HANDOFFS IN HIERARCHICAL MACRO/FEMTO NETWORKS AND AN ALGORITHM FOR EFFICIENT HANDOFFS

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Certificate

This is to certify that the work in the thesis entitled "HANDOFFS IN HIERARCHICAL MACRO/FEMTO NETWORKS AND AN ALGORITHM FOR EFFICIENT HANDOFFS" by Abhishek Mitra is a record of an original research work carried out by him during 2013 - 2014 under my supervision and guidance in partial fulfillment of the requirements for the award of the degree of Master of Technology in Electronics and Communication Engineering (Communication and Networks), National Institute of Technology, Rourkela. Neither this thesis nor any part of it, to the best of my knowledge, has been submitted for any degree or diploma elsewhere.

Place: NIT Rourkela
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ABSTRACT.

The surest way to increase the system capacity of a wireless link is by getting the transmitter and receiver closer to each other, which creates the dual benefits of higher-quality links and more spatial reuse. In a network with nomadic users, this inevitably involves deploying more infrastructure, typically in the form of microcells, hot spots, distributed antennas, or relays. A less expensive alternative is the recent concept of femtocells also called home base stations which are data access points installed by home users to get better indoor voice and data coverage.

In macro/femto hierarchical networks, one of the biggest challenges is ensuring efficient handoffs. Here in this thesis, we first evaluated received signal strength at mobile user using different path loss models (indoor and outdoor) which is the main criterion for performing handoff. We also obtained the interference and SINR scenarios for handoff performance. Then we derived some basic handoff parameters like handoff probability, radio link failure rate, ping-pong handoff for macro/femto environment. Finally we proposed an algorithm for efficient handoff. The main idea of the proposed algorithm is to combine the values of received signal strength from a serving macro BS and a target femto BS in the consideration of large asymmetry in their transmit powers. Numerical results show that there is a significant gain in view of the probability that the user will be assigned to the femtocell while keeping the same level of the number of handoffs.

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List of Abbreviations.

3GPP	3rd Generation Partnership Project
AE	Antenna Element
BS	Base Station
CDMA	Code division Multiple Access
CN	Core network
DSL	Digital subscriber line
FAP	Femtocell Access Point
FBS	Femto Base Station
FGW	Femtocell gateway
FMC	Fixed Mobile Convergence
GSM	Global system for Mobile Communication
HeNB	Home E-UTRAN Node B
HM	Handover margin
ISP	Internet service provider
LHO/EHO	Too late handover/Too early handover
LOS	Line of sight
LTE	Long Term Evolution
MBS	Macro Base Station
MS	Mobile Station
OFDM	Orthogonal Frequency Division Multiplexing

QoS	Quality of services
RB	Resource block
RLF	Radio link failure
RNC	Radio network controller
RSS	Received signal Strength
SON	Self organising network
SINR	Signal to Interference plus noise ratio
TTT	Time to trigger
UE	User Equipment
UL/DL	Uplink/Downlink
WCDMA	Wideband Code Division Multiple access
Wi-Fi	Wireless Fidelity
Wi-MAX	Worldwide interoperability for Microwave access

Chapter 1.

Introduction.

Introduction.

The best way to increase the system capacity of a wireless link is by getting the transmitter and receiver closer to each other, which creates the dual benefits of higher-quality links and more spatial reuse. In a network with nomadic users, this inevitably involves deploying more infrastructure, typically in the form of microcells, hot spots, distributed antennas, or relays. A less expensive alternative is the recent concept of femtocells — also called home base stations — which are data access points installed by home users to get better indoor voice and data coverage.

1.1.Background.

The concept of a compact self-optimising home cellsite has been documented since 1999. Alcatel announced in March 1999 that they would bring to market a GSM home basestation which would be compatible with existing standard GSM phones. They planned to launch the product in 2000 and forecast capturing 50% of the market of 120 million units the following year.

The system design re-used and modified the Cordless Telephony Standard (as used by digital DECT cordless phones), which was a forerunner of the UMA standard used in dual-mode WiFi/Cellular solutions today.

But now Femtocell technology has emerged as a most promising technology for home environments. It gives high coverage and capacity as well as it is very cost effective. Now various researches are going on for its better performance such as interference mitigation from macro cell, proper spectrum allocation etc.

1.2.Contribution.

Here we concentrated on one the most important issues of femto cell performance i.e. handoff from macrocell. First using different indoor and outdoor path loss models received power and SINR from femtocell and macrocell are evaluated which are two main criterion for handoff. Then various handover parameters are optimised considering handover failures. Finally a unique algorithm is proposed for handoff from macro cell to femto cell in hierarchical macro/femto networks. It is shown that implementing this algorithm various handoff performance determining factors such as connectivity to Femto Base station, no. of handoffs are optimised. Therefore throughput and utilization of femto networks are also improved.

1.3.Thesis Organization.

In chapter 2, the basics of femto cell, its benefits, comparisons with other small cell networks, its challenges are described.

In chapter 3, handoff and how it is performed in femtocell and the various criterions are shown.

In chapter 4, different path loss models, channel model for femtocellular network are presented and related parameters are simulated.

In chapter 5, handover probabilities and handover failures are examined for macro/femto networks.

In chapter 6, the proposed algorithm is described and and its performance in different scenarios are valuated. Numerical results are shown.

In chapter 7, this research is concluded and also the references are shown.

Chapter 2.

Femto cell.

2.1.Femto Cell.

Femtocell is a small, low-power cellular base station, typically designed for use in a home or small business. It connects to the service provider's network via broadband (such as DSL or cable). It typically support two to four active mobile phones in a residential setting, and eight to 16 active mobile phones in enterprise settings. A femtocell allows service providers to extend service coverage indoors or at the cell edge, especially where access would otherwise be limited or unavailable. Although much attention is focused on WCDMA, the concept is applicable to all standards, including GSM, CDMA 2000, TD-SCDMA, WiMAX and LTE solutions [15].

In 3GPP terminology, a Home Node B (HNB) is a 3G femtocell. A Home eNode B (HeNB) is an LTE femtocell.

Typically the range of a standard base station may be up to 35 kilometres (22 mi), a microcell is less than two kilometers wide, a picocell is 200 meters or less, and a femtocell is on the order of 10 meters [15].

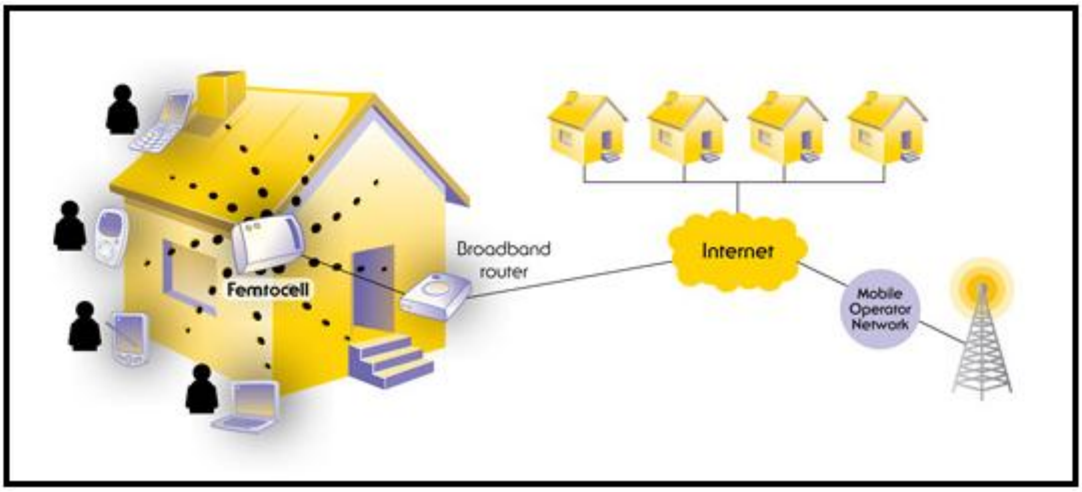


Figure 2.1. Femtocell architecture [6]

2.2.BENEFITS OF FEMTO CELL.

Studies on wireless usage show that more than 50 % of all voice calls and more than 70% of data traffic originate from indoors. Voice networks are engineered to tolerate low signal quality, since the required data rate for voice signals is very low, on the order of 10 kb/s or less. Data networks, on the other hand, require much higher signal quality in order to provide the multimegabit per second data rates users have come to expect. For indoor devices, particularly at the higher carrier frequencies likely to be deployed in many wireless broadband systems, attenuation losses will make high signal quality and hence high data rates very difficult to achieve. This raises the obvious question: why not encourage the end user to install a short-range low-power link in these locations? This is the essence of the win-win of the femtocell approach. The subscriber is happy with the higher data rates and reliability; the operator reduces the amount of traffic on their expensive macrocell network, and can focus its resources on truly mobile users. To summarize, the key arguments in favour of femtocells are the following which is described in [4].

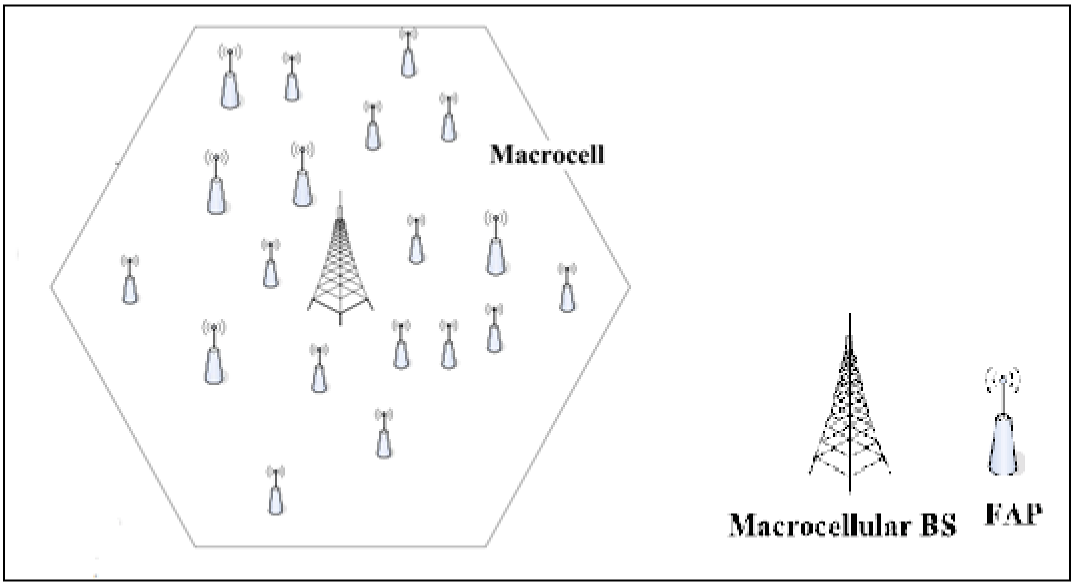


Figure 2.2 : Dense femtocellular network deployment scenario[10]

- **Better coverage and capacity.** Due to their short transmit-receive distance, femtocells can greatly lower transmit power, prolong handset battery life, and achieve a higher signal-to-interference- plus-noise ratio (SINR). These translate into improved reception — so-called *five-bar* coverage — and higher capacity. Because of the reduced interference, more users can be packed into a given area in the same region of spectrum, thus increasing the area spectral efficiency or, equivalently, the total number of active users per Hertz per unit area.

