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Tesi di Laurea Magistrale

Queing models for the analysis and design of heterogeneous cellular networks

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Abstract

In cellular networks, when a user issues a service request to a base station (BS) that has no available radio resources, the request is dropped. In networking terms, a request *blocking* occurs.

Blocking is a standard network performance parameter, that has been used since the early days of circuit-switched telephone networks for network planning and dimensioning.

Blocking can occur both when a new service request is generated by a user located within the area served by the base station, and when a user with an ongoing connection moves from one cell to another (handover, or handoff). The motivation for measuring, analysing and studying the probability of blocking for new calls and incoming handoff calls is that the Quality of Service (QoS) [1], [2] and the end user Quality of Experience (QoE) in cellular networks depend on these two factors. While blocking for new call requests implies the denial of the start of a service instance, blocking for handoffs implies the early termination of a service in progress, and as such can be even more disturbing to the end user. For these reasons, accurate analytical models for the estimation of blocking are important tools for cellular system designer.

In this Thesis, we develop analytical models for the evaluation of three types of blocking probabilities in cellular networks where traditional macro and micro base stations coexist with the new generation of small cell bases stations. Such networks are normally termed Heterogeneous Networks or HetNets. The first type of blocking probability is named *new call* blocking probability, and refers to the probability of blocking for new service requests generated within the area served by the base station. The second type of blocking probability is named *handover* blocking probability, and refers to the early termination of a service in progress due to the end user movement from the area covered by one base station to the area covered by another one. Finally, the third type of blocking probability is named *total* blocking probability, and refers to the blocking of any type of service.

In this Thesis we develop different analytical models to compute blocking probabilities in different contexts.

First of all, we start with a traditional analytical model in which we isolate a single cell, and examine its probability of blocking for different parameter values. The model is based on a queue, and is translated into a one-dimensional continuous-time Markov chain (CTMC). This approach has been traditionally used in the literature for the analysis of cellular networks mostly comprising a number of similar base stations.

As a second step, we develop an analytical model that looks at a group of two neighbouring cells, by using a network of two queues, which translates into a two-dimensional CTMC. This two-dimensional CTMC model is applied to two different configurations of base station pairs. In the first case we consider two symmetric base stations, while in the second case we look at two asymmetric base stations (i.e., two base stations with different characteristics and parameters). In both cases, we estimate the blocking probability for various configurations of the two base stations, observing the effect of changing some parameters in one of the two cells, such as the average service time, the number of channels assigned to each cell, the time before handoff, etc. We observe that in the symmetric case the observed behaviour is equivalent to

the one predicted by the one-dimensional CTMC model, while asymmetrical configurations lead to significant differences.

After that, we consider HetNet configurations. We modify the two-dimensional CTMC model to account for the presence of two types of cells, and we evaluate the blocking probability observed in a macro cell under several different configurations of the small cell base station. This allows us to determine to what extent the parameters of the small cell (new arrival rate, outgoing handoff rate, dimension, etc.) impact the performance of the macro cell.

Finally, considering the different impact on QoE of blocking of new calls and handovers, we assume that some channels are reserved for handovers in HetNet base stations (both macro cell and small cell), and we compute the probability of blocking for varying system parameters.

Contents

Chapter 1

1- Introduction

Mobile radio thelephons were introduced from military communications in the early 20th century. Car-based telephones was first tested in Saint Louis in 1946. This system used a single large transmitter on top of a high rise building. A single channel was used for sending and receiving similar to a half duplex system. To talk,the user pushed a button that enabled transmission and disabled reception. Due to this, these became known as "*push-to-talk*" systems in the 1950s.
To allow user to talk and listen at the same time , IMTS(Improved Mobile Thelephone System) was introduced in the 1960s. It used two channels, one for sending and other for receiving, bringing telecommunication to full duplex mode.

In the 1970s Privet companies have started developing their own systems to evolve the existing system further.Those privet systems are Analogue Mobile phone System (AMPS) used in America, Nordic Mobile Telephone (NMT) used in parts of Europe and Japanese and Total Access Communication system (TACS) used in Japan and Hong Kong. Independently developed system are called as 1st Generation communication, it was introduced in 1980 by Bell Labs and.The key idea here was to divide geographical areas into cells and each cell was served by a base station so that the frequency re-use can be implemented. As a result AMPS could support 5 to 10 times more user than IMTS. Major concern for the first generation was *weak security* on air interface, *full analog mode* of communication and *no roaming*
Now to implement roaming. Individual organisations started working under one umbrella, European Telecommunication Standard institute (ETSI) and developed second Generation system. Second generation cellular telecom networks were commercially launched in 1991 in Finland based on *GSM* standards. It could deliver data at the rate of up to 9.6 Kbps. Three primary benefits of 2G networks over their predecessors were:

- Phone conersations were now digitally encrypted
- More efficient on spectrum
- Allow far greater mobile phone penetration level

2G introduced data service for mobile, starting with SMS text message. Further to achieve higher data rates, GSM carriers started developing a service called General Packet Radio Service (GPRS). This system overlaid a packet switching network on the existing circuit switched GSM network. GPRS could transmit data at up to 160 kbps. The phase after GPRS is called Enhanced Data Rates for GSM Evolution (EDGE), It introduced 8 PSK modulation and could deliver data at up to 500 kbps using same GPRS infrastructure. During this time the internet was becoming popular and data service were becoming more prevalent. Post 2.5G, Multimedia services and streaming started growing and Phones now started supporting web browsing.
3GPP UMTS, the Universal Mobile Telecommunications System succeeded EDGE in 1999.This system uses Wideband CDMA (W- CDMA) to carry the radio transmissions, and often the system is referred to by the name WCDMA (UMTS).
Now before we go further let us understand how the governing bodies were developed. In the interests of producing truly global standards, the collaboration for both GSM and UMTS was expanded further from ETSI to encompass regional Standard Development Organizations, such as ARIB and TTC from Japan, TTA from Korea, ATIS from North America and CCSA from China. The successful creation of such a large and complex system specification required

a well- structured organization. This gave birth to 3GPP and which worked under the observation of ITU-R. ITU-R is one of the sector of ITU, its role is to manage the international radio-frequency spectrum and to ensure the effective use of spectrum. ITU-R defines technology families and associates specific part of the spectrum with these families. ITU-R also proposed requirement for radio technology. Three organizations, 3GPP, 3GPP2 and IEEE started developing standards to meet the requirements proposed by ITU-R.

- Evolution of 3GPP stated from GSM to long term evolution advanced.
- Evolution of 3GPP2, started from 1S95 to CDMA Revision B
- Evolution of IEEE started from 802.16 FIXED WIMAX, to 802.16M

Since 3GPP was dominated and widely accepted, we will only incorporated roadmap evolved by 3GPP.
Now, coming back to 3rd Generation. The goal of UMTS or 3G wireless systems was to provide a minimum data rate of 2 Mbit/s for stationary or walking users, and 384 Kbit/s in a moving vehicle. 3GPP designated it as Release 99. The upgrades and additional facilities were introduced at successive releases of the 3GPP standard.
RELEASE 4: this release of the 3GPP standard provided for the efficient use of IP, this was a key enabler for 3G High Speed Downlink Packet Access (HSDPA).
RELEASE 5: this release included the core of HSDPA. It provided reduced delays for downlink packet and provide a data rate of 14Mbps.
RELEASE 6: this included the core of HSUPA with a reduction in uplink delay it enhanced uplink raw data rate of 5.74Mbps. This release also included MBMS for broadcasting services.
RELEASE 7: this release of the 3GPP standard included downlink MIMO operation as well as support for higher order modulation of up to 64-QAM. Either MIMO or 64- QAM could be used at a time. Evolved HSPA provides data rates up to 28 Mbit/s the downlink and 11 Mbit/s in the uplink. This brings us to the most part Long Term Evolution(LTE).
Initial goal of telecommunication was mobility and global connectivity, but as the technology evolved the services stated expanding. Now services were not restricted to voice and SMS only. For this expansion and efficient execution in LTE, whole new architecture was adopted for both non-Radio part, SAE (System Architecture Evolution) and radio part using pure IP architecture (packet switching). To fulfill the requirement proposed by ITU-R study group formed and LTE standardization, began in 2004. Large number of telecom companies collaborated to achieve their common vision.
In June 2005 Release 8 was finally crystallized after series of refining. Some of the significant feature of Release 8 were:

- Reduced delays, for both connection establishment and transmission latency
- Increased user data throughput
- Increased cell-edge bit rate
- Reduced cost per bit, implying improved spectral efficiency
- Simplified network architecture
- Seamless mobility, including between different radio -access technologies
- Reasonable power consumption for the mobile devices

These requirements were fulfilled by advancement in the underlying mobile radio technology. The three fundamental RADIO technologies that have shaped the LTE radio interface design were:

1- Multi Carrier Technology
2- MIMO
3- Application of Packet Switching to the radio interface

As a result of intense activity by a large number of organizations, the specifications for the release 8 was completed by December 2007. The first commercial deployment took place by the end of 2009 in northern Europe. In the subsequent release multiple services such as

- Multi cell HSDPA
- HETNET
- COORDINATE MULTIPOINT
- CARRIER AGGREGATION
- MASSIVE MIMO

And many more were targeted for a rich customer experience.
Now is time to move from services to multi services approach, in other word from LTE advanced to next generation communication system which is 5th GENERATION. Feature have been planned to be added in the 5th Generation or next generation systems are pervasive networks where user can concurrently be connected to several wireless access technologies and seamlessly move between them.
Group Cooperative Relay is a technique that is being considered to make the high data rates available over a wider area of the cell.
Cognitive Radio Technology would enable the user equipment to look at the radio landscape in which it is located and choose the optimum radio access network, modulation scheme and other parameters to configure itself to gain the best connection and optimum performance.
Smart antennas, another major element of any 5G cellular system will be that the smart antennas. It will be possible to alter the beam direction to enable more direct communications and limit interference and increase overall cell capacity.

