a time interval
    End while
    User j is connected to MBS and reset T
  End if
  If user j is connected to the MBS
    Find $\mathcal{F}_i = \{i | \eta_{0,j} < \min_{i \neq 0} \eta_{i,j}\}$
    While $\mathcal{F}_i$ is not empty
      Find $i^* = \arg\max_{i \in \mathcal{F}_i} \min_{j \in U_i} \eta_{i,j}$
      While $T < T_f$
        If $\eta_{0,j} < \min_{k \in U_{i^*}} \eta_{i^*,k}$
          $T = T + 1$
        Else
          $T = 0$ and break
        End if
        Wait for a time interval
      End while
    End while
    User j is connected to the j^*-th BS and reset T
  End if
End while

4.4 Assumptions and Equations

We consider a total of Y mobile users with their UE, located randomly inside the macrocell coverage area. We can consider the bandwidth to be allocated equally to all serving users. We assume an additional white Gaussian noise (AWGN) at mobile users with power density σ^2. Let $G_{0,k}$ be the channel gain between the MBS and k-th user and P_0 be the MBS transmit power. Similarly, P_i and $G_{i,k}$ where $i \geq 1$ denote the transmit power of the i-th FBS as well as the channel gain between the i-th FBS and k-th user. The capacity at the k-th user from its serving MBS is given by:

$$C_k = \frac{B}{Y_0} \log_2 \left(1 + \frac{|G_{0,k}|^2 P_0}{\sigma^2 + I_{0,k}}\right) \tag{4.1}$$

where B is the network bandwidth, Y_0 is the number of MBS users, and $I_{0,k} = \sum_{i=1}^{M} |G_{i,k}|^2 P_i$ is the interference from FBS's. The capacity at the j-th user from the i-th FBS is represented by:

$$C_j = \frac{B}{Y_i} \log_2 \left(1 + \frac{|G_{i,j}|^2 P_i}{\sigma^2 + I_{i,j}}\right) \tag{4.2}$$

where Y_i is the number of users served by the i-th FBS and $I_{i,j} = \sum_{l=0,l\neq i}^{X} |g_{l,j}|^2 P_l$ is the interference from the MBS and other FBS's.

The capacity at the j-th user from the i-th BS is written by combining eqations (4.1) and (4.2) as follows:

$$\begin{aligned} C_j &= \frac{B}{Y_i} \log_2 \left(1 + \frac{|G_{i,j}|^2 P_i}{\sigma^2 + I_j - |G_{i,j}|^2 P_i}\right) \\ &= \frac{B}{Y_i} \log_2 \left(\frac{\sigma^2 + I_j}{\sigma^2 + I_j - |G_{i,j}|^2 P_i}\right) \\ &= \frac{B}{Y_i} \log_2 \left(\frac{1}{1 - \eta_{i,j}}\right) \end{aligned} \tag{4.3}$$

where $\eta_{i,j} = |G_{i,j}|^2 P_i / (\sigma^2 + I_j)$ is the percentage of desired power in I_j, and $I_j = \sum_{i=0}^{X} |G_{i,j}|^2 P_i$ is the sum of received power from its serving BS and interference from other BS's . Note that I_j is a constant for each user, and it does not depend on which BS the user is connected to.

4.5 Network Capacity and User Assignment

Our purpose is to maximize the total network capacity and hence we start by assigning users in groups. We define U_i as the set of users connected to the i-th BS, we have $Y_i = |U_i|$. The objective function deduced from (4.3), can be expressed as:

$$\text{Maximize: } C_{tot} = \sum_{i=0}^{X} \frac{B}{Y_i} \sum_{j \in U_i} \log_2 \left(\frac{1}{1 - \eta_{i,j}} \right) \tag{4.4}$$

When we solve the above problem, the optimal answer is that each BS chooses one user with the highest $\eta_{i,j}$ to connect. Therefore, this system can only accommodate at most X (the number of BS's) users. This way the highest network throughput is achieved from solution by assigning only one best user to each BS. Since the bandwidth is assumed to be equally divided among users, this results in extremely low capacity for each user. This is unfair to other users as their servie request are rejected. To guarantee the minimum QoS at all serving users, we assume $\eta_{i,j}$ of each user from its serving BS must be greater than the threshold λ_1. On the other hand, some users may jeopardize the total throughput when the users who do not have any good connection to any of BS's. Obviously, an improvement will result from blocking such users and therefore, the users with $\eta_{i,j} < \lambda_1$ should be blocked.