- **Improved macrocell reliability.** If the traffic originating indoors can be absorbed into the femtocell networks over the IP backbone, the macrocell BS can redirect its resources toward providing better reception for mobile users.
- **Cost benefits.** Femtocell deployments will reduce the operating and capital expenditurecosts for operators. A typical urban macrocell costs upwards of $1000/month in site lease, and additional costs for electricity and backhaul. The macrocell network will be stressed by the operating expenses, especially when subscriber growth does not match the increased demand for data traffic . The deployment of femtocells will reduce the need for adding macro-BS towers. A recent study shows that the operating expenses scale from $60,000/year/macrocell to just $200/year/femtocell.
- **Reduced subscriber turnover.** Poor in-building coverage causes customer dissatisfaction, encouraging them to either switch operators or maintain a separate wired line whenever indoors. The enhanced home coverage provided by femtocells will reduce motivation for home users to switch carriers.

2.3.Network Architecture.

Several FAPs are connected to a femto gateway (FGW) through a broadband ISP or another network. The FGW acts like a concentrator and also provides security gateway functionalities for the connected FAPs. The FGW communicates with the RNC through the CN (Core network). The FGW manages the traffic flows for thousands of femtocells. Traffic from different access networks comes to the FGW and is then sent to the desired destination networks. Whenever an FAP is installed, the respective FGW provides the FAP's position and its authorized user list to the macrocellular BS database (DB) server through the CN [10]. It provides SON (Self organising network) mechanisms. The main functionalities of the SON for femtocellular networks are self-configuration, self-optimization, and self-healing. Self-configuration includes frequency allocation. Self -optimization includes transmission power optimization, neighbour cell list optimization, coverage optimization, and mobility robustness optimization. Self-healing includes automatic detection and solution of most of the failures. Neighbour FAPs as well as the macrocellular BS and the neighbour FAPs coordinate with each other. Whenever an MS desires handover in an overlaid macrocell environment, the MS detects multiple neighbour FAPs because of the dense deployment of femtocells along with the presence of macrocell coverage.

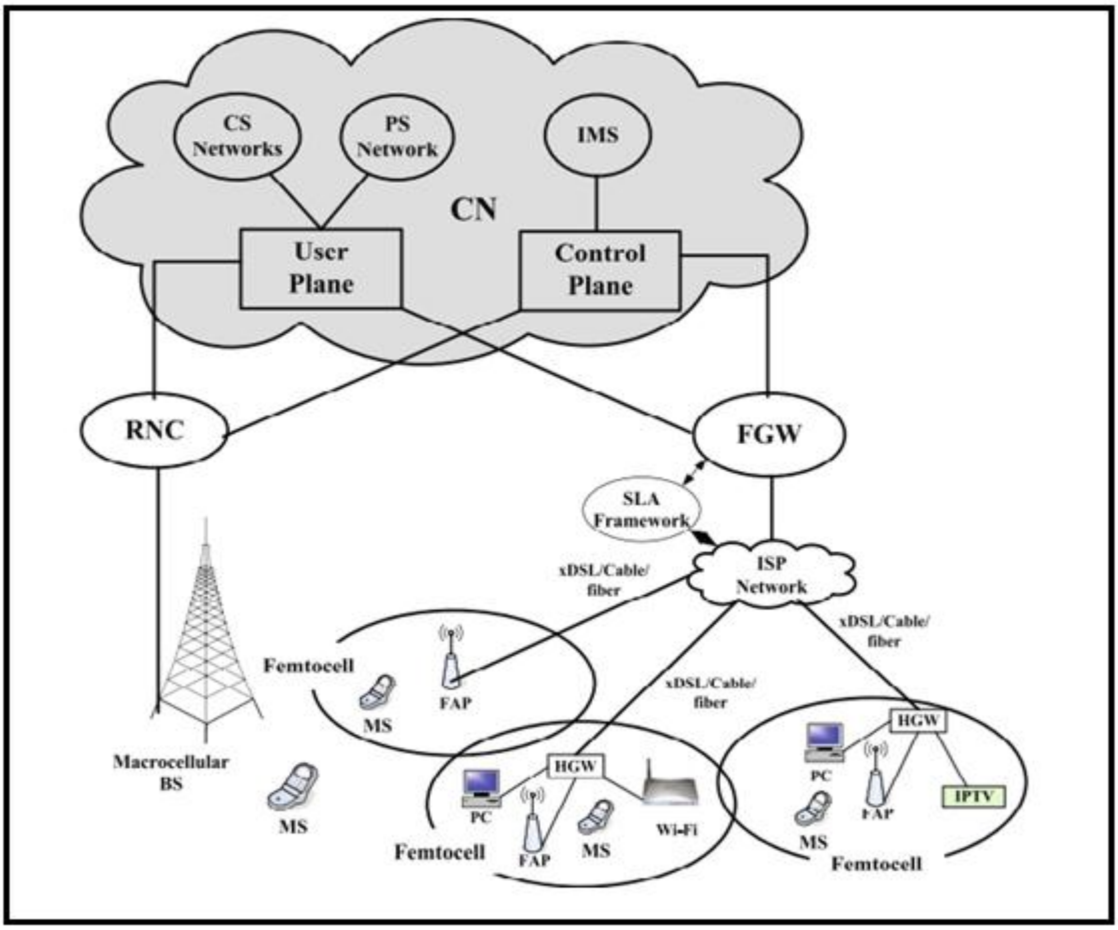


Figure 2.3 :Device to CN connectivity for femto cell deployment[10]

2.4. Other small cell networks.

1. **Distributed antennas**.

Operator installed spatially separated antenna elements (AEs) connected to a macro BS via a dedicated fiber/microwave backhaul link [4].

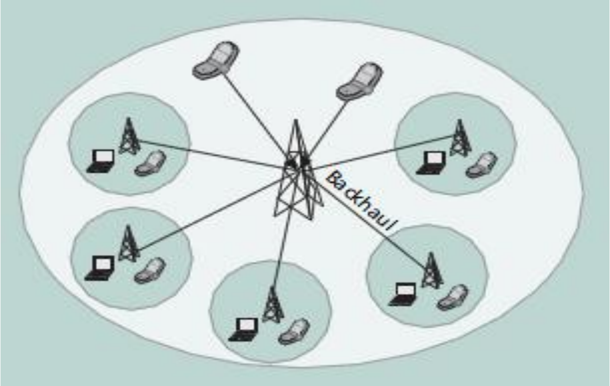


Fig2.4. Distributed Antennas[4]

Benefits. a) Better coverage since user talks to nearby AE;

b) capacity gain by exploiting both macro- and micro-diversity (using multiple AEs per macrocell user).

Shortcomings. a) Does not solve the indoor coverage problem;

b) RF interference in the same bandwidth from nearby AEs will diminish capacity;

c) backhaul deployment costs may be considerable.

2. **Microcells.**

   Operator installed cell towers, which improve coverage in urban areas with poor reception.

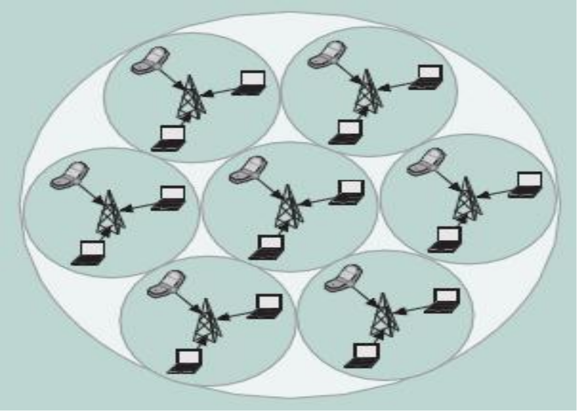


Fig 2.5. Micro cells[4]

Benefits. a) System capacity gain from smaller cell size;

b) complete operator control.

Shortcomings. a) Installation and maintenance of cell towers is prohibitively expensive;

b) does not completely solve indoor coverage problem.

2.5.FEMTOCELLS VS. Wi-Fi.

Key aspect	Femtocells	Wi-Fi
Spectrum availability	• Licensed band • Must reuse operator’s available spectrum allocatio	• Unlicensed band • Operator need not concern with spectrum related issues
Indoor coverage	• Up to 10-30 m. • Transmit power level is less 1-100 mW	• Up to 100 m. • Transmit power levels of most Wi-Fi Aps are higher up to 1W.
Interference issues	• Co-channel interference with macrocell • Interference avoidance and management techniques are necessary.	Interference cancellation features are there.
Network planning	Operator effort is needed for careful frequency planning and interference avoidance	No special effort is needed for network planning
Data rates	• WCDMA- 384 kbps,HSDPA-14.4 Mbps • LTE – 100 Mbps • WiBro (802.16) - 50 Mbps(2*2 MIMO) • WiMAX 802.16m – up to 1 Gbps	• Up to 450 Mbps(802.11n) • Up to 7 Gbps(802.11ac) • Possibility to provide LTE like service in 3G environment

Table 2.1. Femtocells vs. Wi-Fi [15]

2.6.Challenges in femtocells.

- **Interference management.**

  To achieve greater spectral efficiency, macro cell and femto cell typically operate in a common spectrum which is called co channel deployment. The spectrum is divided into sub channels. Therefore the macrocells and femtocells using same subchannels interfere with each other.

  The RF interference will arise from-

  a. Macrocell-to-femtocell interference
  b. Femtocell-to-femtocell interference
  c. Femtocell-to-macrocell interference

- **Resource allocation.**

  Allocating different subchannels for various femtocells is another key issue.

- **Quality of service.**

  A voice call over a femtocell typically requires as an example 40Kbps (in both the uplink and downlink). The impact on a broadband backhaul is minimal for voice services, but there are other variables that can affect user experiences. With multimedia applications, the femtocell shares the cable or DSL connection with the home’s other broadband devices. When some family members are downloading or uploading high bandwidth applications through the femtocells, for instance, priority for femtocell voice traffic can quickly become an important consideration.

- **Handoff.**

  Handoff is one more major issue for femtocell. Handoff should be performed at proper point to get efficient usage of femtocell. Considering many femto cells inside a macro cell, number of handoffs should also be less.

2.7.**Accessing Modes in Femtocells.**

Femtocells being a network used for private, enterprise or service providers purpose needs to operate on different Accessing modes so as to provide the service for targeted user [7].

- **Open Access Mode:**

In Open Access Mode any mobile user trying to access the femtocell service is allowed to do so without any discrimination or extra charge similar to the macrocell. Mostly these type of femtocells are deployed by Network Service Provider to enhance their coverage area and QoS.

- **Closed Access Mode:**

In Closed Access Mode the mobile user who is registered to the Femtocell is only allowed to access the service of these Femtocell. Other users are forced to use service of macrocell even if it is of poor service. These type of Femtocell are deployed by Organizations, Offices for their use and good receptionof the mobile service.

- **Hybrid Access Mode:**

It is a Combination of Open and Closed Access Modes.In this mode the preference is given to the registered user in terms of priority and charging.

Chapter 3.

Handoff.

3.1. HANDOFF.

When a mobile user moves from coverage area of one Base Station to the coverage area of another while engaging in active call then the transfer of call from one Base Station to the other or from one channel to other is known as Handover.

3.2. Types of Handoff.

Handoffs are broadly classified into two categories - hard and soft handoffs. Usually, the hard handoff can be further divided into two different types – intra and intercell handoffs. The soft handoff can also be divided into two different types - soft handoffs and softer handoffs [3].