Chapter 2

2-Cellular Network Modelling Approaches

A cellular network is a radio network distributed over thousands of overlapping geographic areas, or cells. A generic cellular network can be imagined as a grid of hexagonal cells, as shown in figure 1:

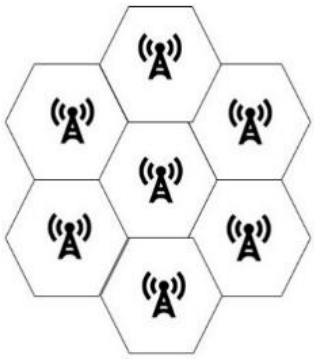


Figure 1: cellular network

Each cell includes its own transceiver known as base station. The cells slightly overlap at the edges to ensure that users countinusly remain within range of a base station. Each base station provides the radio resources to drive the telephon traffic of the users in the cell. Radio resourses are shared between users based on three diffrent schemes,frequency ,time and code division or more frequently, a mix of these thechniques.

RF signals are transmitted by an individual mobile phone and received by the base station, where they are then re-transmitted from the base station to another mobile phone. Transmitting and receiving are done over two slightly different frequencies [3].These cells together provide radio coverage over larger geographical areas. Base stations are connected to each other through central switching centers which track calls and transfer them from one base station to another as callers move between cells; the handoff is (ideally) seamless and unnoticeable. Since a mobile telephony network is too complex to be analyzed, its designe and planning are decomposed into two tasks.

- Finding a feasible assginment of the available radio channels to cells
- Computing the number of channels to be actived in each cell by taking into account the users' needs and behavior

So to obtain acceptable performance while providing the desired quality of service(QoS) to users, mobile telephony operators need to develop a simple, accurate and flexible models for the performance evaluation and design of cellular systems. The model must be simple because it can be efficiently solved and possibly used in complex optimization tools also it can be instrumental to many phases of the system design (similar to Erlang-B in traditional telephony) . besides we mentioned that the model must be Accuratable so that results are reliable and it must be Flexible to modify the calculation of different variations and aspects of the systems under study.

In a model ,we evaluate the performance in terms of

- The average number of active calls in a cell ,which is an indirect metric of revenues generated by the equipment.
- The blocking probabilit for new incoming call.
- The blocking probability for a call in progress due to mobility.

The first analytical model for evaluation of performance and design of cells is called the basic model. this model is extremely simple. It is an introduction to the general modeling methodology and explains how such a model can be used for the cell performance evaluation and design.

2-1 The Basic Model

The basic model for analyzing the performance of a cell in a mobile telephony cellular network is based on the M/G/C/0 queue.

- Users generate calls according to a Poisson process, with rate λ
- calls are blocked and rejected if no free resource is available
- The customer service time S is distributed according to Fs(t), with mean value $E[S]=1/\mu$
- The traffic intensity, is $\rho=\lambda\ E[S]$
- C total resources
- The probability that the number of customer in queue is equal to i is denoted by πi
- The mean value of number of customers in queue is E[A]
- The blocking probability is denoted by B

The solution of the M/G/C/0 queue provides the probability π (i) which represents there are i active calls

$$\pi(\iota)=\frac{\rho^i/i!}{\sum_{j=0}^{c}\rho^j/j!} \quad \text{with } \rho=\lambda\, E[S]= \lambda / \mu$$

The blocking probability is given by the Erlang-B formula (using PASTA)

$$B(N,\rho)=\pi\,(c)= \frac{\rho^C/C!}{\sum_{j=0}^{c}\rho^j/j!}$$

The average number of active connections is

$$E[A]=\sum_{i=0}^{C} i\,.\,\pi(i)$$

THE MARKOVE CHAIN MODEL

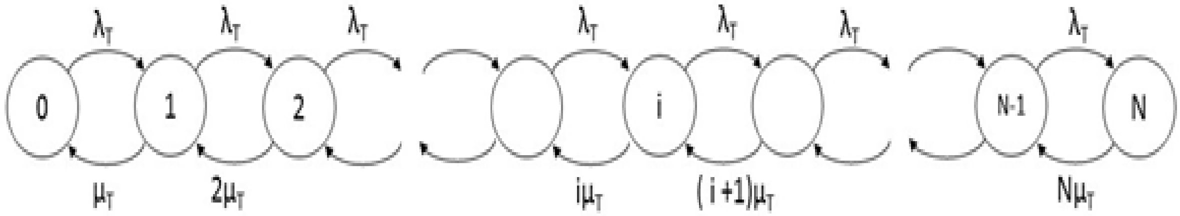


Figure 2-1: Transition diagram for single cell

Under the assumption that the service time is distributed according to a negative exponential pdf with mean $1/\mu$, the same solution will result for the above Markov chain (MC).

2 -2 MODELING MOBILITY (In single cell analysis)

In the basic model , there is no distinction between the generation of a new call and the arrival of an incoming handover call also the possibility that a call release the channel not only for the termination of a call but also for the fact that user moves into other neighboring cell due to mobility. In order to describe mobility, some enhancements to the basic model are necessary.

Arrival process

A distinction between new call and incoming handover call request is based on the following assumptions:

- The new calls generate with Poisson process with parameter λ
- The process of incoming handover calls from other cells is Poisson with rate λ_h

The aggregation process of two kind of calls is also a Poisson process with parameter $\lambda_t = \lambda+\lambda_h$.

Channel holding time

The channel holding time (S) can be a combination of:

- Call duration X which leads to the call termination
- Dwell time D that causes an outgoing handover

By considering the two following cases for the instant in which the channel holding time starts:

Case 1: *The new connection call is set up in the cell*
In this case channel holding time S is the minimum between call duration X and residual dwell time D^r so we have

$$S_1=\min(X,D^r)$$

X has negative exponential pdf with μ, D is negative exponential with μ_h and D^r has negative exponential pdf with μ_h, due to the property of exponentially distributed random variables, the distribution of S1is also negative exponential with parameter $\mu t=\mu+\mu_h$

Case 2: *The accepted call is an incoming handover*
Channel holding time S in this case, is the minimum between the residual call duration $X^{(r)}$and the dwell time D

$$S2=\min(X^{(r)}, D)$$

Since the r.v. X is negative exponential with μ , the memoryless property of exponential distributions makes $X^{(r)}$ distributed as X so $S_2= \min(X, D)$.for that reasone S_2 is distributed as S_1
In conculusion, by combining these two cases,the distribution of S is negative exponential with parameter $\mu t=\mu+\mu_h$

Blocking probability is :

$$B(N,\rho)=\pi(c)=\frac{\rho^C/C!}{\sum_{j=0}^{c}\rho^j/j!} \quad \text{With } \rho=\frac{(\lambda+\lambda h)}{(\mu+\mu h)}$$

The probability that a channel is released because of an outgoing handover, rather than a call completion, is given by: $H=\frac{\mu h}{\mu h+\mu}$

By assuming that dwell times in different cells have the same pdf ,the probability that a call needs exactly *h* handovers is given by:

$$\Pr\{\text{h handovers required}\}= H^h\,(1-H)$$

The mean number of handovers required per call is $E(H)=\frac{1}{(1-H)}$

Given the above assumptions, the model of the cell is now a M/M/C/0 queue with load

$$\rho=\frac{(\lambda+\lambda h)}{(\mu+\mu h)}$$

in order to compute incoming handover into a cell, an approach presented in literature [[4]] is to balance the incoming and outgoing handover flow rate for a cell, so that, on avarage the number of outgoing and incoming handovers per time unit is the same.