From the above discussion, we find that the maximum total network capacity is achieved when each BS chooses only one user with the highest $\eta_{i,j}$. However, this scheme is not fair for other users because their service requests are refused. With network performance and fairness as parameters, an agreement or trade off between them needs to exist. Before introducing our scheme, we adopt l thresholds λ_i's to classify $\eta_{i,j}$ into $l+1$ levels:

$$Q_{i,j} = \begin{cases} 0, & \eta_{i,j} < \lambda_1 \\ l, & \lambda_q \leq \eta_{i,j} < \lambda_{q+1}, q \in \{1, \cdots, l-1\} \\ l, & \eta_{i,j} \geq \lambda_{q+1} \end{cases} \tag{4.5}$$

According to $Q_{i,j}$, the users are divided into $l+1$ groups. Our idea is to group these users and allow them to connect to the same BS. We can see the η values of the users in the same group are very close. Thus, we can replace $\eta_{i,j}$ with the average value. Then, the objective function in (4.4) can be rewritten as:

$$\begin{aligned} C_{tot} &= \sum_{i=0}^{X} \frac{B}{Y_i} \sum_{q=0}^{l} \sum_{j \in U_i, Q_{i,j}=q} \log_2 \left(\frac{1}{1-\eta_{i,j}} \right) \\ &\approx \sum_{i=0}^{X} B \sum_{q=0}^{l} \frac{Y_{i,1}}{N_i} \log_2 \left(\frac{1}{1-\overline{\eta}_{i,l}} \right) \end{aligned} \tag{4.6}$$

where $Y_{i,l}$ is the number of users connected to the $i-th$ BS at the $(q+1)$-th level and $\overline{\eta}_{i,l}$ is the average value of η in this group. We can denote C_{NC} and C_{UC} as the total network capacity achieved by maximizing network capacity in (4.4) and (4.6), respectively. Following the maximization based on the equations we arrive at the following cell association algorithm presented in table 1.

Table 4.3: Cell Association Algorithm

```
Initialize 𝒬, ℱ and 𝒰
For q = l to 1
    While ℱ is not empty and 𝒰 is not empty
        For i ∈ ℱ
            For j ∈ 𝒰
                If Q_{i,j} = l
                    Remove j from 𝒰
                    Set a_{i,j} = 1
                End if
            End for
            If ∑_j a_{i,j} is not zero
                Remove i from ℱ
            End if
        End for
    End while
End for
```

Chapter 5

Stability based Handover Scheme

We consider a network with M macrocells and N femtocells. The set of MBS and FBS is denoted by $\mathcal{M}$ and $\mathcal{F}$, respectively. There are K mobile users traveling within the coverage of MBS's and FBS's. Our focus being on reduced processing time and resulting fast handover mechanism by realizing nodes to occupy a unique queue which can be broadcasted as a list i.e., assuming complete synchronization. The map could be represented as a (x,y) co-ordinated system representing nodes FBS and MBS which are fixed positions for our scenario.

5.1 Connection Time

The distance between user i and FBS j is denoted by $d_{i,j}$, which can be computed as:

$$d_{i,j}^2 = (x_i - a_j)^2 + (y_i - b_j)^2 \tag{5.1}$$

where (x_i, y_i) and (a_j, b_j) are positions of user i and BS j. Denote θ_i as the moving direction and R_j as the coverage radius of FBS j. The distance from the current position (x_i, y_i) to the edge of the coverage, denoted by $S_{i,j}$, satisfies the following equation:

$$(x_i + S_{i,j}\cos\theta_i - a_j)^2 + (y_i + S_{i,j}\sin\theta_i - b_j)^2 = R_j^2 \tag{5.2}$$

Combining (5.1) and (5.2), we have the following quadratic equation:

$$S_{i,j}^2 + 2\eta_{i,j}S_{i,j} + d_{i,j}^2 - R_j^2 = 0 \tag{5.3}$$

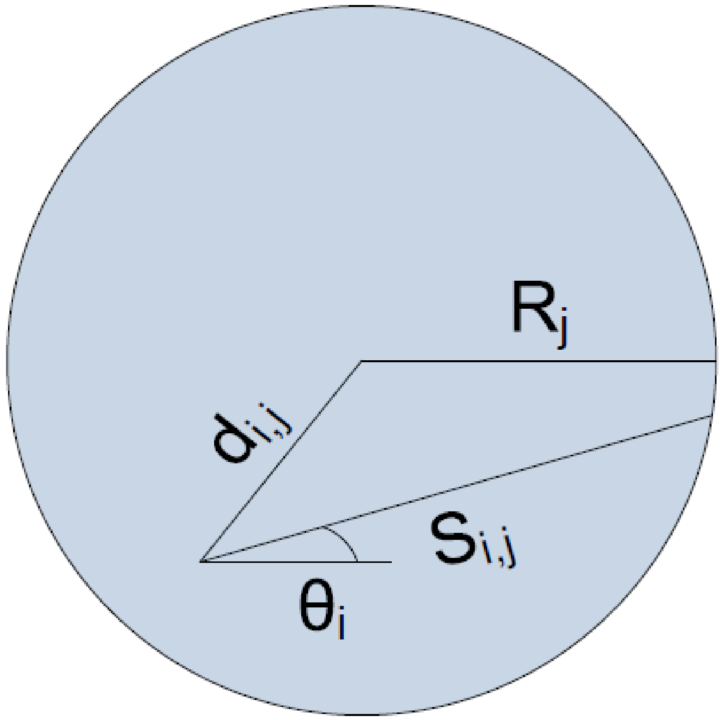

Figure 5.1: The Definition of Parameters in Connection Time

where $\eta_{i,j} = (x_i - a_j)\cos\theta_i + (y_i - b_j)\sin\theta_i$. It has two solutions. Since $S_{i,j}$ should be greater than 0, we choose the positive value

$$S_{i,j} = \sqrt{\eta_{i,j}^2 + R_j^2 - d_{i,j}^2} - \eta_{i,j} \tag{5.4}$$

If user i stays within the coverage of FBS j, then $d_{i,j} \leq R_{i,j}$. Denote the velocity of user i is v_i. Then, the estimated connection time that user i stays within the cell j can be given by

$$T_{i,j} = \frac{S_{i,j}}{v_i} \tag{5.5}$$

$T_{i,j}$ is used to estimate how long user i will stay within cell j. It means inter-cell handover is not necessary within $T_{i,j}$. Therefore, the larger $T_{i,j}$, the less unnecessary handovers.