- **Hard Handoff:**

A hard handoff is essentially a "break before make" connection. Under the control of the MSC, the BS hands off the MS's call to another cell and then drops the call. In a hard handoff, the link to the prior BS is terminated before or as the user is transferred to the new cell's BS; the MS is linked to no more than one BS at any given time. Hard handoff is primarily used in FDMA (frequency division multiple access) and TDMA (time division multiple access), where different frequency ranges are used in adjacent channels in order to minimize channel interference.

It is the handoff procedure primary in GSM network but also occurs in CDMA network.

- **Soft Handoff:**

If the handoff is between two base stations but operating channel of the call remains the same then this type of handoff is called soft handoff. In this type of Handoff, only the Mobile Base station handling the call changes but the operating channel remains same. This type of handover is found in CDMA network. If the sectors are from the same physical cell site(a sectored site), it is referred to as **softer handoff**.

3.3. **Handoff performance metrics.**

- *Handover blocking probability* - the probability that a handover attempt is blocked.

Handover probability - the probability that, while communicating with a particular cell, an ongoing call requires a handover before the call terminates. This metric translates into the average number of handovers per call.

- *Call dropping probability* - the probability that a call terminates due to a handover failure. This metric can be derived directly from the handover blocking probability and the handover probability.
- *Probability* of *an unnecessary handover* - the probability that a handover is stimulated by a particular handover algorithm when the existing radio link is still adequate.
- *Rate* of *handover* - the number of handovers per unit time. Combined with the average call duration, it is possible to determine the average number of handovers per call, and thus the handover probability.
- *Duration* of *interruption* - the length of time during a handover for which the mobile terminal is in communication with neither base station. This metric is heavily dependent on the particular network topology and the scope of the handover **.**
- *Delay* - the distance the mobile moves from the point at which the handover should occur to the point at which it does.

3.4. Handover Procedure in Femtocell:

Macrocell to femtocell handover is complex and most challenging procedure in the femtocell network compared to Femtocell to Macrocell Handover. It is because there are many possible target femtocells for handover. So, in this handover Mobile Station needs to choose the proper target Femtocell Base Stations among many candidate FBSs. Serving Node B coordinates the handover of Mobile Station from Macro BS to a Femto BS by providing information of allowed FAPs .Here, we assume mostly Closed Access Femtocell are present. So, the Serving Node B scans the area for making a FBS neighbour list [16].

To reduce the unnecessary handovers, the velocity and angle of movement of the user is obtained and hence approximate stay time of the user in femtocell is calculated.

RSS BASED HADNOFF CRITERION.

The primary criterion for handoff between a macrocell to femtocell is as follows

$$s_m < s_{m,th} \text{ and } s_f > s_m + \Delta \tag{3.1}$$

where $s_{m,th}$ and Δ represent the minimum RSS level from a serving macro BS and the value of hysteresis, respectively. And s_m and s_f are the received signal powers from macro and femto base station respectively which can be calculated by the following equations

$$s_m = P_{m,tx} - PL_m - u_m \tag{3.2}$$

$$s_f = P_{f,tx} - PL_f - u_f \tag{3.3}$$

Transmit power from macro cell and femto cell are $P_{m,tx}$ & $P_{f,tx}$ and path losses are $PL_m[k]$ and $PL_f\,[k]$ from the macro BS and the femto BS. $U_m[k]$ and $u_f\,[k]$ represent the log-normal shadowing with mean zero and variance σ^2_m and σ^2_f, respectively [1].

3.5. Temporary Femtocell visitor.

We define temporary femtocell visitor using mathematical notations and present a new handover decision criterion to prevent unnecessary handover. Firstly, we use the threshold time T_{th} to identify temporary femtocell visitor. T_{th} can be set differently depending on the administration policy of each femtocell. If handovered user stays in the femtocell for more than T_{th}, we assume that it is appropriate femtocell user (appropriate handover). Conversely, if handovered user stays in the femtocell less than T_{th}, it becomes temporary femtocell visitor (unnecessary handover). Thus, we define a new criterion of macro → femto handover as follows:

$$S_f > S_{th} \text{ and } T_c > T_{th} \tag{3.4}$$

where S_f denotes the received signal strength of femtocell, S_{th} denotes the predefined threshold value, T_c is cell residence time of user. Our scheme is to predict T_c using future mobility prediction scheme so that we can perform selective macro → femto handover not to accept temporary femtocell visitor [14].

3.6. TTT.

UE speed is a very important factor in handoff. It should stay inside the femtocell at least for certain amount of time. Because basically the use of femtocell is not for high speed mobile users. This minimum amount of time UE needs to stay for handoff is called time to trigger(TTT). Therefore now condition for handoff is

$$S_f > S_m + \Delta \quad \text{for TTT} \tag{3.5}$$

And for femtocell to femtocell handoff

$$S_{f1} > S_{f2} + \Delta \quad \text{for TTT} \tag{3.6}$$

If we know the speed of the user, we can estimate the time it will reside in the femtocell. Then it would be easy to make decision for handoff[16].

3.7. **SINR criterion.**

Now for more accuracy, we will also take into account SINR value at user from both cellular network. The condition added for macrocell to femtocell handoff is as follows

$$SINR_f > SINR_m \tag{3.7}$$

Calculation of SINR.

Interference and noise are present for both macrocell and femtocell. The value of SINR for macrocell and femtocell are

$$SINR_m = \frac{RSPm0}{N + \Sigma\ RSPm + \Sigma RSPf} \tag{3.8}$$

$$SINR_f = \frac{RSPf0}{N + \Sigma\ RSPf + \Sigma RSPm} \tag{3.9}$$

RSP is received signal power m_0 and f_0 are current macrocell and femtocell. N is noise power.

$$N = N_0B$$

$$N_0 = -174 \text{ dBm/Hz and bandwidth} = 10 \text{ MHz}$$

$$N = -174 + 10\log(10^7)$$

$$= -104 \text{ dBm}$$

3.8. User's state algorithm.

Handoff can be defined on user's state. We define a parameter R_{ms} as follows

$$R_{ms} = f(v)*f(q)$$

$$\text{Where} \quad f(v) = \begin{cases} 1 & \text{for } v > v_{th} \quad (v_{th} \text{ is MS velocity threshold}) \\ 0 & \text{for } v < v_{th} \end{cases}$$

$$\text{And} \quad f(q) = \begin{cases} 1 & \text{for data service} \\ 0 & \text{for voice service} \end{cases} \tag{3.10}$$

Now, If $SINR_f > SINR_m$,

If $R_{ms} > 0$, then handoff to femto-BS else keep associated with macro-BS.

Chapter 4.

Femto cell performance evaluation.

4.1. PATH LOSS MODELS.

There are many path loss models by which we can calculate the path losses in the received power in indoor and outdoor environment. For femto cell, properly analysing indoor environment is very important.

4.2. Outdoor path loss models.

1. **Okumura model.**
   It is expressed by

$$L_{50}(dB) = L_F + A_{mu}(f, d) - G(h_{te}) — G(h_{re}) — G_{area} \qquad (4.1)$$

where L_{50} is the 50th percentile (i.e., median) value of propagation path loss, L_F is the free space propagation loss, A_{mu} is the median attenuation relative to free space, $G(h_{te})$ is the base station antenna height gain factor, $G(h_{re})$ is the mobile antenna height gain factor, and G_{AREA} is the gain due to the type of environment [17].

2. **Hata model.**
   The Hata Model for Urban Areas is formulated as following:

$$L_U = 69.55 + 26.16\log(f) – 13.82\log(h_B) – C_H + [44.9 – 6.55\log(h_B)] \qquad (4.2)$$

For small or medium sized city,

$$C_H = 0.8 + (1.1\log(f) – 0.7)h_M - 1.56\log(f)$$

and for large cities,

$$C_H = \begin{cases} 8.29(\log(1.54h_M))^2 - 1.1 & \text{if } 150 < f < 200 \\ 3.2(\log(11.75h_M))^2 – 4.97 & \text{if } 200 < f < 2000 \end{cases}$$

3. **Cost 231 model.**

   COST 231 Walfisch-Ikegami propagation model gives a better prediction of path loss

$$P_L(dB) = 59.86 + 20\log(d) + 20\log(f) - 10\log(w) + 10\log(f) + 20\log(h_{roof} – h_{UE}) – 18(1+ (h_{Tx} – h_{roof})) + (h_{Tx} – h_{roof}) + 18\log(d) – [4+ 0.7(f/925 – 1)]\log(f) - 9\log(b) \qquad (4.3)$$

Where P_L is the path loss in dB, *d* is the distance between UE and the Transceiver in Km, *f* is the frequency in MHz, *w* is the mean value for width of the street in meters, h_{roof} is the mean value of height of the buildings in meters, h_{UE} is the height of the UE in meters, h_{Tx} is the height of the transceiver in meters, *b* is the mean value of building separation in meters.

4. **UMi Model.**

   This model is designed specifically for small cells with high user densities and traffic loads in city centres and dense urban areas. The path loss for the LoS condition is calculated as

$$L_{UMi,LOS} = \begin{cases} 22\log_{10} d + 42 + 20\log_{10}(f_c/5) & 10m<d<d_{BP} \\ 40\log_{10} d + 9.2 - 18\log_{10} h_{eNB} & \\ -18\log_{10} h_{UE} + 2\log_{10}(f_c/5) & d_{BP}<d<5km \end{cases} \quad (4.4)$$

Here, the distance between transmitter and receiver is d, the effective breakpoint distance is calculated as $d_{BP} = 4h_{eNB}h_{UE}f_c/c$, where f_c is the centre frequency in Hz and h'_{eNB} and h'_{UE} are the effective antenna heights for the eNB and UE, respectively [12].

The path loss for the non-line-of-sight (nLoS) model is computed as

$$L_{UMi,NLOS} = 36.7\log_{10} d + 40.9 + 26\log_{10}(f_c/5) \qquad 10m<d<5km \qquad (4.5)$$

But in simulation for macrocell/femtocell handoff phenomenon, rather than using these models, a simplified model is used. It is given below

$$\textbf{Path loss } L(dB) = 128.1 + 37.6\log(d) \qquad \textbf{(4.6)}$$

Where d is the distance between transmitter and receiver.

4.3. Indoor path loss models.

1. **Indoor hotspot model.**

   This model is used to model the channel for links lying inside the femto-cells. The LoS path loss is calculated as

$$L_{InH,\,LoS} = 16.9\log_{10}(d) + 46.8 + 20\log_{10}(f_c/5);\ 3m < d < 100m. \qquad (4.7)$$

   The path loss for the nLoS model is calculated as

$$L_{InH,\,nLoS} = 43.3\log_{10}(d) + 25.5 + 20\log_{10}(f_c/5);\ 10m < d < 150m. \qquad (4.8)$$

2. **ITU indoor propagation model.**

   For indoor path loss ITU indoor path loss model is taken which is as follows [17]

$$PL(dB) = 20 \log(f) + N \log(d) + P_f(n) - 28 \qquad (4.9)$$

where,

L = the total path loss (dB).
f = frequency of transmission.(MHz).
d = Distance. Unit: metre (m).
N = The distance power loss coefficient.
n = Number of floors between the transmitter and receiver.
$P_f(n)$ = the floor loss penetration factor.

For residential area N= 28 and $P_f(n) = 4n$

4.4.Outdoor to indoor (and vice-versa) model.