At steady state, the avarage number of departures in the time unit per cell is equal to λ_t.(1-B) . The fraction of departures due to a handover is given by H, therefore the flow rate of outgoing handover calls is given by

$$fo=\lambda_t\,(1-B)\,H=\frac{(\lambda+\lambda_h)(1-B)\ \mu_h}{(\mu+\mu_h)}$$

by applying $\lambda_h = fo$, the flow balance ration becomes

$$\lambda_h=\frac{\lambda(1-B)\ \mu_h}{(\mu+\mu_h)[1-(1-B)]\mu_h/(\mu+\mu_h)}$$

since B depends on λ_h and its expression is not invertible, a solution based on a fixed point is needed. It will present in next chapter

Performance metrics

As we mentioned earlier, failure probability is one of indicators for measuring performance. A call is not successfully terminated under the condition of failure of either a handover request or a new generated call request and of the probability of dropping which is the probability that an active call is forced to terminate before completion, due to a failed handover.

assume that the behaviour of neighboting cells is uncorrelated and on avarage, the blocking probability is the same,The failure probability U can be compute :

$$1\text{-}U = P\{\, success \,\} = \sum_{h=0}^{\infty} P\{\, success \mid h\ handovers\} \, P\{h\ handovers\}$$

where the terme P{ $success$ } is the probability to successfuluy access the channel at the call generation.

$$U=1 - \sum_{h=0}^{\infty}(1-B)^{h+1} H^{h}(1-H) = 1 - \frac{(1-B)(1-H)}{1-(1-B)H}$$

Similarity, the dropping probability D can be defined as:

$$1 - D = \sum_{h=0}^{\infty} P\{\, success \mid h\ handovers\} \, P\{h\ handovers\}$$

$$D = 1 - \sum_{h=0}^{\infty}(1-B)^{h} H^{h}(1-H) = 1 - \frac{(1-H)}{1-(1-B)H}$$

2-3 Channel Reservation (in single cell analysis)

From the point of view of the user, dropping of an active call in progress is significantly worse than blocking, there are several policies for reducing the dropping propability of a call in case of moving to other cells. The simplest one is *channel reservation.*

Let m be the number of channels reserved to handovers out of total c channels in a cell.

An incoming call, either a new generated call or a incoming handover is accepted if the number of free channels in cell is more than C – m

If there are free channels in a cell and the number of free channels in a cell is equal or smaller than c-m, a new generated call is blocked and only incoming handover can enter the cell

In the case of no free channel in a cell, both of new and incoming handoff are blocked.

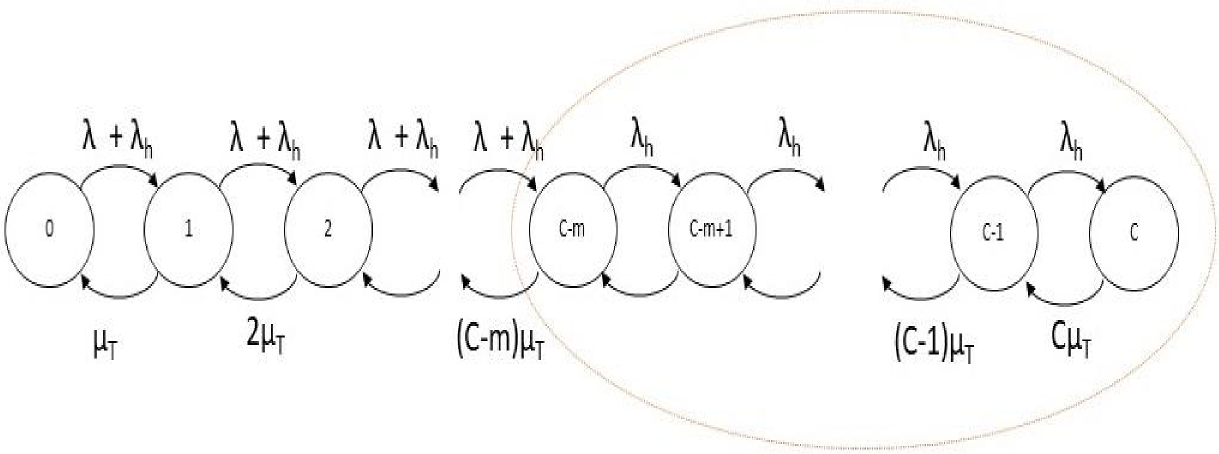


Figure 2-2 Transition Diagram for channel resevation

The steady state probability π(i) that there are i active calls is :

$$\pi(i)=\begin{cases}\pi(0)\frac{1}{i!}\left(\frac{\lambda+\lambda h}{\mu+\mu h}\right)^{i} & for\ i \le c-m\\ \pi(0)\frac{1}{i!}\left(\frac{\lambda+\lambda h}{\mu+\mu h}\right)^{c-m}\left(\frac{\lambda h}{\mu+\mu h}\right)^{i-c+m} & for\ i > c-m\end{cases}$$

The blocking probability of new call is given by the probability that the system is in the satate

S={ π(i)| i ≥ c-m} $\quad B_n = \sum_{i=c-m}^{c} \pi(i)$

The blocking probability of a handover call is

$$B_h=\pi(c)$$

As we mentioned before, the incoming and outgoing handover flow rate into a cell are the same. The outgoing handover flow rate is given by

$$fo= [\lambda(1 - B_n) + \lambda_h(1-B_h)] H$$

The failure and dropping probability can now compute as:

Failure probability= U =1-P{access} where P{access}=1-B_n and

Dropping probability =D

$$U=1-(1-B_n)\sum_{h=0}^{\infty}(1-B_h)^h H^h(1-H)= 1 - \frac{(1-Bn)(1-H)}{1-(1-B_h)H}$$

P{ SUCCESS | h handovers} is $(1-B_h)^h$

$$D=1 - \frac{(1-H)}{1-(1-B_h)H}$$

Chapter 3

3-The Markovian Models

The efficient dimensioning of cellular wireless access networks depends extremely on the accuracy of the underlying mathematical models of user distribution and traffic estimations. The mathematical models used to describe user movements in the network is Markove model. In order to utilize the additional information present in the mobile user's movement history thus providing more accurate results than other widely used models. In addition, the memoryless property of Markov process makes the Markovian models easily applicable.

NOMENCLATURE

- N Number of total channels in a cell
- λ Arrival rate for new calls
- λ_h Arrival rate for handover calls
- $1/\mu$ Average duration calls
- $1/\mu_h$ Average dwell time
- K Number of busy channels in a cell
- Q Transition rate matrix describing the rate a continuous time Markov chain moves between states

3-1: One-Dimensional Model (One-Single- Cell Analysis)

In this section, we start with a traditional analytical model in which we isolate a single cell and examine its probability of blocking for different parameter values. The model is based on the M/G/N/0 queue, used to study and dimension telephone system for almost a century. Customers of the queue represent telephone calls. There is limitation for admission of call into the network. If the number of calls (any type of incoming calls to a cell) exceed the capacity of a cell when any arriving call will be blocked otherwise a call will be set up as long as resources are available. The user releases the channel under either of completing the call or moving to another cell due to the mobility. This kind of moving while a call is in progress is called handoff. The model is translated into a one-dimensional continuous-time Markov chain (CTMC). This approach has been traditionally used in the literature for the analysis of cellular networks mostly comprising a number of similar base stations.

The following assumptions and notation are adopted

- New Customers arrive according to Poisson process with parameter λ
- service time distributed according to a negative exponential with mean $1/\mu$
- $\lambda_T = \lambda + \lambda_h$: the total arrival rate into one cell

- The probability that number of customers in the queue (number of busy channels in a cell) is equal to i, is demonstrated by π_i
- μ_h: as mention before

- $\mu_T = \mu + \mu_h$

Figure 3-1 Indicates the transition diagram in one -dimensional case. Each state S is defined as S = { (k1) | 0 < k1 < N1 }

Where N1 denotes the total channels assigned to cell 1 or A. Let q(i ,j) signifies the probability transition rate from state (i) to state (j), then we have:

$q(i ; i-1) = i \mu_T$

$q(i ; i+1) = \lambda_T$

$q(i; i) = -\sum_{i \neq j} q_{ij}$

Where (i) and (j) are feasible states in S.

Global balance equations

The global balance equations are a set of equations that characterize the equilibrium distribution (or any stationary distribution) of a Markov chain when such a distribution exists.

For a continuous time Markov chain with state space S, transition rate from state i to j given by q_{ij} and equilibrium distribution given by πi, the global balance equations are given by:

$$\sum_{I \in s} \pi_i \, q_{ij}$$

The probabilty of blocking

As we mentioned before, in this case, if all of channels in a cell are fully occupied, any next arriving call will be blocked.

In this thesis for realizing the probability of each state π_i , and in consequence the probability of blocking, we use the inverse of transition matrix Q (figure 3-2), for solving the global balance equations Π Q =0

There is an issue referring to the fact that the result of multiplying every matrix to its invers will be identity matrix (I) so as a result we can not able to find matrix π. By satisfying the normalization condition it can be solved.

Normalization condition : $\sum \pi_i = 1$

We inserted one column of 1 in the end of matix Q called Q',

So the euation Π Q =0 was changed to Π Q'= (0,0,0………..1).