5.2 Service Rate

The second factor is service rate each FBS can provide. Let P_j be the transmit power of FBS j and $h_{i,j}$ be channel gain between user i and FBS j. We assume an additional white Gaussian noise (AWGN) at mobile users with power density N_0. The downlink data rate, denoted by $C_{i,j}$, at user i provided by FBS j is given by:

$$\begin{aligned} C_{i,j} &= B_j \log_2 (1 + \gamma_{i,j}) \\ &= B_j \log_2 \left(1 + \frac{|h_{i,j}|^2 P_j}{N_0}\right) \end{aligned} \tag{5.6}$$

where B_j is the bandwidth FBS j can provide and $\gamma_{i,j}$ is SNR from FBS j to user i.

Usually, FBS is able to provide larger service rate than MBS. However, the coverage of FBS is relatively smaller than that of MBS and the time that mobile user stays within the femtocell is very small.

5.3 Handover Initiation

In this step, the mobile user compares the QoS periodically with a critical value C_h. If QoS of the present FBS j' is less than C_h, it will start spectrum sensing process to find a set of available FBSs. The list of candidate FBS can be expressed by:

$$\mathcal{B}_i = \{j | C_{i,j} > C_h \text{ and } T_{i,j} > T_h \text{ and } j \neq j'\} \tag{5.7}$$

where T_h is handover latency. The mobile user should stay within the candidate cell until the handover process is completed. During the spectrum sensing process, the measurement of user position, velocity, SNR, and bandwidth is performed.

Table 5.1: Stability based Handover Algorithm

WHILE True
IF QoS of the connected network less than the threshold C_h
Start spectrum sensing
Find the list of candidate BSs $\mathcal{B}_i$
IF $\mathcal{B}_i$ is empty
Continue with the connected network
ELSE
Send the measurement results to decision module
Select the optimum BS using evaluation technique
Switch to the selected BS
END IF
ELSE
Continue with the connected network
END IF
Wait for a small time interval
END WHILE

5.4 Handover Decision

The measurement results are sent to the handover decision module. With the measurement results, we can compute connection time $T_{i,j}$ and service rate $C_{i,j}$ as in (5.5) and (5.6). We define the following metric to evaluate the FBSs.

$$L_{i,j} = \alpha T_{i,j} + (1 - \alpha) C_{i,j} \tag{5.8}$$

where α is a weight $0 \leq \alpha \leq 1$. In the decision process, the BS j^* with the highest $L_{i,j}$ is selected as the target BS.

$$j^* = \max_{j \in \mathcal{B}_i} L_{i,j} \tag{5.9}$$

The handover diagram is shown in Fig. 5.2, at every iteration, users thresholds are checked and categorized according to the 5.1. The combination factor is then the measure for the strength of association each user has with all BSs. A list of eligible and available BSs is created for making handover decision. At every iteration, equal priority is given to all users to connect to any BS irrespective of their state, thus providing the fairness. Considering the advantage of picking a BS for the list of $\mathcal{B}_i$ to MBSs during the selection process, we first look for any available FBSs. This step is taken because we do not want to load the MBS with users when FBSs are available. This process of scanning for available BSs is a continuous one. The inputs to the handover algorithm are provided periodically. The inputs include the present position, direction and velocity of the user. The typical value for the maximum number of users handled by FBS is $Nf = 10$. The connection time determination happens only when the user is withing the radius of the FBS i.e. $r = 10$ and is zero otherwise.

In the last two chapters we have introduced and detailed the proposed schemes namely the Counter based scheme and the Stability based scheme. The mathematical equations that govern them and the system models were discussed. In the following chapters, we analyze their performance.