The UMi path loss model assists in modelling the indoor↔outdoor path loss as

$$L_{oi} = L_b + L_{tw} + L_{in};\ 50m < d < 5\ km. \qquad (4.10)$$

Here, L_b is the basic path loss calculated using the UMi model as $L_b = L_{UMi}(d_{out} + d_{in})$. The parameters d_{out} and d_{in} refer to the outdoor and indoor distances respectively. The parameter L_{tw}, is the wall penetration loss and L_{in}, dependent on the indoor distance alone, is calculated as $L_{in} = 0.5d_{in}$ [12].

4.5.Capacity calculation in femto cells.

Here an LTE OFDMA-FDD system is considered with system bandwidth W which is divided into N_{RB} resource blocks(RBs), each of bandwidth W_{RB} such that

$$W=N_{RB}W_{RB} \qquad (4.11)$$

Where the RB represents the basic OFDMA time frequency unit. Two RBs comprise one subframe and ten subframes together make one LTE frame.

Universal frequency reuse is considered, so that both macro and femto-cells utilise the entire system bandwidth W, in the uplink (UL) and DL.

The received UL or DL signal power associated with UE u on RB n, Y^{u}_{n} is given by

$$Y^{u}_{n} = P^{u}_{n}\, \Sigma\, G^{u}_{m},{}^{vu}_{n} + I_{n}^{u} + \eta_{RB} \qquad (4.12)$$

Where $G^{u}_{m},{}^{vu}_{n}$ is the channel gain between UE u and its serving HeNB or eNB vu, observed at receive antenna m and at RB n. Furthermore, η_{RB} accounts for thermal noise per RB which is constant across all RBs and both directions of communication. In the DL, the transmit power is set to $P^u{}_n = P_{eNB}$ and $P^u{}_n = P_{HeNB}$ if UE u is served by an eNB or HeNB, respectively. In the UL, $P^u{}_n = P_{FUE}$ or $P^u{}_n = P_{MUE}$, depending on whether the UE in question is served by a HeNB or an eNB, respectively. The values P_{HeNB}, P_{eNB}, P_{MUE} and P_{FUE} are constant across all RBs. The aggregate interference $I^u{}_n$ is composed of macro and femto-cell interference [12].

$$I_n{}^u = \sum_{i\epsilon M_{int}} G^u{}_{m,}{}^i{}_n P_m + \sum_{i\epsilon F_{int}} G^u{}_{m,}{}^i{}_n P_f \tag{4.13}$$

where the first and second addends represent the macro and femto-cell interference, respectively. Here, P_m is set respectively to P_{eNB} and P_{MUE} in the DL and UL. Similarly, P_f is set respectively to P_{HeNB} and P_{FUE} in the DL and UL. M_{int} represents the set of interfering macro UEs in the UL and the set of interfering eNBs in the DL. Similarly, F_{int} denotes the set of interfering femto Ues in the UL and the set of interfering HeNBs in the DL.

The SINR observed in the UL or DL with regards to UE u on RB n,

$$\Gamma_n{}^u = \frac{P_n{}^u \, \Sigma \, G_m{}^u{}_{,n}{}^{vu}}{I_n{}^u + \eta_{RB}} \tag{4.14}$$

Thus the capacity C_u is calculated by shannon’s law

$$C_u = \Sigma \, W_{RB}. \log_2(1+\gamma_n{}^u) \tag{4.15}$$

4.6.Channel model.

The channel gain, $G^u{}_{n,}{}^v{}_m$ between a transmitter v and a receiver u, observed at receive antenna m on RB n is composed of distance dependent path loss, log-normal shadowing and channel variations due to frequency-selective fading

$$G^u{}_{n,}{}^v{}_m = |H^u{}_{n,}{}^v{}_m|^2 \, . \, 10^{(-L+X_\sigma)/10} \tag{4.16}$$

where $H^u{}_{n,}{}^v{}_m$ denotes the channel transfer function (CTF) between transmitter v and receiver u, observed at receive antenna m and on RB n, L is the distance-dependent path loss (in dB), and X_σ is the log-normal shadowing value (in dB) with standard deviation σ [12].

4.7.VALUES OF DIFFERENT PARAMETERS.

Parameter	Value
Macro cell Tx power	46 dBm
Femto cell Tx power	10dBm
Carrier frequency	2 GHz
Bandwidth	10 MHz
Macro cell transmitter height	30m
Femto cell transmitter height	1.5m
Macro cell antenna gain	14dBi
Femto cell antenna gain	5dBi
Macro cell noise figure	5dB
Femto cell noise figure	8dB
Wall loss	10dB
Macro cell radius	500m
Femto cell radius	10m
Macro cell inter site distance	1.732km
Signal threshold value for macro cell	-108 dBm
Signal threshold value for femto cell	-72 dBm
Hysteresis value	6 dB
Time to trigger	160 ms
UE speed	3-15 km/hr
No. of subchannels in femto environment	8
No. of femtocells in a macro cell	10-100
Shadowing variable for macro cell	8 dB
Shadowing variable for femto cell	4 dB

Table 4.1. Simulation parameters for macrocell/femtocell handoff

4.8.Simulation results.

1. Received power at UE from femto cell with distance.

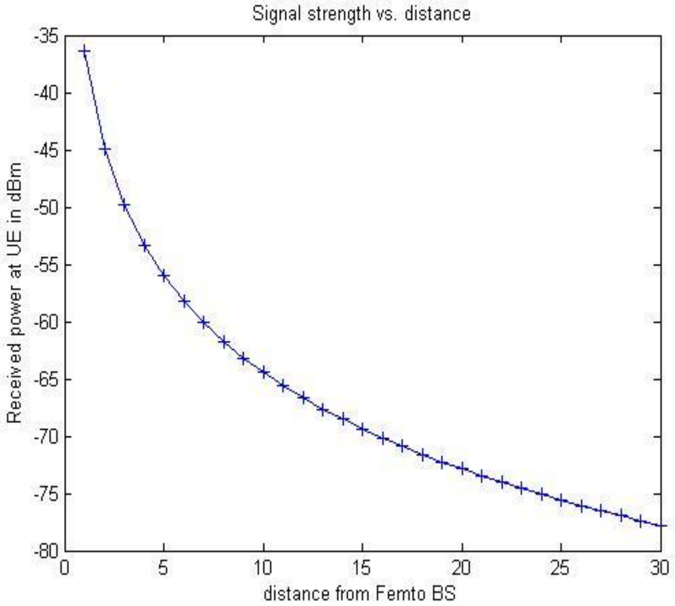


Figure 4.1. Received power from femtocell with distance

Here we can see the received power decreases as the distance increases. But here we can see although femtocell radius is normally 10 meter and femtocell threshold power for handoff $s_{f,th}$ = -72 dBm, even after 20 meters of distance received power is not less than -72 dBm. So handoff doesn't occur according to the RSS algorithm. Here it needs the additional criterion for SINR. Now in different buildings, femto cell setup will be different. So the biggest challenge is reducing no. of handoffs by putting femto cell at proper location and finding optimal location for handoff.

2. Received power at MS(dBm) vs distance(meter) from macro cell in cost 231 model and simplified outdoor path loss model.

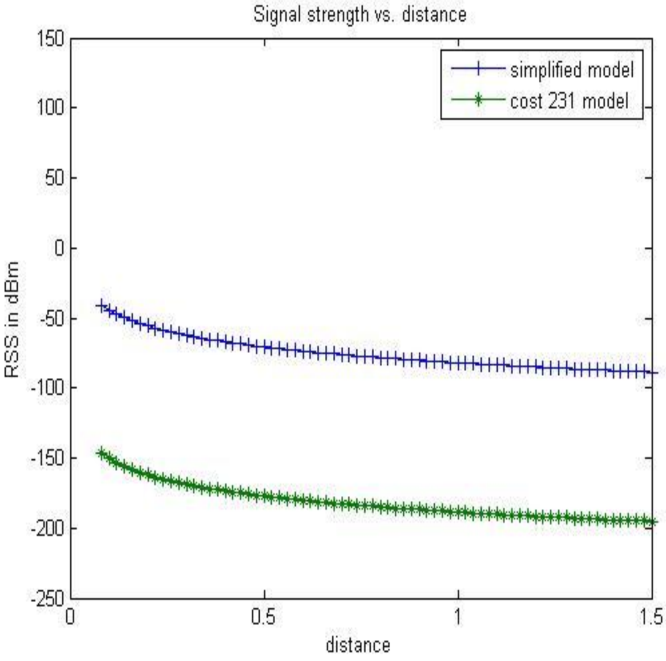


Figure 4.2. Received power from macrocell with distance

This graph depicts the received power at MS from macro base station with distance. Two curves are according to two different path loss models. We can have an idea of handoff performance between macro cell and femto cell if we compare this graph and the previous one. Exactly at which point handoff is taking place. It also depends on how the macro cell and femto cells are distributed.

3. SINR at MS(dB) which moves from a macrocell towards femtocell.

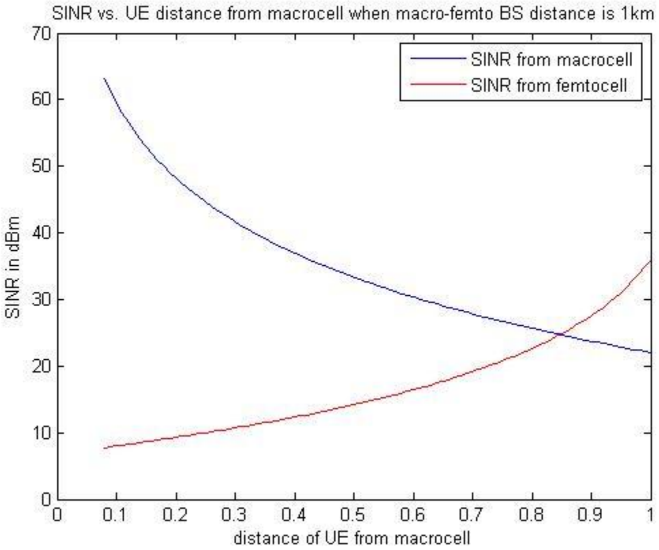


Figure 4.3. SINR from macrocell/femtocell with distance

This figure shows SINR values at user equipment when it moves from macro cell towards a femto cell when the distance between them is 1km. The blue line depicts when the UE takes signal from macro cell and the red line is for femto cell. We can clearly see the SINR decreases as the mobile moves away from the macro cell (blue curve) and the other SINR increases as it comes closer to the femto cell. But clearly the handoff should not be only based of SINR value comparison because received power from macro cell will always be greater than that of the femto cell due to the difference of transmitter power of those two.

4. Throughput.

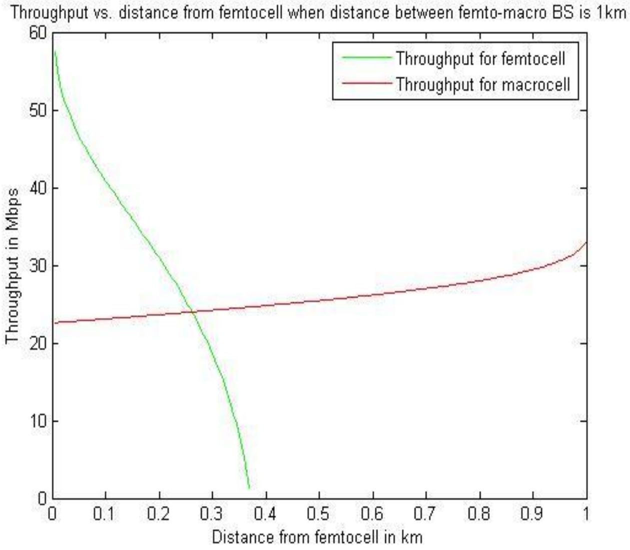


Figure 4.4. Throughput from macrocell/femtocell with distance

In this figure, we can see the throughput variation as the user moves from femto cell towards macro cell. It can also be noted that throughput is much higher near femtocell because of its high bandwidth and so it’s high coverage in indoors.