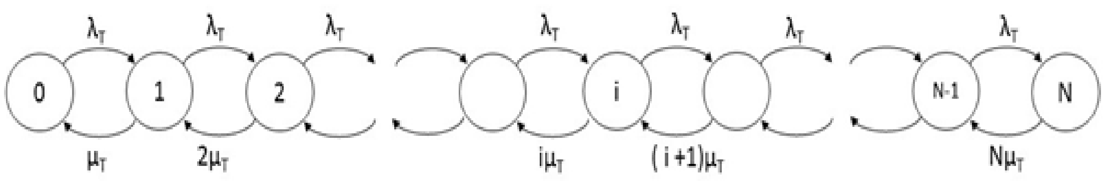


Figure 3-1: Transition diagram single cell (One- Dimensional Case)

STATE(i)	1	2	3	4	i-1	i	i + 1		N -1	N
1	$-(\lambda_T)$	λ_T	0	0	0	0	0	0	0	0
2	μ_T	$-\lambda_T - \mu_T$	λ_T	0	0	0	0	0	0	0
3	0	$3\mu_T$	$-\lambda_T - 3\mu_T$	λ_T	0	0	0	0	0	0
i	0	0	0	0	$i\mu_T$	$-\lambda_T - \mu_T$	λ_T	0	0	0
N	0	0	0	0	0	0	0	0	$N\mu_T$	$-N\mu_T$

Figure3.2: Transition matrix for one-dimensional model

Flow of incoming handover to a cell

The handoff or handover process is one of the most impotant subjects whithin any cellular telecommunications network. [5].

According to handover flow blance assumption [4], the flow of outgoing handovers in a cell must be equal to the flow of incoming handovers.

$\sum$ Incoming handover into a cell $=$ $\sum$ outgoing handoff from a cell (fo)

$$\lambda_h = fo = \sum_{I=0}^{N1} (i * \pi_i * \mu_h) = E(N)\ \mu_h \quad \text{(Figure 3-3)}$$

All of the results reaching by this method is exactly as same as the result of erlang formula. In the next chapter we will put some results and functions.

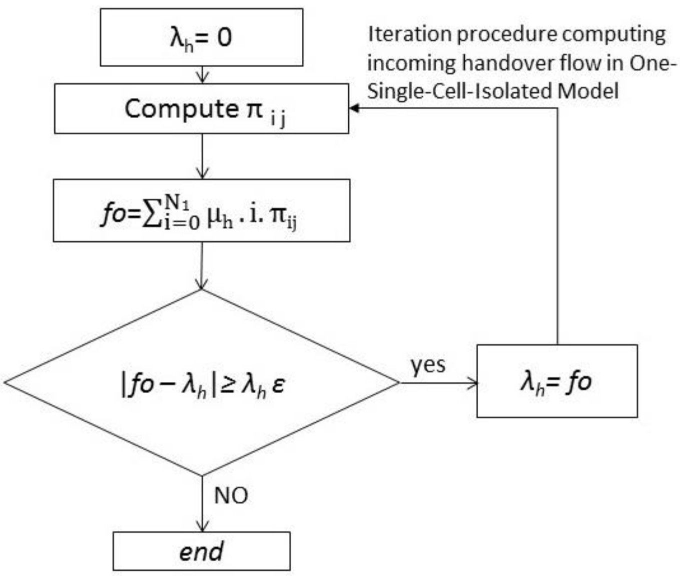


Figure 3.3: Handover flow balance in one-dimensional

3-2 Two-Dimensional Model

We develop an analytical model that looks at a group of two adjacent cells by using a network of two queues. in each cell i, new calls are generated according to an independent Poisson process with rate λ_i. When the event of outgoing handoff due to the mobility in each cell happens, each outgoing handoff from one of two isolated cells, goes to either another cell belonging to this group with probability α or to 5 other neighbors with probabilty 1- α. We will represent all of parameters for cell A with index1 and for cell B with index2. We assume that the probability of travelling a handoff call to each of its 6-neighbors is same so one handoff-call from A will go to B with the rate equal to 1/6 μh1, and to its 5 other neighbors with the rate equal to 5/6 μh1. So in the figure 3-4, α=α'=1/6 and β=β'=5/6 (FIIG 4)

We translates this model into a Two-Dimensional-CTMC -Model(figure 3- 5).

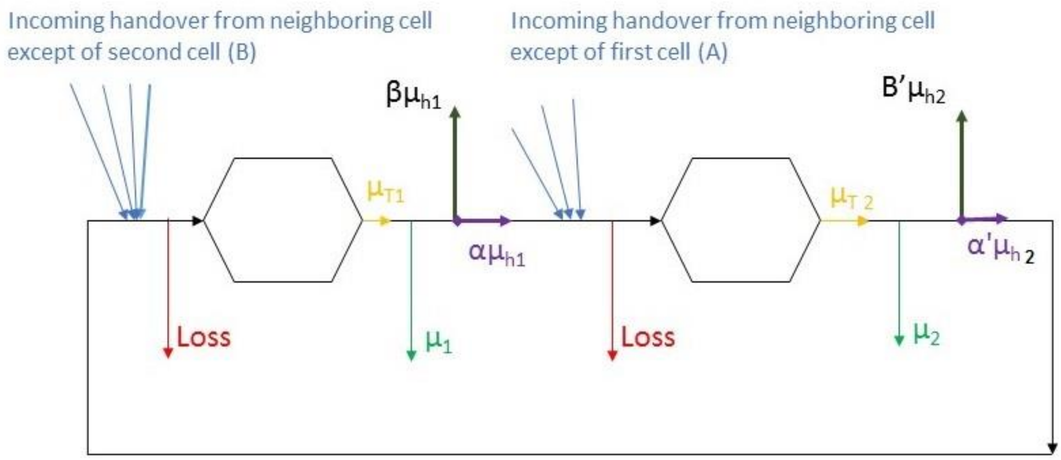


Figure 3-4: Two isolated cell in 2-D Model

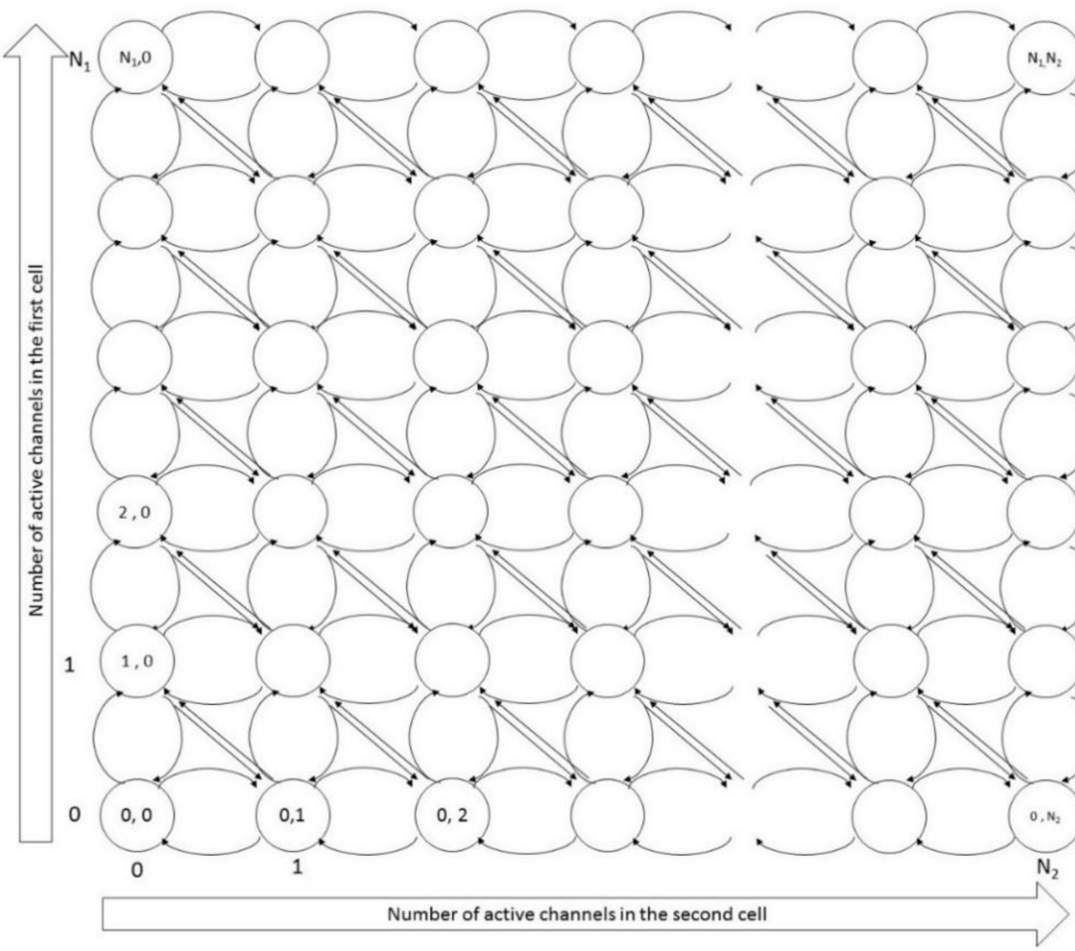


Figure 3-5: Transition Diagram Tow-Isolated-Cell

This Two-Dimensional- CTMC- Model is applied to two different configurations of base station pairs.