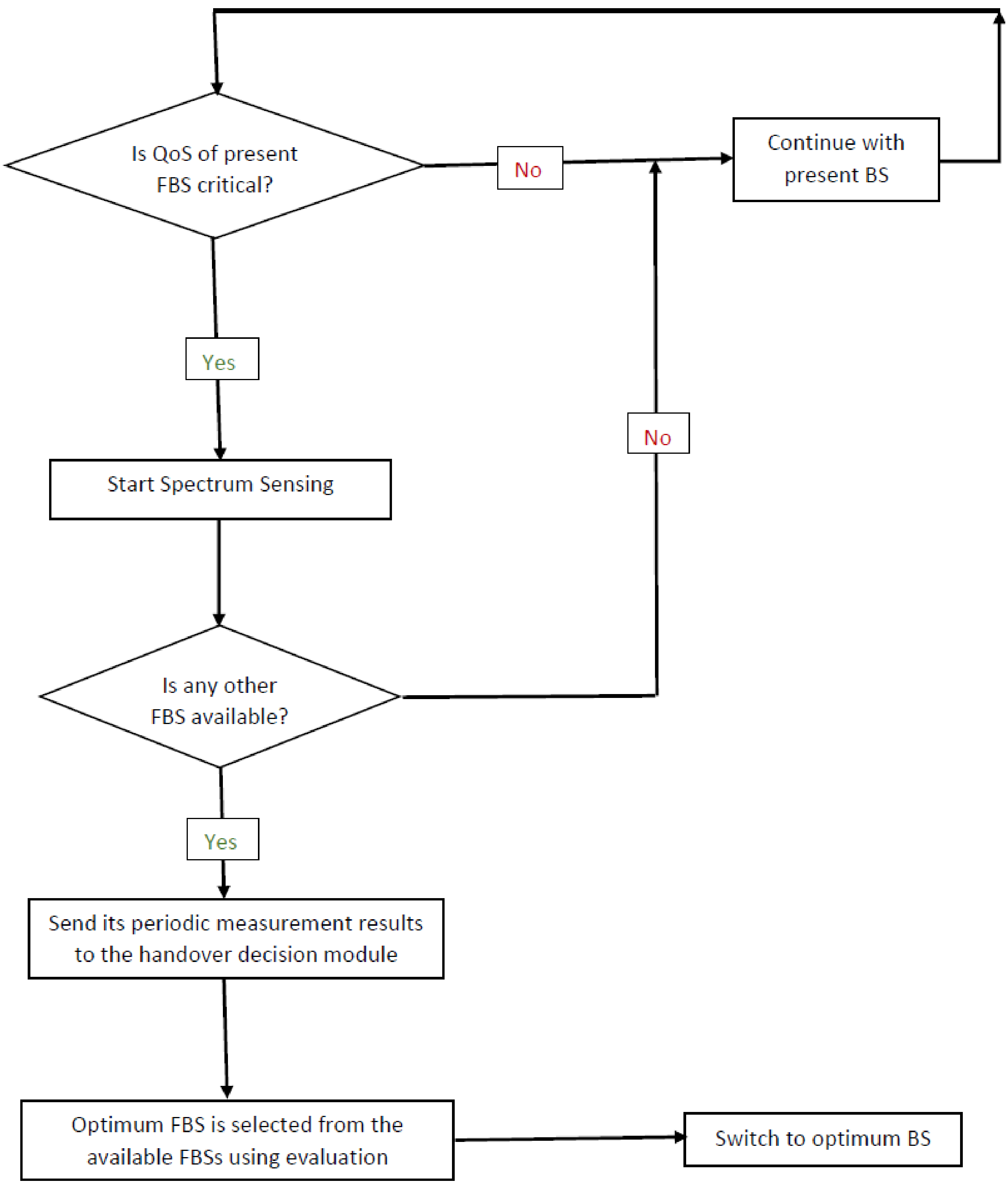

Figure 5.2: The flowchart of handover algorithm

Chapter 6

Results for Counter based Scheme

We evaluate the performance of this scheme under different conditions on a test bed created in MATLAB. The data collected is an average of 10 simulation runs plotted graphically. Updates from users are received at every tenth of a second mainly maintaining the speed v, direction and present position (X_p,Y_p). From the information available the distance from each user to respective BSs, $d_{i,j}$ is computed to find the channel gain $h_{i,j}$, SNR, capacity and connection time are deduced. The free space propagation model is considered for calculating the pathloss and hence SNR. Shadowing effect is also included in SNR calculations which follows a normal distribution. Capacity is then a measure of SINR from the Shannon's formula. Connection time is a function of the direction and $d_{i,j}$, the mathematical model for which was illustrated in the previous section.

6.1 Average number of handovers vs. number of users

In Fig. 6.1, we plot the impact of the number of users on the average number of handovers. The count for the number of handover includes FBS to MBS, FBS to other FBS transfers. We increase the total number of users in the network Y, from 20 to 100 with step-size 20. We find that when the number of users is less than 60, the average number of handovers in the heuristic scheme grows larger with the number of users. It is due to the fact that the more users, the more frequently handovers take place. Once the number of users gets beyond 60, the average number of handovers decreases because the probability of finding available FBSs gets smaller. However, the average number of handovers in our proposed scheme is much lower than that of the heuristic scheme and decreases slowly with the number of users. Scheme 2, performs better under less ($N = 20, 40$) number of users