4.9.Femtocell interference.

Till now we considered macro/femto network with only one macro cell and one femto cell. Here we will be considering no. of femtocells to show how it affects handoff.

When FMCs and UEs transmit their signals in the same frequency band (same subchannel) within the same environment, interference will occur.

Downlink OFDMA.

FMCs transmits in different subcarriers than BS in OFDMA systems, which help in interference avoidance. In addition, in OFDMA system, FMCs are deployed in subchannels distribution. In downlink the UE which is indoors and receiving signal from indoor FMC must have different subchannels from the UE which is outdoors and receiving signal directly from the outdoors BS [9].

Scenario network layout.

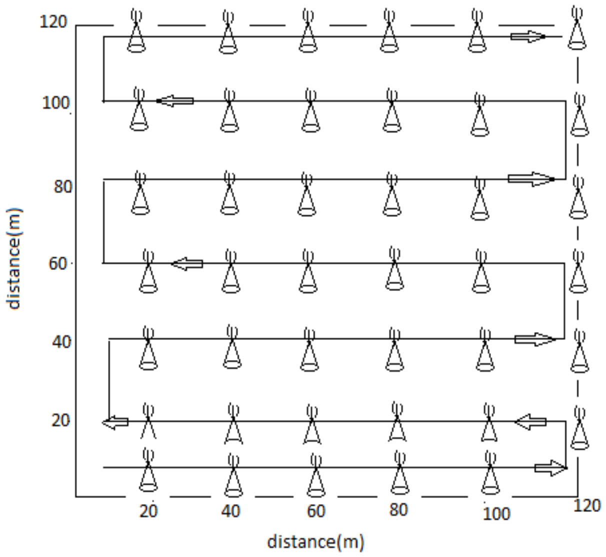


Figure 4.5. Serving and interfering FMC and path of the user

In this scenario we assumed a one level hospital building which is 120 m in the X-axis length and 120 m in the Y-axis width. And 144 FMCs installed indoors each is serving up to 4 Ues.

This is a downlink scenario where the main signal is transmitted from the serving FMC to the target UE, while the interference is transmitted from the interferer neighbouring FMCs to the target UE. The serving FMC is chosen by calculation as the nearest FMC to the target UE, while the target UE is initiated by X to be 0.2 m and Y to be 0.2 m. This simulation calculates the average interference that comes from every interferer neighbouring FMC on the target UE locations at the X and Y grids. The simulation continues by increasing X by 1 m up to 120 m while Y fixed in 1 m and vice-versa. This continues until Y reaches 120 m and X is 120 m. This is repeated within every interferer neighbouring FMC increment and added to the previous interference which calculated from the previous interferer neighbouring FMCs.

Propagation loss model.

In indoor residential premises, the path loss model we took as before

$$PL(dB) = 20\log(f) + 28\log(d) - 24 \qquad (4.17)$$

$$= 42 + 28\log_{10}(d) \qquad \text{where, } f=2000\text{ MHz}$$

This equation is used to evaluate path loss power between serving FAP and target UE as well as interferer FMCs and target UE where d is the distance between them and obtained by

$$d =[(UE(x) - X(k))^2 + (UE(y) - Y(k))^2]^{0.5} \qquad (4.18)$$

Here UE(x) and UE(y) are the x and y coordinates of target UE and X(k) and Y(k) are the x and y coordinates of serving femto cell and k^{th} interfering femtocells in respective cases [9].

FAP-UE interference analysis.

Interference occurs in downlink when the signal transmitted from the specific FMC to the target UE overlap in subchannel with the signals which transmits from the neighbouring FMCs. This simulation neglect WiMAX BS to FMC interference, and concentrate on the FMC, neighbouring FMCs and UE interference.

$$Si = P_i \cdot G_i \cdot L_i \cdot PL_{ix} \cdot G_x \cdot L_x dB \qquad (4.19)$$

where S_i is the received signal by the target UE from the serving FMC, P_i is the serving FMC transmission power, G_i is the serving FMC antenna gain, L_i is the serving FMC cable loss, PL_{ix} is the path loss between the serving FMC and the target UE, G_x is the target UE antenna gain, L_x is the target UE loss.

$$Sj = P_j \cdot G_j \cdot L_j \cdot PL_{jx} \cdot G_x \cdot L_x dB \qquad (4.20)$$

hereS_j is the received signals from the interferer FMC by the target UE, G_j is the interferer neighbouring FMC antenna gain, L_j is the interferer neighbouring FMC cable loss, PL_{jx} is the path loss between the interferer neighbouring FMC and the target UE. Our simulation will accumulate to compute the interference value that caused by all interferers neighbouring FMCs on the target UE. The transmitted signal from the specific FMC to the target UE is considered as the mean signal, and the sum of the transmitted signals of all interferers neighbouring FMCs to the target UE as the interference [9].

$$SINR = Si / (\Sigma S_j + \sigma) \text{ dB} \qquad (4.21)$$

Where, S_i is the transmitted signal from the serving FMC to the target UE, S_j is the accumulation of all the transmitted signals from the interferer FMCs to the target UE.

$$\Sigma = n + n_F \text{ dB}$$

$$n = - 174 - 30 + 10 \log_{10} (f) \text{ dB} \qquad (4.22)$$

here, n is the thermal noise in dB, f is the Channel bandwidth frequency which is 5 MHz and n_F is the noise Figure of the target UE which is 8 dB. σ is the sum of the thermal noise and the target UE noise Figure.

Simulation results.

The desired FMC coverage distance is suggested to be 10 m in each direction and 10 m by 10 m area will be covered by the individual FMC, here for the whole area we used 144 FMCs. The interference of the target UE is evaluated in the grids of the X and Y axis's by substituting the target UE location and calculates the average interference. The simulation evaluates the interference, SINR, and the probability of connection.

1. Interference.

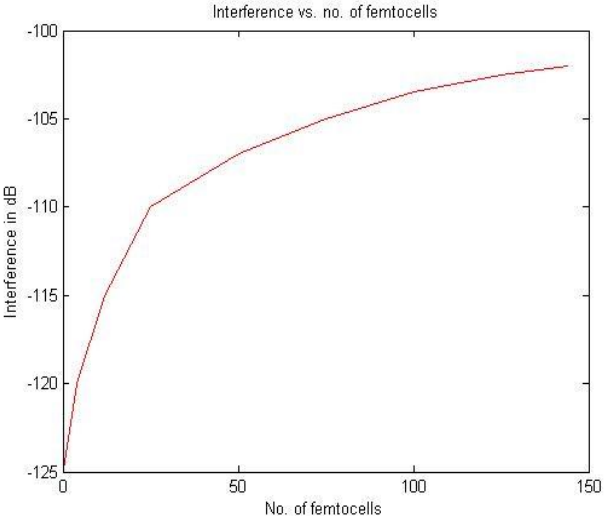


Figure 4.6. Interference with no. of femtocells

Result clearly shows that as number of femtocells increases, magnitude of interference to the target femtocell increases gradually. The reason being the number of interfering femtocells is increasing.

2. SINR.

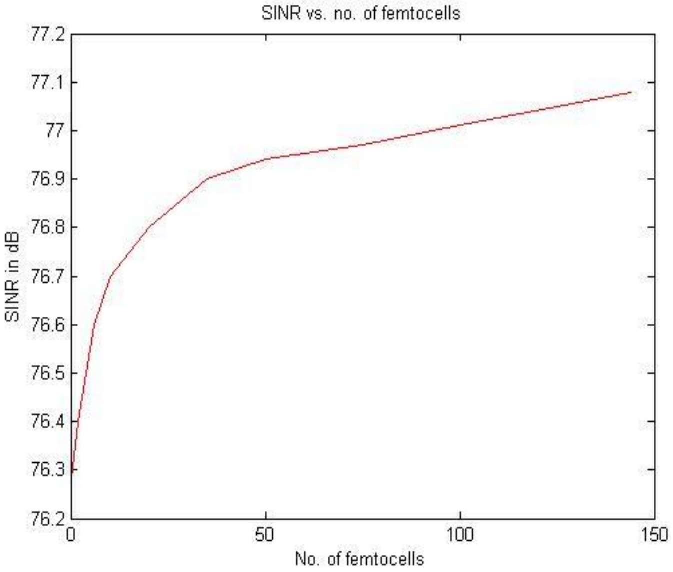


Figure 4.7. SINR with no. of femtocells

This figure depicts the signal-to-interference and noise ratio SINR, which is calculated by the main signal that transmitted from the served FMC to the target UE, and the interference that are accumulated from all the neighbouring FMCs to the target UE. The SINR increases slightly with the increase of FMCs number.

3. Probability of connection.

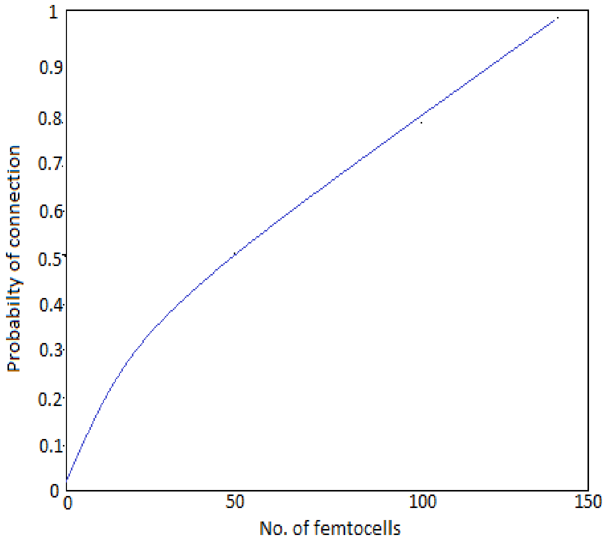


Figure 4.8. Probability of connection with no. of femtocells

This figure shows the probability of connection at the indoors within 0 dB SINR threshold value and a varied number of FMCs 1 FMC up to 144 FMCs. The probability of connection from the FMCs to the UEs increases approximately in straight deviation trend within the increase in FMCs.

Chapter 5.

Handoff probabilities and failures.

5.1. Handoff probabilities and call arrival rates in macro/femto hierarchical environment.

Three important handoff probabilities for normal cellular network to femto network handoff are

$$P_{f|m,RSS} = P\{s_m > s_{m,th} \, , \, s_f > s_m + \Delta \mid M\}$$

$$P_{f|m,SINR} = P\{SINR_f > SINR_m \mid M\}$$

$$P_{f|m,SINR \,\&\, user} = P\{SINR_f > SINR_m \, , \, R_{ms} > 0 \mid M\} \tag{5.1}$$

M is the event that the user is currently connected to macro cell.