1. Symmetic 2D model
2. Asymmetric 2D model

First of all, we consider two symmetric base stations, each cell has the same capacity of N channels and all assigned parameters to each cell are same. while in the second case we look at two asymmetric base stations (i.e., two base stations with different characteristics and parameters). In both cases, we estimate the blocking probability for various configurations of the two base stations. From the analysis of the effect of changing some parameters in one of the two cells, such as the average service time, the number of channels assigned to each cell, it clearly can be observed that in the symmetric case, this model has a completely result as same as One-Single- Cell isolated model. There is no any difference in terms of neither the probability of blocking nor of average number of active channels.
To discribe the chain, let λ, λ_h, μ_h and μ be as defined before , as we mentioned earlier, we represent all of parameters for cell A with index1 and for cell B with index2.
Each state is determined by

$S=\{ (i,j) | 0 \le i \le N_1, 0 \le j \le N_2\}$

Where i denotes the number of busy channels in cell A and j is the number of occupied channels in cell B, Let q(i,j : i',j') define the probability transition rate from state (i,j) to

State (i',j'), then we have

$q((i,j):(i,j)) = -\sum_{(i,j)\neq(i',j')} q((i,j):(i',j'))$ For $0 < i < N_1$, $0 < j < N_2$

1. $q(i,j : i,j+1) = \lambda_2 + \lambda_{h2}$
2. $q(i,j : i,j-1) = j(\mu_2 + 5/6\ \mu_{h2})$
3. $q(i,j : i+1,j-1) = j(1/6\ \mu_{h2})$
4. $q(i,j : i+1,j) = \lambda_1 + \lambda_{h1}$
5. $q(i,j : i-1,j) = i(\mu_1 + 5/6\ \mu_{h1})$
6. $q(i,j : i-1,j+1) = i(1/6\ \mu_{h1})$

The first one shows the number of busy channels in cell A does not change(neither incoming nor outgoing call), while the number of busy channels in cell B is increased by 1 call, so one incoming call(either new generation call or one incoming handover from other neighbor except of A) to cell B has occurred in cell A

The second indicates, that the number of active channel in cell A does not change while the number of busy channels in cell B is decreased by 1 call, so one user in cell B releases the channel under either of terminating the call, or handoff to its neighbour, except of A.

In the third equation, the number of busy channels is increased in A by one call, while it is decreased in B, by releasing one channel, so there is one transfer from B to A

In the fourth, equation we observe a rise into the first cell, without changing in the number of user into the second cell, it is possible under one new incoming call, either in case of handover calls, or new generated call into this cell

The description of fifth equation is similar to second equation, and the last equation is similar to third equation.

The case in which the second cell is saturated earlier than the first cell all of transition maybe occure are:

1. $q(i,j : i,j-1) = j(\mu_2 + 5/6\ \mu_{h2})$
2. $q(i,j : i+1,j-1) = j(1/6\ \mu_{h2})$
3. $q(i,j : i+1,j) = \lambda_1 + \lambda_{h1}$
4. $q(i,j : i-1,j) = i(\mu_1 + \mu_{h1})$

1,2,3 as we mentioned earlier, and the fourth illustrate one releasing channel for the first cell and no change in cell B, in case $j=N_2$, all of channels in cell B are fully occupied therefore, even if one handoff call from A release the channel and moves toward B, it is not accepted and the number of busy channels in B is still N_2 ,so realising channel from A can happen either in case of completing call or hand off toward any 6 neighbours including B

In contrast if the first cell is saturated while there is any free channel in the second cell, all possibility transition including:

1. q (i, j : N_1 , j+1)= $\lambda_2 + \lambda_{h2}$
2. q(i,j : N_1 , j-1)= j ($\mu_2 + \mu_{h2}$)
3. q(i,j : i-1, j)= N_1(μ_1+5/6 μ_{h1})
4. q(i,j : i-1, j +1)= N_1 (1/6 μ_{h1})

And if we suppose that both of two isolated cell are fully occupied and there is no free channel neither for handover call nor for new generated call so any type of incoming call into each cell will be blocked .There are only two possible transitions:

1. q(i,j : N1,j-1)= j ($\mu_2 + \mu_{h2}$)
2. q(i,j : i-1 , j)= i ($\mu_1 + \mu_{h1}$)

let assume that both of channel is free so there is no any limitation for accepting call in each cell and becase both channel are empty, there is no outgoing flow from each cell. The transiactions are:

1. q(i,j : i,j+1)= $\lambda_2 + \lambda_{h2}$
2. q(i,j : i+1,j)= $\lambda_1 + \lambda_{h1}$

Under the situation that all of channels related to second cell are completely free(there is no any user in the second cell) while in the first cell there are user and also free channels so there is no any outgoing hand off from second cell to any other cell. All possible tansition are:

1. q (i, j : i+1,j)= $\lambda_1 + \lambda_{h1}$
2. q (i, j : i,j+1)= $\lambda_2 + \lambda_{h2}$
3. q(i,j : i-1,j)= i (μ_1+5/6 μ_{h1})
4. q(i,j : i-1,j +1)= i (1/6 μ_{h1})

In contrast with the previous situation, if there is no user in first cell but some of channels of second cell are occupied by user but not all of them, there may be one of the follwing transitions

1. q (i, j : i+1,j)= $\lambda_1 + \lambda_{h1}$
2. q(i,j : i,j+1)= $\lambda_2 + \lambda_{h2}$
3. q(i,j : i+1,j -1)= j (1/6 μ_{h2})
4. q(i,j : i,j-1)= j (μ_2+5/6 μ_{h2})

other possible situatin is the case in which first cell is completely free so there is no possibility of outgoing handover from this cell while second cell is completely full so there is no possibility for entering any call either incoming handover or new generated call into this cell. All transitions related to this situation are:

1. q(i,j : i+1,j)= $\lambda_1 + \lambda_{h1}$
2. q(i,j : i+1,j -1)= j (1/6 μ_{h2})
3. q(i,j : i,j-1)= j (μ_2 + 5/6 μ_{h2})

And the last situation is the case in wich all of assigned channels ti=o the first cell are busy while the second cell is comlpetely free. In this situation we have:

1. $q(i,j : i,j+1) = \lambda_2 + \lambda_{h2}$
2. $q(i,j : i-1,j+1) = i\ (1/6\ \mu_{h1})$
3. $q(i,j : i-1,j) = i\ (\mu_1 + 5/6\ \mu_{h1})$

In Matlab'S code, for representing transition matix Q, we display each state(i,j) with a number equal to $K = i\ (N_2+1)+(j+1)$

Three Mthods computing Handover flow into a cell

As we mentioned before, according to handover flow blance assumption:

The flow of outgoing handovers(*fo*) must be equal to the flow of incoming handovers(λ_h) per cell. In this model(traditional 2D-CTMC) for computing λ_h in a cell,we consider the incoming and outgoing handoffs from all of neighboring cells except of the cell belonging to two-isolated group. we compute λ_h for each cell separately(figure 3-5), by three diffrent methods .

Method 1: First method for computing the flow of incoming handover into each isolated cell

In the first method, we increase and check both λ_{h1} for first cell, and λ_{h2} for second cell simultaneously, untill one of them satisfies the condithion of exiting from computing itertion. It happens, when the following condition will occures (figure 3-6).

Condition for extiting handover's interation is:

$$|fo_1 - \lambda_{h1}| \geq \lambda_{h1} .\varepsilon \quad \text{or} \quad |fo_2 - \lambda_{h2}| \geq \lambda_{h2} .\varepsilon$$

After that we stop computing of handover's interation which is satisfed, we fixed it and continu to increase other λ_h to reach its own exiting condition.This method is convenient and the most simple method rather than other appling method, in terms of complexity

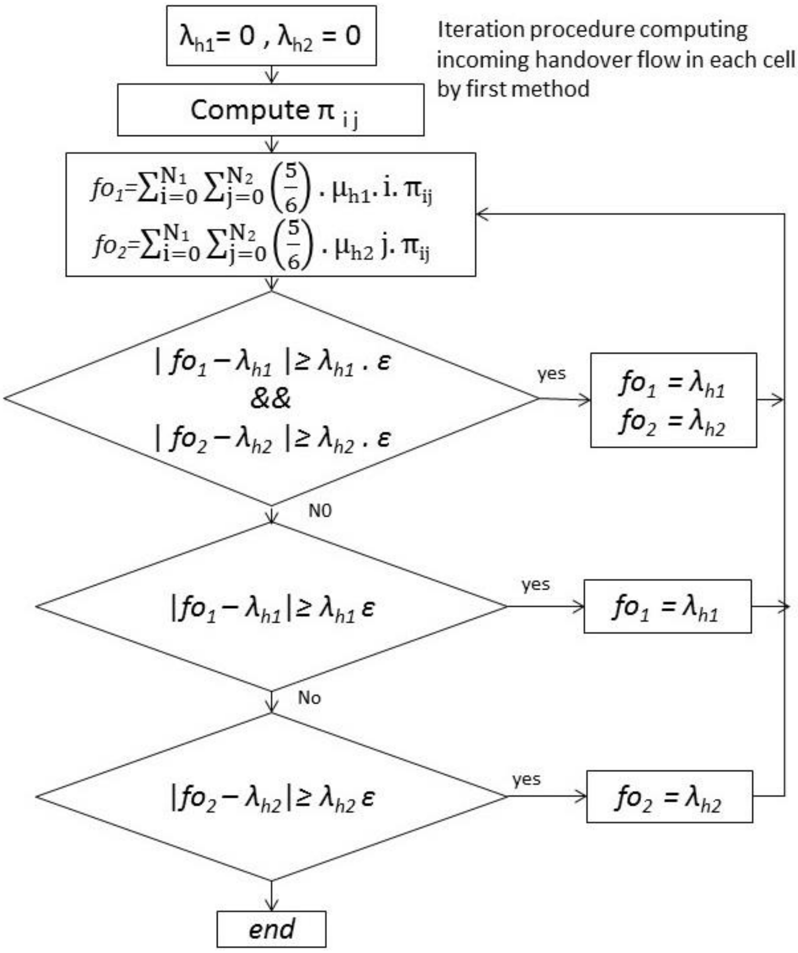


Figure 3-6: iterative procedure to compute λ_h in each cell by first metho

Method 2: Second method for computing the flow of incoming handover into each isolated cell