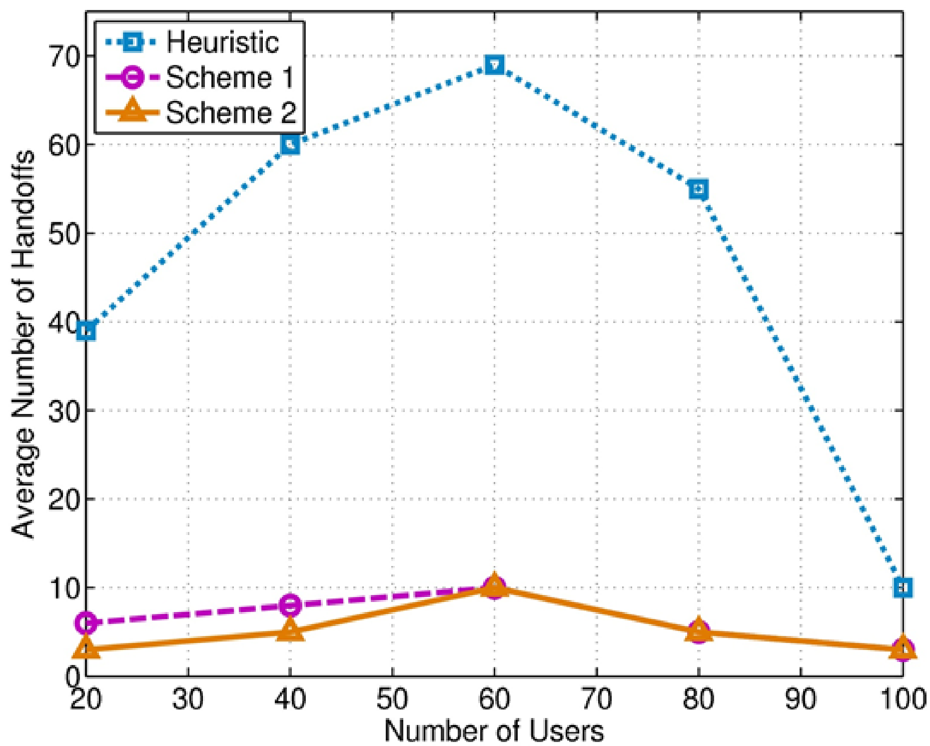

Figure 6.1: Average number of handovers vs. number of users

Table 6.1: Simulation Parameters for Counter based Scheme

Symbol	*Definition*
$M = 9$	The number of femtocells
$B = 10$ MHz	Total network bandwidth
$P_0 = 43$ dBm	Transmit power of the MBS
$P_i = 31.5$ dBm	Transmit power of the i-th FBS
$PL_0 = 28 + 35\log_{10}(d)$	Path loss model for MBS
$PL_i = 38.5 + 20\log_{10}(d)$	Path loss model for FBS
$\delta_0, \delta_i = 6$ dB	Shadowing effects for MBS and FBS
$N_{max} = 10$	Maximum number of users per BS

contrasted to peak number of users ($N = 60$). This could be understood by knowing that the SINR values to choose from changes very rapidly due to the fact that all the FBS are available to provide services to the few users.

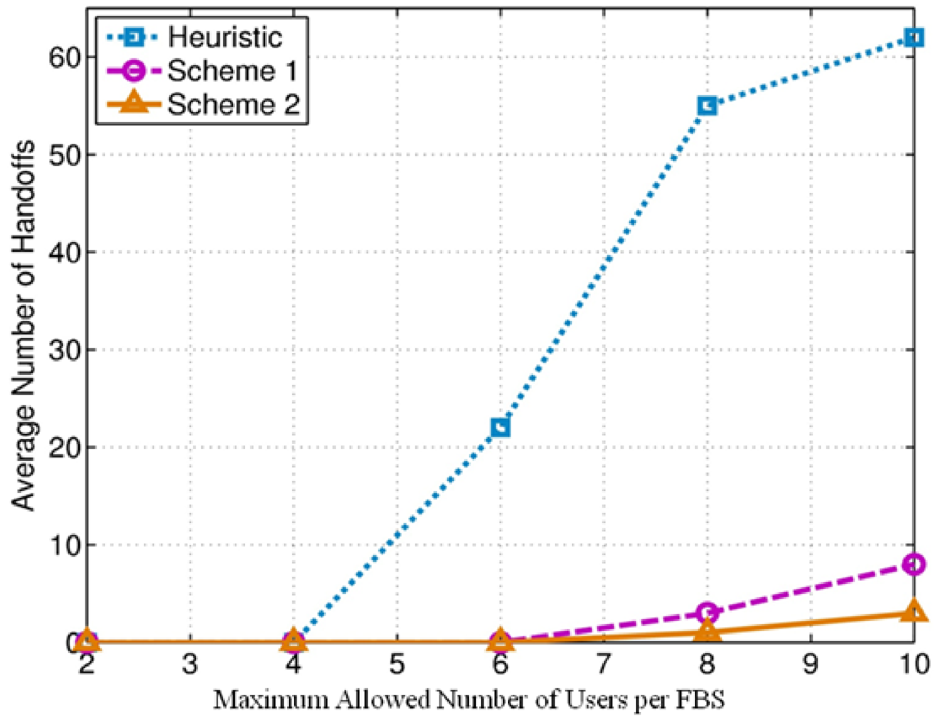

Figure 6.2: Average number of handovers vs. Y_{max}

6.2 Average number of handovers vs. maximum number of users each FBS

In Fig. 6.2, we examine the impact of maximum allowed number of user per FBS versus the average number of handovers. We increase Y_{max} from 2 to 10 with step-size 2. When Y_{max} is below 4, the average number of handovers is close to 0 for both heuristic and proposed scheme because all FBSs are busy and users are not allowed to connect to the new FBS. Beyond this critical point, the average number of handovers in proposed scheme is significantly reduced compared with heuristic scheme.