$\lambda_{o,f}$ and $\lambda_{o,m}$ denote the total originating call arrival rates considering all n number of femtocells within a macrocell coverage area and only the macrocell coverage area, respectively. $\lambda_{h,mm}$, $\lambda_{h,ff}$, $\lambda_{h,fm}$, and $\lambda_{h,mf}$ denote the total macrocell-to-macrocell, femtocellto-femtocell, femtocell-to-macrocell, and macrocell-tofemtocell handover call arrival rates within the macrocell coverage area, respectively. $P_{B,m}$ ($P_{B,f}$) is the new originating call blocking probability in the macrocell (femtocell) system. $P_{D,m}$ ($P_{D,f}$) is the handover call dropping probability in the macrocell (femtocell) system [10].

We also use two threshold levels of SNIR to admit a call in the system. The first threshold level Γ_1 is the minimum level of the received SNIR that is needed to connect a call to any FAP. The second signal level Γ_2 is higher than Γ_1. The second threshold is used in the CAC to reduce the unnecessary macrocell-to-femtocell handovers. We assume that for a femtocell-to-femtocell handover, the probability that the received SINR of the T-FAP is greater Γ_2 and is represented by α, and the received SINR of the T-FAP is between Γ_1 and Γ_2 and is represented by β.

Equating the net rate of calls entering a cell and requiring handover to those leaving the cell, the handover call arrival rates are calculated as follows

The macrocell-to-macrocell handover call arrival rate is

$$\lambda_{h,mm} = P_{h,mm} \cdot \frac{(1-P_{B,m})(\lambda_{m,o} + \lambda_{f,o}P_{B,f}) + (1-P_{D,m})\{ \lambda_{h,fm} + \lambda_{h,ff}(1-\alpha+\alpha P_{D,f})}{1 \quad - P_{h,mm}(1-P_{D,m})} \qquad (5.2)$$

the macrocell-to-femtocell handover call arrival rate is

$$\lambda_{h,mf} = P_{h,mf} \cdot \frac{(1-P_{B,m})(\lambda_{m,o} + \lambda_{f,o}P_{B,f}) + (1-P_{D,m})\{ \lambda_{h,fm} + \lambda_{h,ff}(1-\alpha+\alpha P_{D,f})}{1 \quad - P_{h,mm}(1-P_{D,m})} \qquad (5.3)$$

the femtocell-to-femtocell handover call arrival rate is

$$\lambda_{h,ff} = P_{h,ff} \cdot \frac{\lambda_{f,o} (1-P_{B,f}) + \lambda_{h,mf}(1-P_{D,f})}{1-P_{h,ff}(1-P_{D,f})\{\alpha+(1- \alpha)P_{D,m}\}} \qquad (5.4)$$

and the femtocell-to-macrocell handover call arrival rate is

$$\lambda_{h,fm} = P_{h,fm} \cdot \frac{\lambda_{f,o} (1-P_{B,f}) + \lambda_{h,mf}(1-P_{D,f})}{1-P_{h,ff}(1-P_{D,f})\{\alpha+(1- \alpha)P_{D,m}\}} \qquad (5.5)$$

where $P_{h,mm}$, $P_{h,mf}$, $P_{h,ff}$, and $P_{h,fm}$ are the macrocell-tomacrocell handover probability, macrocell-to-femtocell handover probability, femtocell-to-femtocell handover probability, and femtocell-to-macrocell handover probability, respectively.

The probability of handover depends on several factors such as the average call duration, cell size, and average user velocity. The handover probabilities from a femtocell and to a femtocell in integrated femtocell/macrocell networks also depend on the density of femtocells and the average size of femtocell coverage areas. We derive the formulas for $P_{h,mm}$, $P_{h,mf}$, $P_{h,ff}$, and $P_{h,fm}$ as follows which is described in [10].

- Macrocell to macrocell handoff probability

$$P_{h,mm} = \eta_m/(\eta_m+\mu) \qquad (5.6)$$

- Femtocell to macrocell handoff probability

$$P_{h,fm} = [1-n(r_f/r_m)^2].\ \eta_f/(\eta_f+\mu) \qquad (5.7)$$

- Femtocell to femtocell handoff probability

$$P_{h,ff} = (n-1)(\ r_f/r_m)^2.\ \eta_f/(\eta_f+\mu) \qquad (5.8)$$

- Macrocell to femtocell handoff probability

$$P_{h,mf} = n(r_f/r_m)^2 . (\eta_m \sqrt{n})/(\eta_m \sqrt{n}+\mu) \qquad (5.9)$$

where $1/\mu$, $1/\eta_m$, and $1/\eta_f$ are the average call duration, average cell dwell time for the macrocell and the average cell dwell time for the femtocell respectively. r_f and r_m are femto cell and macro cell radius respectively. n is the number of femtocells in the macrocell area.

$1/\mu =$ 120 sec

$1/\eta_m$ = 240 sec

$1/\eta_f$ = 360 sec

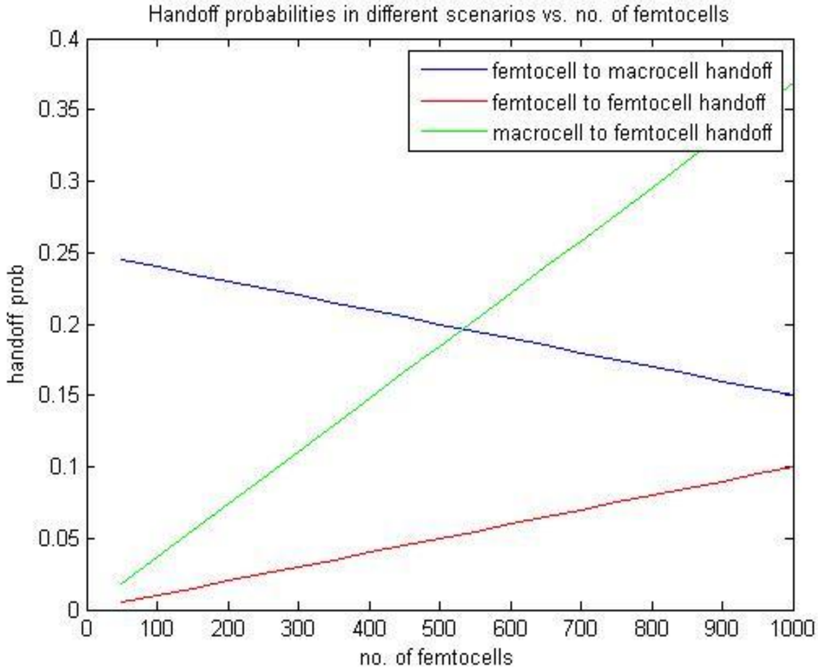


Figure 5.1. Handoff probabilities with no. of femtocellls

This figure shows the effect of different handover probabilities with an increase in the number of deployed femtocells within a macrocellular network coverage. With an increase in the number of deployed femtocells, the femtocell-to femtocell handover and macrocell-to-femtocell handover probabilities are significantly increased. In addition, the femtocell-to-macrocell handover probability is very high. Thus, the management of this large number of handover calls is the important issue for dense femtocellular network deployment.

5.2. Handover failures.

Inbound mobility and outbound mobility are supported in LTE-based femtocell system . Inbound mobility corresponds to the handoff (HO) from the macro cell to the femtocell, outbound mobility to the macro cell from the femtocell. For inbound mobility, the UE connecting to the macro cell can move inside the femtocell without the occurrence of radio link failure (RLF) since the macro and femtocells use different frequency bands. However, the failure during outbound HO will lead to the disconnection of UE from the femtocell, which causes serious degradation of user’s experience [11].

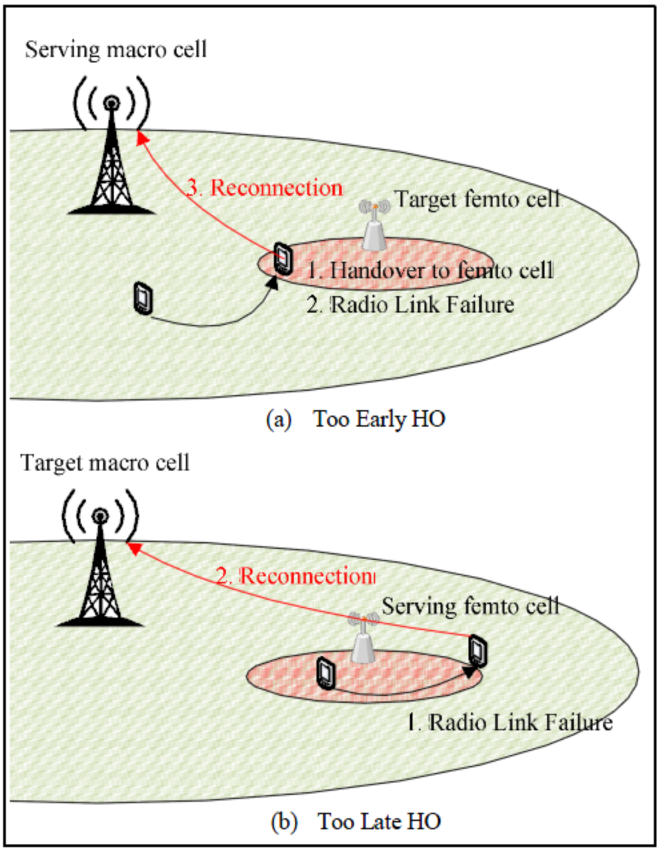
Two very important factors in handoff which needs to be avoided are

1. **Ping-pong handover.**

   It is basically repeated handover due to ambiguity of signal power and lack of strategy. In a building, lot of femtocells can be there. And user’s movement is random. So we need to make sure that no unnecessary handoff occurs.

2. **RLF.**

   RLF is radio link failure. It means getting disconnected to current network before handoff occurs. For these two factors correctly choosing the values of hysteresis and time to trigger is very crucial.



(a) Too Early HO

(b) Too Late HO

There are two cases of failures during handover: failures due to too late handover (LHO) and failures due to too early handover (EHO). As illustrated in Fig.5.2 -(a) and (b), if handover is triggered too early, though the signal strength of the target cell is too low, RLF will occur shortly after the handover procedure; the UE will re-establish the radio link connection to the serving cell.

On the other hand, if handover is triggered too late, though the signal strength of the serving cell is already too low, RLF will occur before the handover is initiated or during the handover procedure; the UE will re-establish the radio link connection to the target cell.

The number of HO-related radio link failures could be reduced by HO parameter optimization. The most relevant handover parameters in 3GPP LTE are time to trigger (TTT) and handover margin (HM), where HM is equivalent to the subtraction of the cell specific offset (CIO) from the handover hysteresis (Hyst). The UE monitors the signal strengths of all detected cells and checks whether the signal strengths of the neighbour cells is at least HM decibels better than the serving cell. If the entering condition is satisfied and lasts for duration of TTT, the UE will send report to the serving cell. After that, a handover procedure will be initiated on UE which is described in [11].