In the second method, we use nested loop. In the begining we set both of λ_{h1} and λ_{h2} to zero, after that we increase λ_{h2} untill reach to the final its evaluation, in this time we fix λ_{h2} and compute λ_{h1} according to the computed value of λ_{h2} , we iterate it to reach the final value which satisfy the exiting condition (figure 3.7)

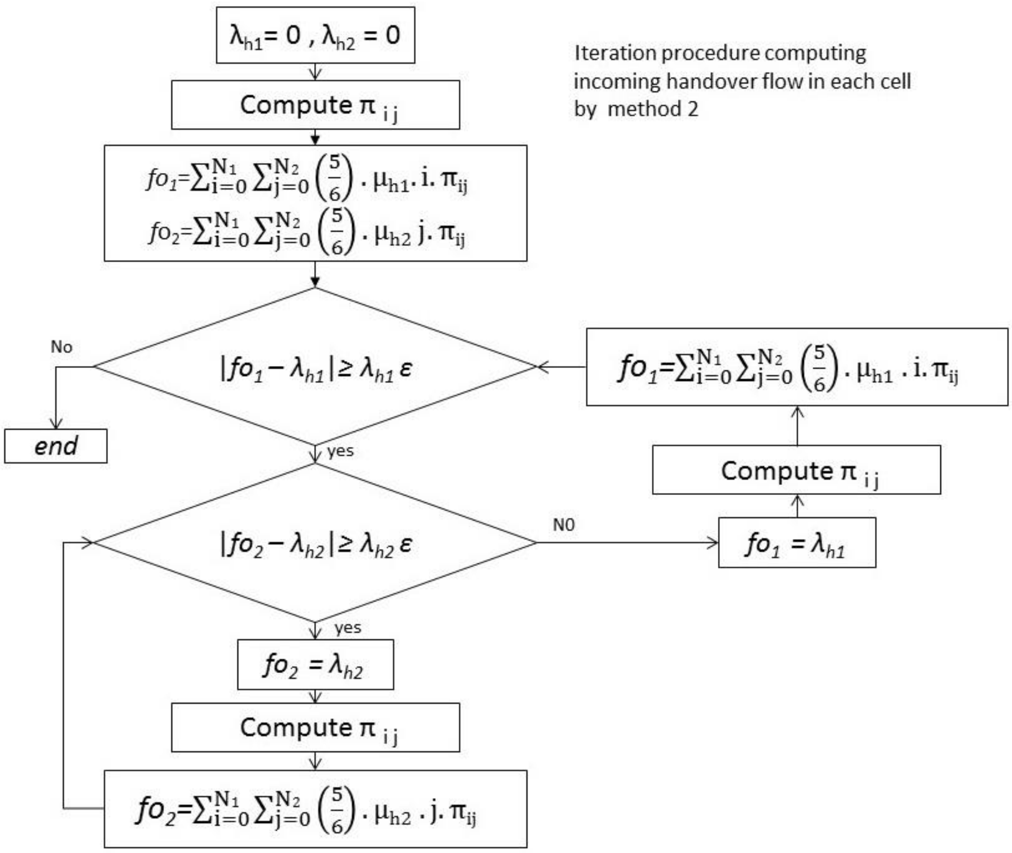


Figure 3-7: iterative procedure to compute λ_h in each cell by second method

Method 3: Third method for computing the flow of incoming handover into each isolated cell

Finally in the third method, we compute flow of incoming handover calls in each cell according to the total handover calls in a group of cells composing of these two isolated cells(figure 3.8).

As a result of several experiments under diffrent parameters, it is conclued that there was no converge in these three methods, but the first method and second method have exactly same result while the third one shows result with amount of difference(maybe ignorable).

For simplisity we use first method.

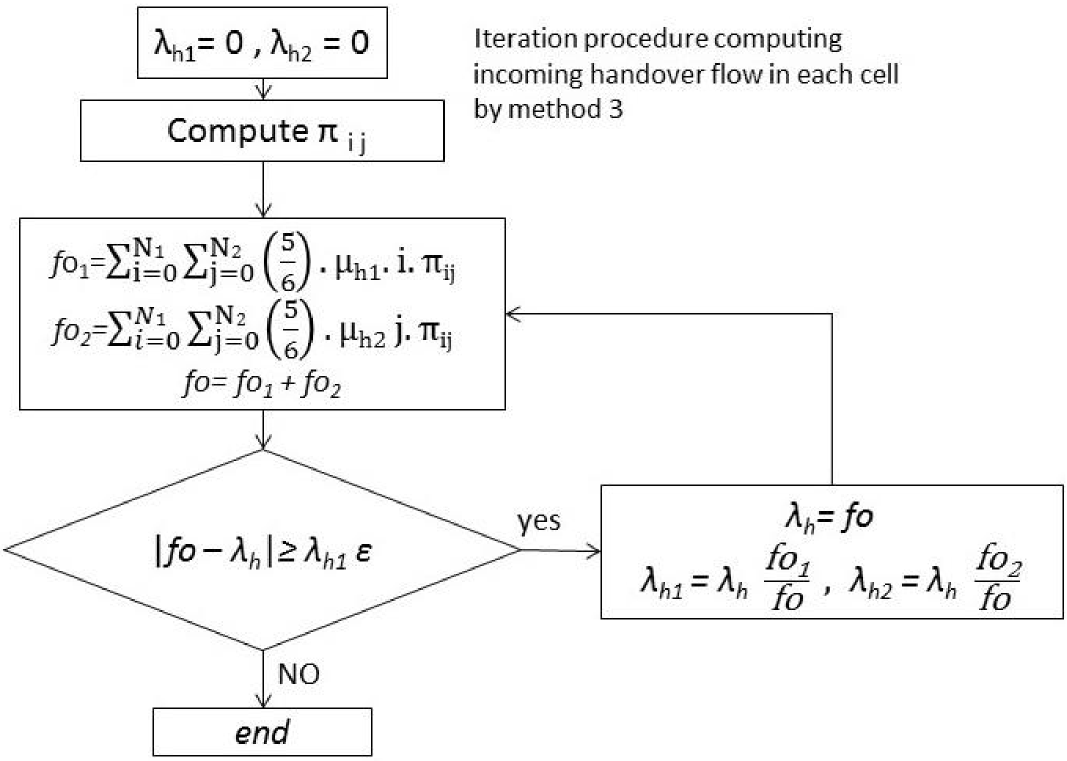


Figure 3-8 : iterative procedure to compute λh in each cell by third method.

3-3: Heterogeneous Cellular Networks, HetNet (HTCN)

Driven by the proliferation of fast developing wireless devices and the emergence of new services, the wireless and mobile data traffic has been approximately doubling every year and this growth is continuing unabatedly [6]. According to the prediction and statistical analysis from International Telecommunication Union (ITU [7]) [6]1000-fold increase in wireless and mobile traffic is expected between 2010 and 2025, with a further 10–100 times growth in the period from 2020 to 2030. To address this exponential growth of mobile data traffic, various solutions are needed to meet the continuously increasing demand and offload traffic for the current cellular networks [8], therefore the network operators recenly have been facing many problems not only for the coverage, but also in the case of capacity . They will have to significantly increase the capacity of their networks as well as reduce the cost per bit .
The cellular network has developed as a multi-tier network that comprises a conventional cellular network (i.e., macrocell network) with multiple low-power base stations (i.e., small cells) [9]. Massive use of small cells in such heterogeneous networks (HetNets), including

picocells and femtocells overlaid on a macrocell network, is one of the promising techniques to cater for the ever increasing huge demand for future wireless data [10], [11], [12], [6] Heterogeneous cellular network is an aproach for cellular networks to provide the coverage and capacity needed to move forwards. The heterogeneous networks,composed of a variety of formats of base station, radio access networks, transmission solutions and power levels. Combining such a variety of technologies together enables the best option to be chosen for a given area, but it also presents problems in terms of ubiquity and operation with such a variation of technologies and approaches [5]

The HTCN discussed in this thesis consists of two kinds of cells: Macro cells and Micro cells. Macro cells are used to provide coverage. Pico cells and micro cells are used to enhance capacity in the crowded areas,such as city centers, shopping malls, airports and train stations.