Busy hour traffic represents the peak time when maximum number of service requests are handled by the network. Peak in a day represents the maximum data rate handled by a network in a particular day, this function helps in traffic engineering. Also notice non-busy hour traffic i.e., when requests are fewer and resources are widely available. We need to understand that there's a cost involved in making a handover, hence should be done only when necessary. Preventing several unnecessary handovers will result in a much power efficient network.

Chapter 7

Results for Stability based Scheme

We compare the results of the proposed scheme to a heuristic. Heuristic scheme follows an algorithm similar to the proposed model with less computational complexity. Here, the complexity is relative to the heuristic. During the calculation of SINR, we collect distance information of each user to nearby FBSs. Connection times are derived from the same information within the same loop, by including a minor division of distance by velocity. According to the algorithm, a user is assigned to a new FBS which has the maximum SNR with it. In a huge coverage area a heuristic scheme might just be enough but for the present case of dealing femtocells with such short coverage areas, you will notice the need of the proposed scheme.

7.1 Average number of handovers vs. number of users

In Fig. 7.1 the impact of the number of users N on the performance of the network is depicted. We vary the number of users from 100 to 1000 and note the average number of handovers at every instance. Initially, when N is small, the network is free and users find stable FBSs. As the number of users increase, the handovers increase too, but this does not continue. When the number of users increases to a point where the network is overwhelmed, saturation is reached. It can be inferred that beyond a point of saturation, the service to new users will be rejected due to the fact that all FBSs are busy.

7.2 Average number of handovers vs. velocity of users

Fig. 7.2 is of more importance to our study. The area of coverage for a FBS is less than that of a MBS due to the difference in power between the MBS and FBS, the latter

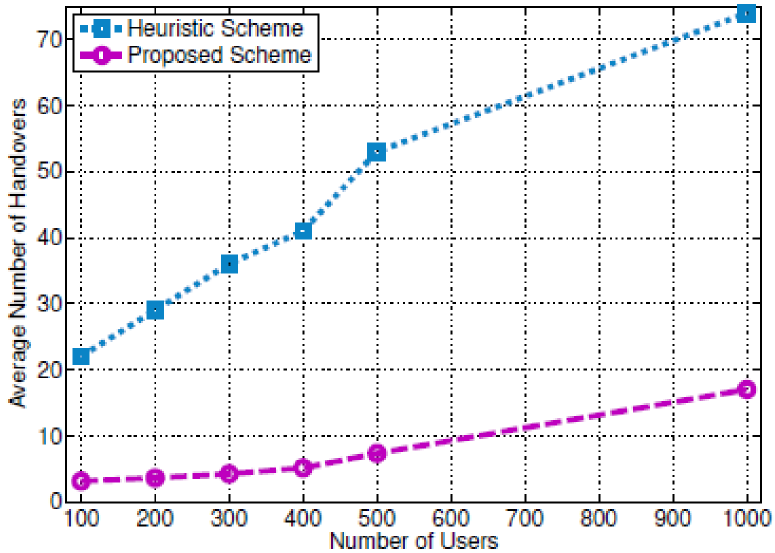

Figure 7.1: Average number of handovers vs. number of users

Table 7.1: Simulation Parameters for Stability based Scheme

Symbol	*Definition*
$N = 1000$	Femtocells randomly deployed under the area in study
$M = N/100$	Macrocells deployed uniformly covering the area
$B = 10$ MHz	Total network bandwidth
$P_0 = 43$ dBm	Transmit power of the MBS
$P_i = 31.5$ dBm	Transmit power of the i-th FBS
$PL_0 = 28 + 35\log_{10}(d)$	Path loss model for MBS
$PL_i = 38.5 + 20\log_{10}(d)$	Path loss model for FBS
$\delta_0, \delta_i = 6$ dB	Shadowing effects for MBS and FBS
$N_{max} = 10$	Maximum number of users per BS

being lower. It implies that velocity has a prominent impact on FBS which typically covers a radius of 10 meters. We can notice from the figure that the number of handovers increases with the increase in velocity v from 5 to 30. It can be noted that at higher velocities, the performance of the proposed scheme is way better than that of the heuristic. This can be understood based on the stability provided by the choice of FBS selected by user with critical connection time.