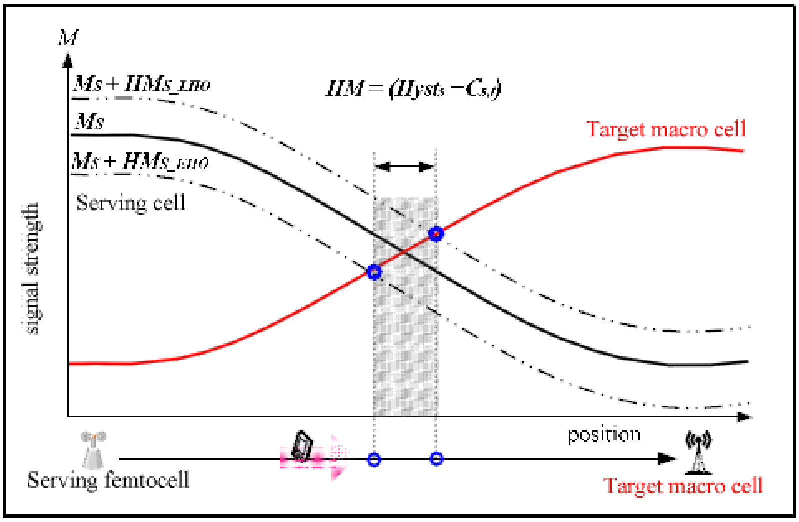


Figure 5.3: Effect of handover margins on radio link failures due to too early and too late handover [11]

In Fig. 5.3, HM_{S_LHO} is the maximum HM values at the serving cell that is the entering condition for event A3 that cannot cause RLFs due to LHO. HM_{S_EHO} is the minimum HM values preventing RLFs due to EHO or ping-pong HO. The UEs moving from the femtocell to the macro cell will handover successfully if the entering condition is triggered inside the shaded area in Fig. 2. Larger values of HM than HM_{S_LHO} will lead to the disconnection due to LHO. On the other hand, lower values of HM than HM_{S_EHO} will cause the ping-pong HO or RLFs due to EHO. Therefore, efficient values of HM need to be investigated to achieve the low ping-pong rate and low RLFs simultaneously. The level of user’s speed also has a quite direct impact on the handover failures.

Simulation results.

We evaluate ping-pong rate and RLF rate with various HM values assuming all the UEs are moving at the fixed speed of 3km/h and 15km/h, respectively. We apply various HM of 1dB to 8dB with a fixed TTT value of 160ms for all UE speeds. We assume that the RLF occurs when SINR from the serving cell drops below -6dB before completing the HO execution.

1. RLF.

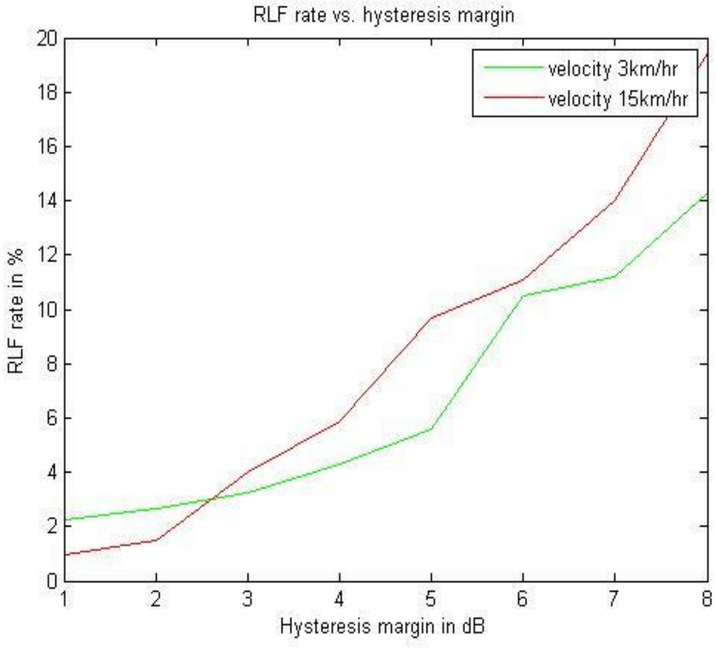


Figure 5.4. RLF rate with hysteresis for different UE speed

This figure shows RLF rates according to various hysteresis values in macro/femto handoff scenario for UE speed 3 km/hr and 15 km/hr. As the HM value increases, RLF rate increases.

2. Ping-Pong.

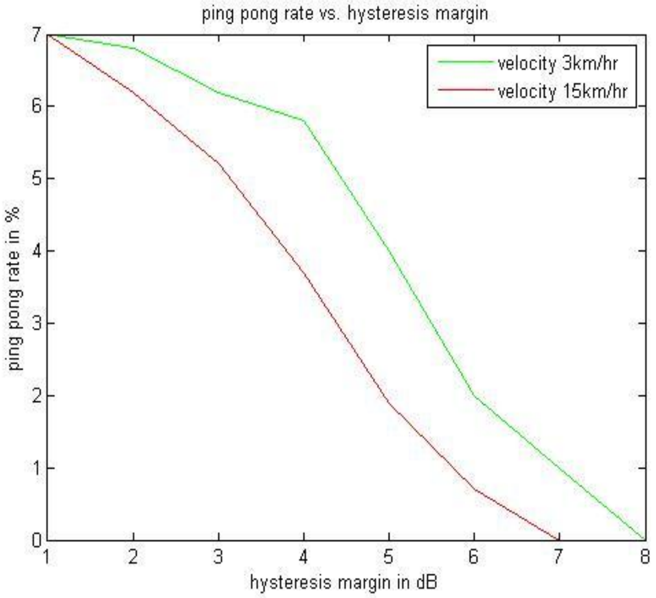


Figure 5.5. Ping-Pong rate with hysteresis for different UE speed

Here we can see as the HM value increases, the ping-pong rate decreases. Therefore, the criteria for selecting proper HM values is to minimize pingpong rates while keeping RLF rate below 2%, which will lead to the best trade-off between RLF rate and ping-pong rate.

From this evaluation we chose the value for hysteresis as 6 dB when the user velocity is 3km/hr which we will be using for later simulations.

5.3. **Handover latency.**

Another important parameter in handoff is the handover latency which is the delay between actual handoff and the moment when handoff should have been occurred which happens due to signal reception and protocol verification.

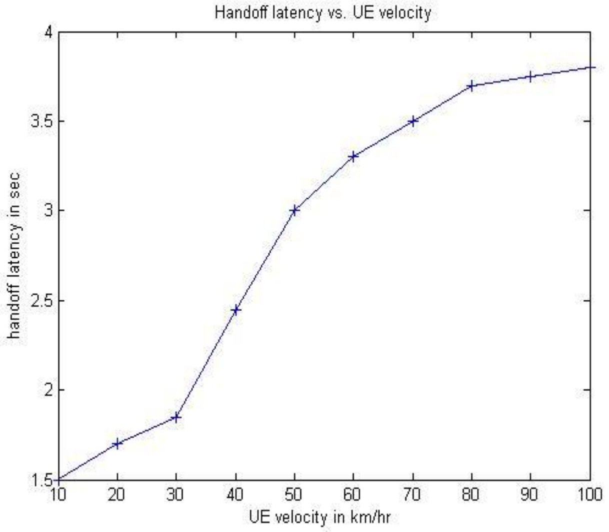


Figure 5.6. Handover latency with UE velocity

This figure shows the variation of handoff latency with increasing UE speed. It is quite clear that, with increasing speed, the handover latency initially increases and then becomes saturated.

Chapter 6.

Proposed algorithm.

Proposed algorithm.

The main objective of handoff algorithm is to decide an optimal connection with respect to user or system performance, while minimizing handoff latency and the number of handoffs. The most commonly used algorithm is based on the comparison of RSS’s and the concept of hysteresis and threshold. The threshold sets a minimum RSS from a serving BS and the hysteresis adds a margin to the RSS from the serving BS over that from a target BS. This handoff decision algorithm especially can be utilized by a mobile station (MS) moving from a macrocell to a femtocell. Here, it is assumed that the MS has a capability to detect neighbouring femtocells. In hierarchical macro/femtocell networks, there are two interesting requirements about mobility management. First, an MS gives higher priority to a femto BS over a macro BS when the MS selects its serving BS. A reason for this requirement is not only the high utilization of femtocells but also the usage of different billing models between two types of cells. Thus, performing handoff from a macrocell to a femtocell efficiently can be seen as a way of increasing user satisfaction. Second, the deployment of femtocells should not cause drastic changes on mobility management procedures used in conventional macrocell networks. It means that conventional methods, such as cell scanning and handoff, can also be applied to the hierarchical macro/femto-cell networks. In the aspect of fulfilling these requirements, various handoff algorithms based on received signal strength (RSS) with hysteresis and threshold have a common and critical drawback: that is, a criterion for handoff from a macrocell to a femtocell is hard to be satisfied when the femto BS is installed in the center or inner region of the macrocell. This phenomenon is caused by much lower transmit power of the femto BS compared to that of the macro BS. The typical values of the transmit power are 10 dBm for the femto BS and 46 dBm for the macro BS, respectively. Therefore, it is necessary to design a suitable handoff decision algorithm for the situation where a user’s call is handed off from a macrocell to a femtocell.

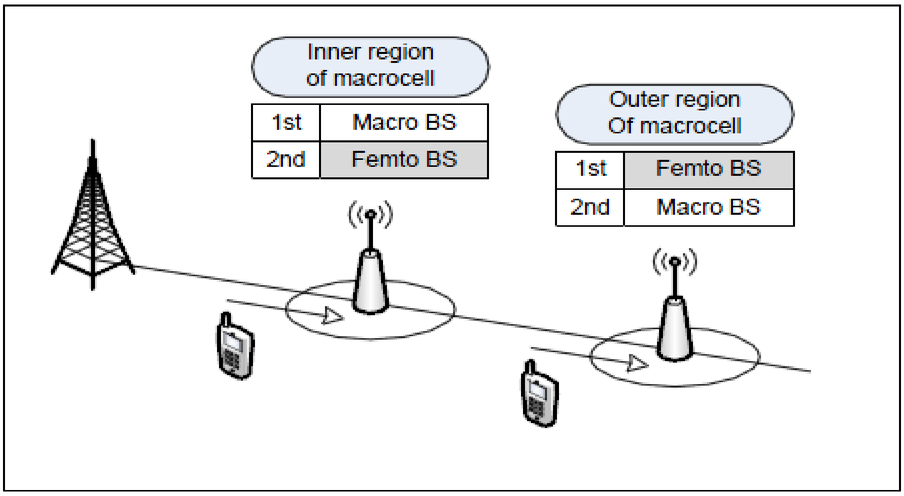


Fig 6.1 : Handoff scenario of MS moving from macrocell to femtocell [1]

The main idea of a proposed RSS based handoff decision algorithm is to multiply the values of RSS by some constant from a target femto base station which is currently connected to macro cell in the consideration of each femto BS's own situation for efficient handoff which was not occurring due to the huge transmit power difference between macro cell and femto cell.

$$S_{fmod} = \alpha S_f \qquad \text{where } \alpha > 1 \qquad (6.1)$$

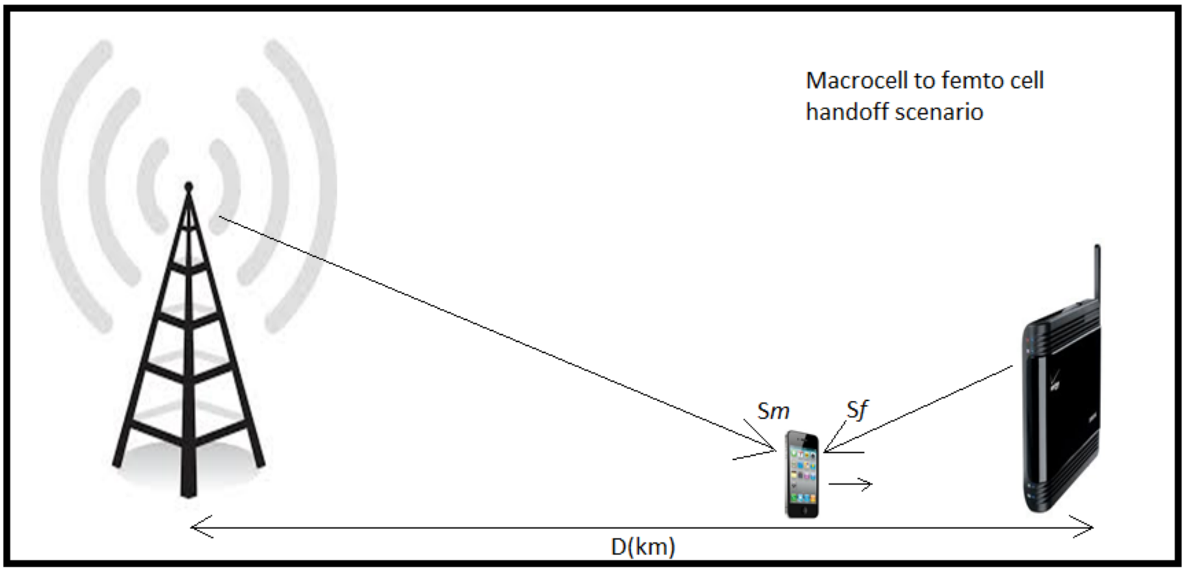


Figure 6.2. Mobile user at macrocell/femtocell boundary scenario

6.1.Mathematics of the algorithm.