For simplicity, we model a network composed of one macro cell surrounding one micro cell and neighboring 6 other cells, then we investigate about transactions between Macro base station and micro(small) cell, We modify the two-dimensional CTMC model to account for the presence of two types of cells, and we evaluate the blocking probability observed in a macro cell under several different configurations of the small cell base station.

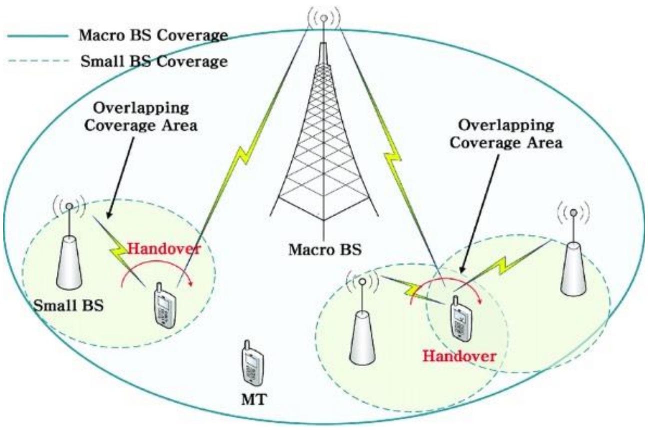


Figure 3-9 : Heterogeneous Network

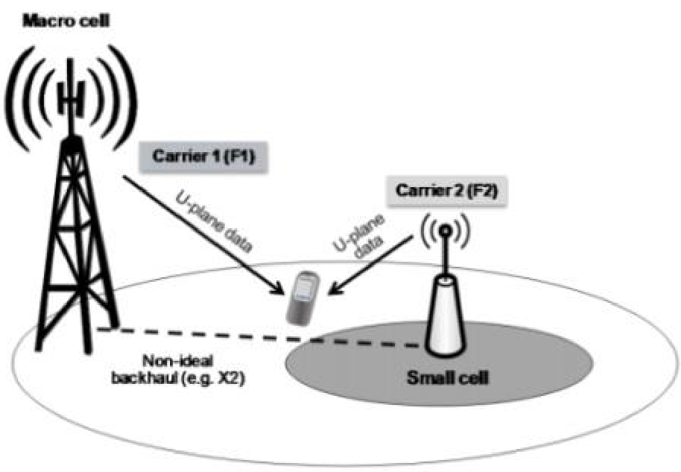


Figure 3-10 our investigaed Het-Net model

In this model we assume that the probability of entering one outgoing handoff from macro cell into micro cell be equal to 1/3 and entering to its neighbours is 2/3 while the probability of directing one outgoing handoff from micro cell to macro cell is equal to 1(Figure 3-10).

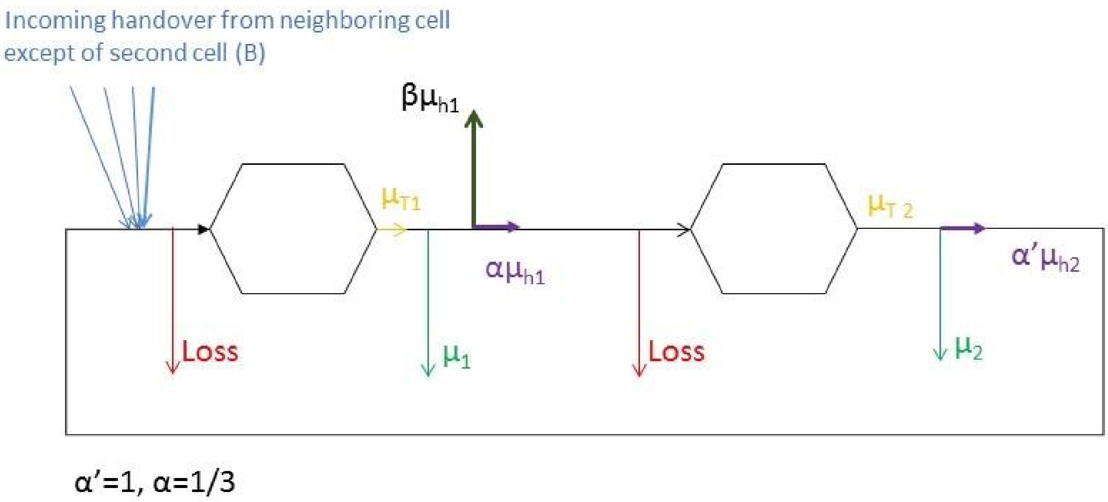


Figure 3-11: incoming and outgoing calls for macro and micro cell in Het-Net

Each state is determined by

S={ (i,j)| $0 \leq i \leq N_1$, $0 \leq j \leq N_2$}

Where i denotes the number of busy channels in macro cell and j represents the number of occupied channels in micro cell (Transition diagram for this case is like figure 3-5). If we define q(i,j: i',j') as the probability transition rate from state (i,j) to State (i',j'), it will be defined as before in case two- dimensional but with different assumption such as:

- 1/6 μ_{h1} will change to 1/3 μ_{h1}
- 5/6 μ_{h1} will change to 2/3 μ_{h1}
- 1/6 μ_{h2} will change to μ_{h2}
- 5/6 μ_{h2} will change to 0 (there is no outgoing handoff from micro cell to any cell except of macro cell)
- λ_{h2}=0 (there is no incoming handover from other cells except of macro cell to micro cell, micro cell is surrounded by macro cell).

Handovers into a Macro cell

As figures 3-7 and 3-8 demonstrate, in this case incomming handoffs will occur only for macro cell. there is no incoming handover into micro cell from any cell except of portion of outgoing handoff calls coming from surrounding macro cell.

for computing the iteration of incoming handovers to macro cell, as we mentioned earlier, the probability rate of directing one handoff call from macro cell to other external neighboring cell is equal to 2/3 μh1, hence we can consider

$$fo(macro) = 2/3\ \mu_{h1} \sum_{i=0}^{N1} \sum_{J=0}^{N_2} i.\pi_{i\ j}$$

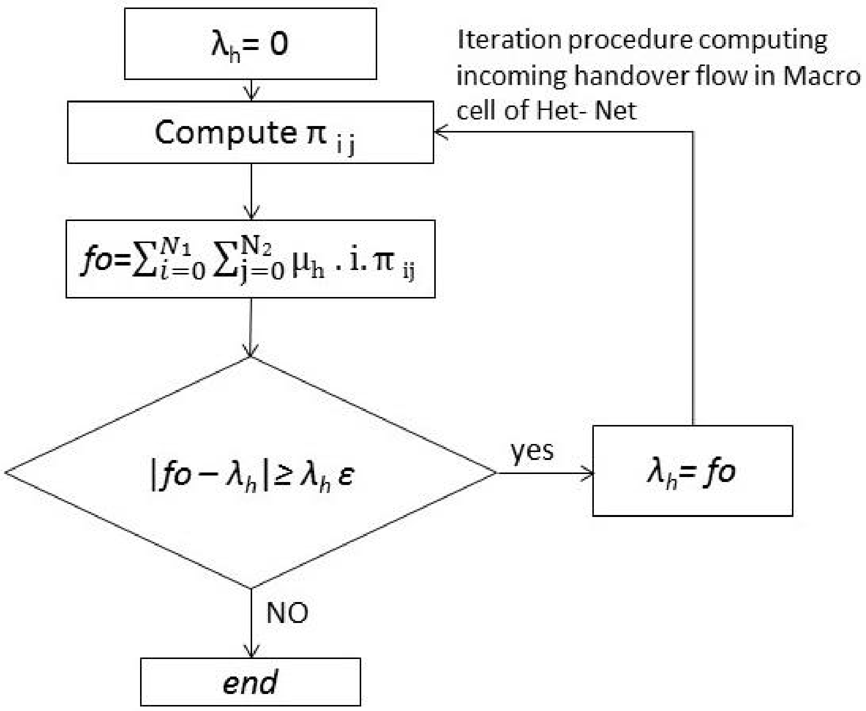


Figure 3-12 : incoming handoff calls into macro cell in het net

3-4: Two-Reserved-Channels for incoming handoff in Het-Net

An accepted call that has not completed in the current cell may have to be handed off to another cell.During the process, the call may not be able to gain a channel in the new cell to continue its service due to the limited resource in wireless networks, which will lead to the call dropping. Thus, the new call and handoff calls have to be treated differently in terms of resource allocation. Since users tend to be much more sensitive to call dropping than to call blocking,handoff calls are normally assigned higher priority over the new calls. Various handoff priority-based CAC schemes have been proposed [13] One of schemes is *cutoff Priority scheme*.

cutoff Priority scheme:

Let denote the threshold, upon a new call arrival. If the total number of busy channels is less than m , the new call is accepted, otherwise, the new call is blocked. The handoff calls are always accepted unless no channel is available upon their arrivals [13]

In this part we denote m equal to two reserved channels only for incomming handoff calls in Heterogeneous Networks for both macro and small cell.we develop analytical models for the evaluation of three types of blocking probabilities in Heterogeneous Networks .The first type of blocking probability is named *new call* blocking probability, and refers to the probability of blocking for new service requests generated within the area served by the base station. The second type of blocking probability is named *handover* blocking probability, and refers to the early termination of a service in progress due to the end user movement from the area covered by one base station to the area covered by another one. Finally, the third type of blocking probability is named *total* blocking probability, and refers to the blocking of any type of service.