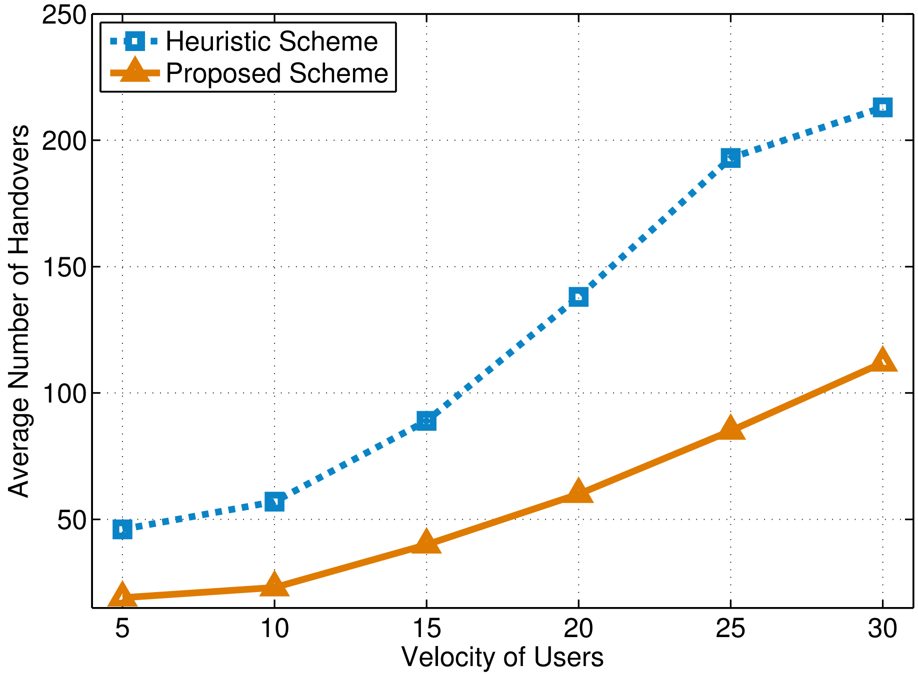

Figure 7.2: Average number of handovers vs. velocity of users

7.3 Average number of handovers vs. different weights for parameters

In Fig. 7.3 we prioritize our parameters to check the effect of their weights (α). α is varied from 0 to 1 in steps of 0.25 implying the contribution of SNRs to the total factor for handover decision. It can be seen that the average number of handovers is highest when α =1 i.e., when only SNR is considered for handovers. The other cases considering connection time's contribution have nearly the same average handover value.

7.4 Throughput vs. number of users

Average throughput is the measure of overall network capacity or bandwidth utilization. Fig. 7.4 shows that throughput increases with the number of users which is because more users are available for each FBS to handle. But it does have saturation, if the number of users is beyond a point they block the other users with requests for service and cause network

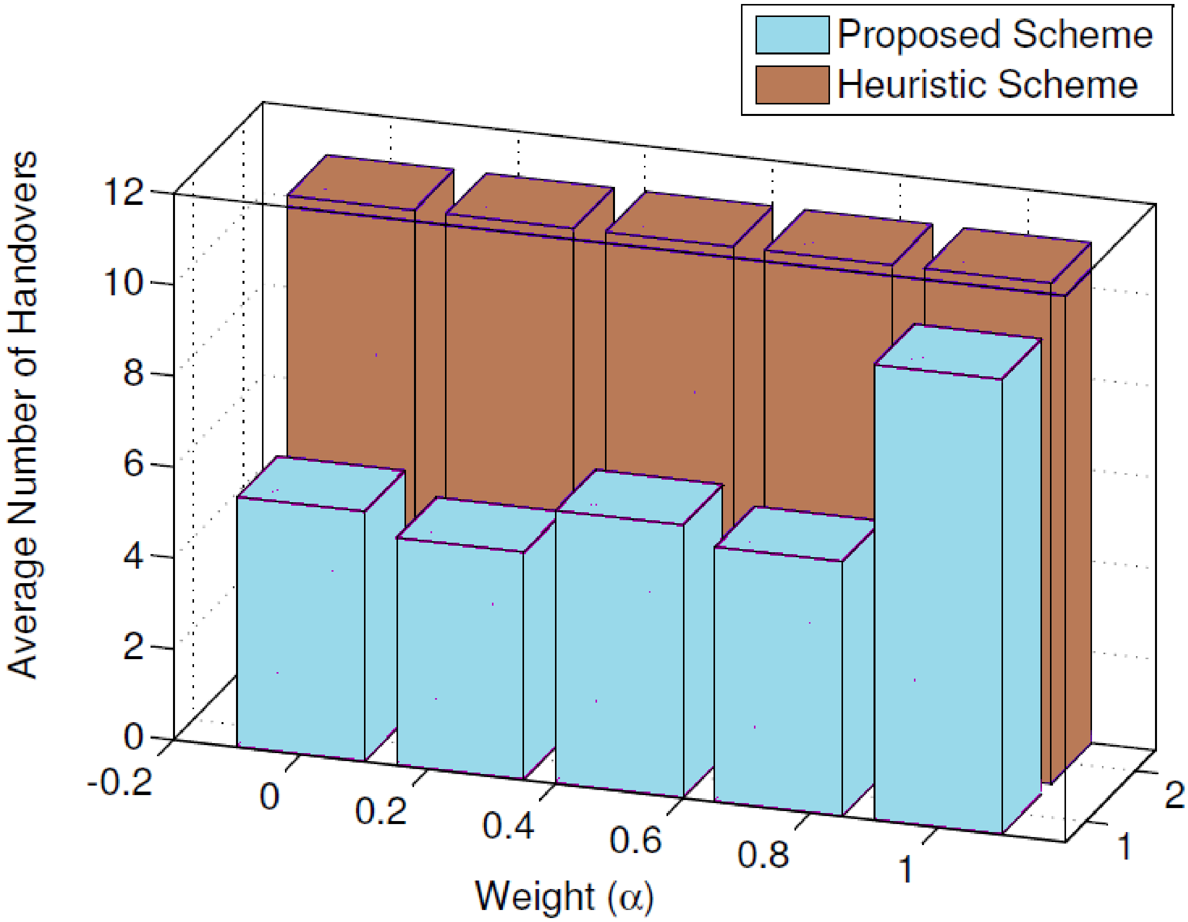

Figure 7.3: Average number of handovers vs. weight combinations

congestion. All the figures illustrated above show that the proposed scheme performs better in comparison to a heuristic.