Let the distance between macro cell and femto cell be D km. Femto cell radius is r_f which is taken as 10m.

Macro cell transmit power = 46 dBm

Femto cell transmit power = 10 dBm

Macrocell path loss = 128 + 37.6 $\log_{10}d(km)$

Femtocell path loss(simplified) = 42 + 28$\log_{10}d(m)$

Therefore at femtocell boundary, received signal strength from femtocell should not be less than that of macro cell.

$$S_f = [10-(42+28\log_{10}d(m))]$$

$$S_m = 46- [128+37.6 \log_{10}(D-d)(km)]$$

Now replacing $d= r_f = 10m$ at boundary, we get

$$S_f = [10-(42+28\log_{10}10)] = -60dBm$$

$$S_m = -82-37.6 \log_{10}(D-0.01) \text{ dBm}$$

$$S_{diff} = S_f - S_m = 22+37.6 \log_{10}(D-0.01)$$

$$\text{And } \alpha = 1+(S_{diff}/S_f) \qquad (6.2)$$

6.2.Handoff criterion for proposed algorithm.

if $S_f > S_{f,th}$ **and** $S_{fmod} > S_m + \Delta$

or if $S_f < S_{f,th}$ **and** $S_f > S_m + \Delta$

then connect to femto BS

if $S_f > S_{f,th}$ **and** $S_{fmod} < S_m + \Delta$

or if $S_f < S_{f,th}$ **and** $S_f < S_m + \Delta$

then connect to macro BS (6.3)

6.3.Performance analysis.

$P_m[k]$ and $P_f[k]$ denote the probabilities that the MS will be assigned to the macro BS and the femto BS at time *k*, respectively, and $M(k)$ and $F(k)$ indicate the corresponding events and the probability of handoff at *k*, denoted by $P_{ho}[k]$, can be expressed as follows [2]:

$$P_m[k] = P_m[k-1](1 - P_{f|m}[k]) + P_f[k-1]P_{m|f}[k] \quad (6.4)$$

$$P_f[k] = P_m[k-1]P_{f|m}[k] + P_f[k-1](1 - P_{m|f}[k]) \quad (6.5)$$

$$P_{ho}[k] = P_m[k-1]P_{f|m}[k] + P_f[k-1]P_{m|f}[k] \quad (6.6)$$

Where, $P_{f/m}[k]$ represents the probability of handoff from a macrocell to a femtocell at *k*, and vice versa for $P_{m/f}[k]$. Then, $P_{f/m}[k]$ can be calculated by using the concept of conditional probability, as follows:

$$P_{f|m}[k] = \frac{\Pr\{F(k) and\ M(k-1)\}}{Pm[k-1]} \quad (6.7)$$

Then, the total number of handoffs N_{ho} can be obtained by summing the probability of handoff for all *k*, that is,

$$N_{ho} = \Sigma_k P_{ho}[k]. \quad (6.8)$$

6.4.Results and discussion.

We observe a single MS moving straightly from a macro BS to a femto BS with the speed of 1 m/s. Then, the MS measures RSS's from both BSs at an interval of 1 second and a proposed handoff decision algorithm is operated based solely on the measured values of the RSS's.

1. Optimum multiplicational factor vs. different positions of femto BS.

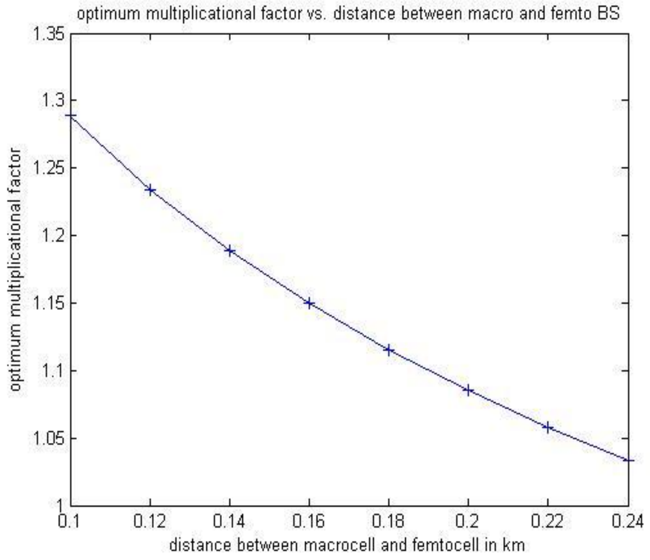


Figure 6.3. Optimal multiplying factor vs. distance of femto-macro BS

As distance between macro and femto BS increases, α decreases. After 250 meter there is no need of α. That means α is more needed when FBS is closer to MBS.

2. Femtocell assignment probability with distance between femto cell and macro cell.

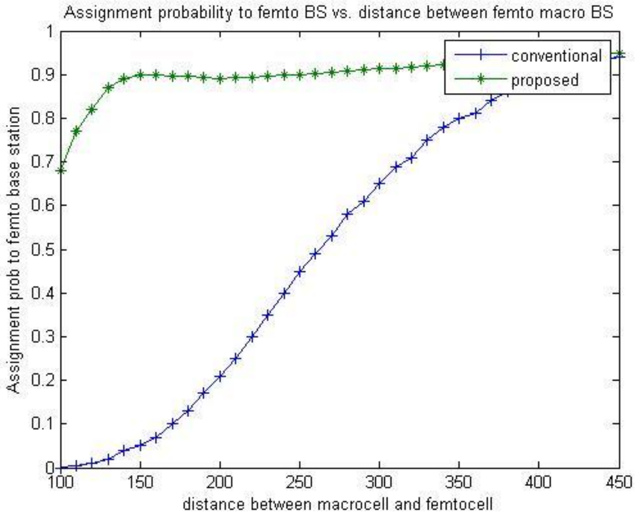


Figure 6.4. Assignment probability to femto BS vs. distance of macro-femto BS

When the femto BS is closely located to the macro BS, proposed algorithm has much higher assignment probability to femto BS compared to conventional algorithm. It is to be noted that each value is measured at the location separated by 10 m from the femto BS.

3. No. of handoffs with distance between femto and macro cell.

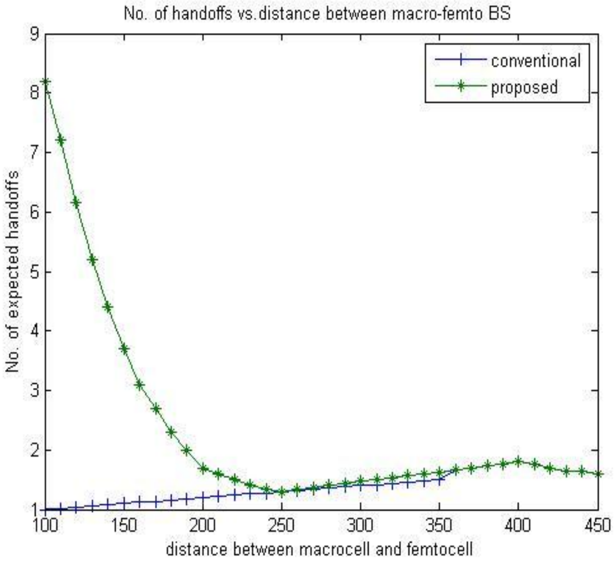


Figure 6.5. Number of handoffs vs. distance of macro-femto BS

It can be seen that when femto and macro BS are closely located, no. of handoffs are also increased. So a tradeoff exists between assignment prob. to femto BS and no. of handoffs. It should also be noted that when the distance is greater than 200 m, the number of handoffs has the same level for both the conventional and proposed algorithms while the proposed algorithm still has the gain in the assignment probability to the femto BS. Therefore, it is possible to use the proposed algorithm with adaptive hysteresis that is decided by the RSS from the macro BS.

Chapter 7.

Concluding remarks.

7.1. Conclusion.

- First handoff scenarios in macro cell/femto cell coexisting network based on received signal strength and SINR are observed using different indoor and outdoor path loss models.
- Interference and SINR are calculated in dense femto cell environment and their effects on handover are obtained. Here we increased the number of femtocells in a fixed area saw the effect on the interference and SINR considering no macrocell interference to users. Interference increases with number of femtocells. Probability of connection also increases.
- Different handoff parameters like handover probability, RLF rate, ping –pong rate, handover latency are evaluated in macro/femto handoff. Like handoff probability to femto cell increases with increase of the number of femtocells. RLF and Ping-Pong rate depends on hysteresis value and Time to trigger. There is a trade-off exist between RLF and ping-pong rate. For reducing handover failures, we had to carefully select the values of HM and TTT. Also handover latency is seen as a function of user velocity.
- Finally an algorithm is proposed for efficient handoff from macro cell to femto cell. First it is seen how the value of α varies when the distance between macro cell and femto cell is varied from 100 m to 1km. As the distance increases, the value of α decreases and finally becomes 1. We can also see assignment probability to the FAP is much higher after applying α when distance between macro cell and femto cell is less which was our main objective. Then we had also shown the effect of α on the number of handoffs in the network. Therefore it can be concluded that this proposed algorithm gives much better performance in case of macro cell to femto cell handoff scenario than conventional one.

Limitations.

- Here we considered only one femto cell and one macro cell while applying this algorithm. But practically the number of femtocells lying inside a macro cell is quite large.
- Sometimes due to introduction of the multiplying factor unnecessary handoffs take place even though the received power from the target femto cell is not good enough.

Future scope of work.

- As future works, system performance, such as utilization of femtocells and user throughput, may be investigated when the proposed handoff decision algorithm is used. Then, the derivation of optimal handoff location and the corresponding application of the proposed algorithm can be examined. With more extensive analysis and study, we are expecting that the proposed algorithm will give the desirable effects on the improvement of the hierarchical macro/femto cell networks.
- Also in real time scenario, using signal estimation, it can be examined how this algorithm works and what the exact effect on handoff probability, assignment probability to femto cell and number of handoffs are occurring.

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