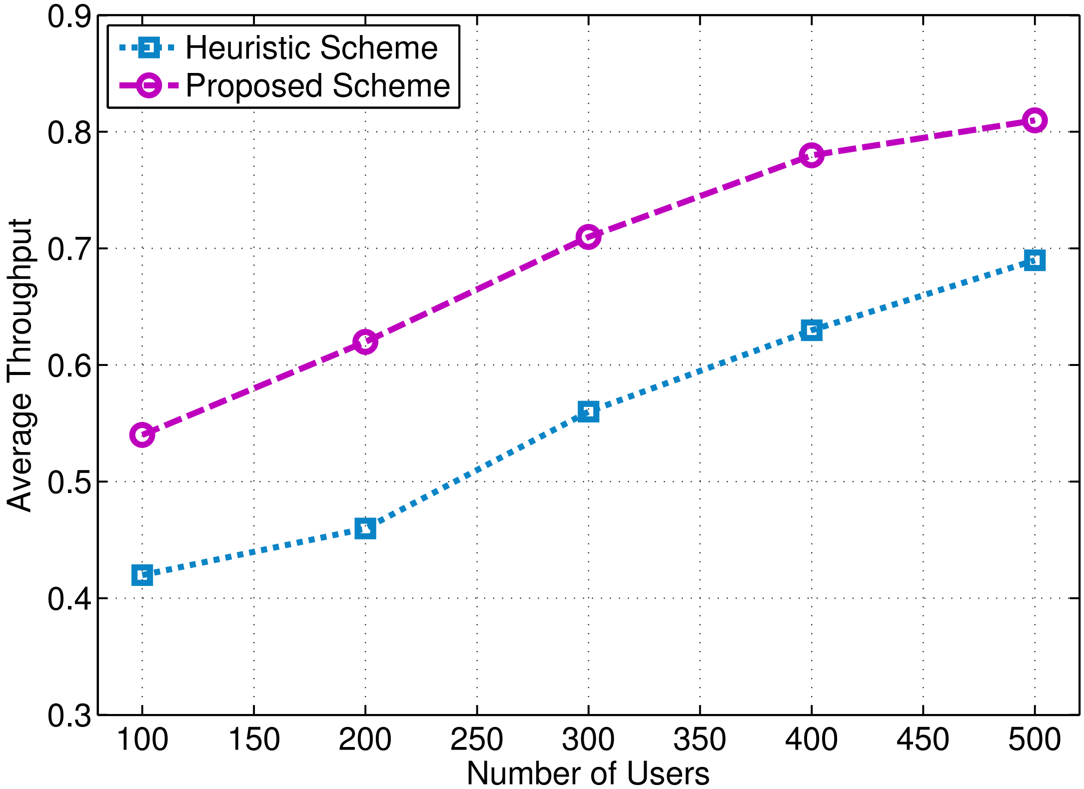

Figure 7.4: Average throughput vs. number of users

Chapter 8

Conclusion

We observed the need of implementing femtocell technology in the next generation communications. Even though the technology is promising, some issues are to be dealt with before we harvest their full potential. One important issue is the efficient management of handovers among BSs. The algorithms that can be accommodated on a network have a trade off between the complexity and the resource availability *vs.* the overall benefit in terms of better QoS and throughput gains. We proposed and studied two handover schemes whose viability depends on the requirements of the various distributed networks.

In the counter based scheme, deciding the delay time requirements and utilizing the cell association algorithm for allocating each user to a single station was the primary theme. We tabulated the number of handovers for all the schemes introduced and simulation results were studied. We acknowledged the role played by proper decision making to prevent unnecessary handovers. Analysis of the results supports the effect of dwell times between MBS and FBS for limiting redundant handovers. We consistently observed our proposed scheme to reduce unnecessary handovers when the number of users in a deployment scenario are few. These considerable gains in conserving resources will enhance network capacity in total.

In the discussion of *stability* based scheme, we introduced the issue of fast handovers and described how traditional methods alone are not sufficient. We proposed the inclusion of connection time as a metric for determining the combination factor apart from SNR. The handover scheme proposed took into consideration fairness, QoS and minimum thresholds to determine each FBS's eligibility to serve a user. Based on the factor we analyzed, the set of users in a network are randomly distributed in various states. Then, we introduced a handover algorithm considering an *initiation* and *decision* as steps in conducting a stable handover. We observed that the proposed scheme for determining the combination factor and the algorithm for handover together contribute to a marked improvement needed by these special networks. Our results showed that the scheme was quite robust and the slight increase in the computational complexity did not compromise noticeable resources when compared to the benefits reaped.

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