Each state, in this CTMC, is define as the previous section (*Het-Net*) such as $S=\{ (i,j) | 0 \leq i \leq N1, 0 \leq j \leq N2\}$ which i represents the number of busy channels in macro cell and second item j defines the number of busy channels in small cell. all of assumption for previous section (Het-Net) are assumed also here also as before we define q(i,j: i',j') as the probability transition rate from state (i,j) to State (i',j') . we have

Let start with the situations in which the number of free channels in both macro and small cell is greater than m=2 so there is no limitation for accepting any type of calls including handover and new calls neither in in macro cell nor in small cell so there are six possibility of transition in this case such as:

1. $q(i,j : i,j+1)= \lambda_2$
2. $q(i,j : i,j-1)= j (\mu_2)$
3. $q(i,j : i+1,j -1)= j (\mu_{h2})$
4. $q(i,j : i+1,j)= \lambda_1+ \lambda_{h1}$
5. $q(i,j : i-1,j)= i (\mu_1+2/3 \mu_{h1})$
6. $q(i,j : i-1,j +1)= i (1/3 \mu_{h1})$

as we see, in the first equation we do not mention incoming handover flow while we said earlier that there is no limitation for accepting any type of incomming call. If we remebre we analize the model in which small cell is serunded just by macro cell and there is no incoming handover flow from other cell except of macro cell.that is the reason we do not mention incoming handover in the first equation. In this equation the number of busy channels in second cell is increased by one so the only probability of this situation is that one new generated call with rate λ_2 comes to second cell

Another situation is the case in which the number of available free channles in the first cell is greater than m=2 while this number for second cell is less or equal to m=2 but there is availabel channels in second cell only for accepting incoming handover call ($0 \leq i < N_1-2$, $N_2-2 \leq j < N_2$) so all of possible transactions in this case including:

1. $q(i,j : i+1,j -1)= j (\mu_{h2})$
2. $q(i , j : i+1,j)= \lambda_1+ \lambda_{h1}$
3. $q(i,j : i-1,j)= i (\mu_1+2/3 \mu_{h1})$
4. $q(i,j : i-1,j +1)= i (1/3 \mu_{h1})$

as we see in all related abow equations, there is no any equation in which number of active channels in second cell incrtease by one while there is no changing in the number of active channels of first cel. The only case in which we observe increasing of active channels in the second cell is fourth equation, this increasing in the second cell is due to the fact that an outgoing handoff call from macro cell moves to the small cell.

in contrast with previous situation , there is other state in which in the first cell, there is no any limitation for accepting any kind of incoming calls while in small cell, only incoming handover calls will be accepted ($N_1-2 \leq i < N_2$, $0 \leq j < N_2-2$) . Involving transition are:

1. $q(i , j : i,j+1)= \lambda_2$
2. $q(i , j : i,j-1)= j (\mu_2)$
3. $q(i , j : i+1,j -1)= j (\mu_{h2})$
4. $q(i , j : i+1,j)= \lambda_{h1}$
5. $q(i , j : i-1,j)= i (\mu_1+2/3 \mu_{h1})$
6. $q(i , j : i-1,j +1)= i (1/3 \mu_{h1})$

In the postion that there is restriction for admiting new call for both isolated cell and both of them have free availabe channels only for incoming handover calls ($N_1-2 \leq i < N2$, $N_2-2 \leq j < N2$) and any new generated call toward this group with be blocked.The following transition may occure

1. $q(i,j : i,j-1)= j (\mu_2)$
2. $q(i,j : i+1,j -1)= j (\mu_{h2})$
3. $q(i,j : i+1,j)= \lambda_{h1}$
4. $q(i,j : i-1,j)= i (\mu_1+2/3 \mu_{h1})$
5. $q(i,j : i-1,j +1)= i (1/3 \mu_{h1})$

If the first cell has enough channel for accepting any type of calls and second(small cell) is fully occupied ($0 \leq i < N_1-2, j = N_2$) so there is no possibility for entering new calls or handoff calls into second cell and there is no restriction for accepting any type of call in first cell, The possible transitions are:

1. $q(i,j : i,j-1)= j (\mu_2)$
2. $q(i,j : i+1,j -1)= j (\mu_{h2})$
3. $q(i,j : i+1,j)= \lambda_1+ \lambda_{h1}$
4. $q(i,j : i-1,j)= i (\mu_1+\mu_{h1})$

Under the situation that there are available channels only for handoff calls into first cell and second cell is completely saturated ($N_1-2 \leq i < N_1, j = N_2$) so any kind of incoming call toward second cell will be blocked and the only acceptable incoming call toward this isolated group is incoming calls into first cell. The potential transitions in this case are:

1. $q(i , j : i , j-1)= j (\mu_2+5/6 \mu_{h2})$
2. $q(i , j : i+1, j -1)= j (1/6 \mu_{h2})$
3. $q(i , j : i+1 , j)= \lambda_{h1}$

4. $q(i,j \ : i-1,j) = i (\mu_1+\mu_{h1})$

Another position is one that the first(macro cell) is full and the second cell (small) has free enough available channels for any incoming call including hanoff calls or new generated calls ($i = N_1$, $0 \leq j < N_2-2$), but as we know in this case the only incoming handoff calls towards the second cell comes from first cell .In this case we have:

1. $q(i,j \ : i,j+1) = \lambda_2$
2. $q(i,j \ : i,j-1) = j (\mu_2+ \mu_{h2})$
3. $q(i,j \ : i-1,j) = i (\mu_1+2/3 \ \mu_{h1})$
4. $q(i,j \ : i-1,j +1) = i (1/3 \ \mu_{h1})$

If first cell is completely busy and there is free available channels only for accepting handover calls in the second cell($i = N_1$, $N_2-2 \leq j < N_2$), the following transition may happen

1. $q(i,j \ : i,j-1) = j (\mu_2+ \mu_{h2})$
2. $q(i,j \ : i-1,j) = i (\mu_1+2/3 \ \mu_{h1})$
3. $q(i,j \ : i-1,j +1) = i (1/3 \ \mu_{h1})$

And finally, the last situation is the case in which both two isolated cells are fully occupied. There is no possibility for admitting any kind of call towards this group ($i=N_1$, $J=N_2$).

1. $q(i,j \ : i,j-1) = j (\mu_2+ \mu_{h2})$
2. $q(i,j \ : i-1,j) = i (\mu_1+ \mu_{h1})$.

probability of blocking**:**

as we mentioned before, we consider that m is the number of channels which will be reserved for just incoming handoff calls

Probability(blocking for new incoming calls in macro cell)

$$= \frac{\sum_{i=N_1-m}^{N_1} \sum_{J=0}^{N_2} \pi_{i\ j}\ \lambda_1}{\sum_{i=0}^{N_1} \sum_{J=0}^{N_2} \pi_{ij}\ .\ \ \lambda_1}$$

Probability(blocking for incoming handoff calls in macro cell)

$$= \frac{\sum_{J=0}^{N2} \pi(N_1,j)\ .(\lambda_{h1}+j\mu_{h2})}{\sum_{i=0}^{N1} \sum_{J=0}^{N2} \pi(i,j)\ (\lambda_{h1}+j\mu_{h2})}$$

Probability total (blocking for any type of call in macro cell)

$$= \frac{\sum_{i=N_1-m}^{N1} \sum_{J=0}^{N2} \pi(i,j)\ \lambda_1 + \sum_{J=0}^{N2} \pi(N_1,j)\ .(\lambda_{h1}+j\mu_{h2}+\lambda_1)}{\sum_{i=0}^{N1} \sum_{J=0}^{N2} \pi(i,j)\ (\lambda_{h1}+j\mu_{h2}+\lambda_1)}$$

Chapter 4

4-Some Numerical Results

The goal of this chapter is to provide some numerical results of simulation to determine to what extent the parameters of the second cell (small cell in Het-Net) impact the performance of the first cell. These simulations are related to four different models:

- Two Isolated Symmetric Cells or Symmetric-Two- Dimensional Model
- Two Isolated Asymmetric Cells or Asymmetric-Two-Dimensional Model
- Heterogenous Network without reserved channels for ant types of calls
- Heterogenous Network with two reserved channels for incoming handoff calls

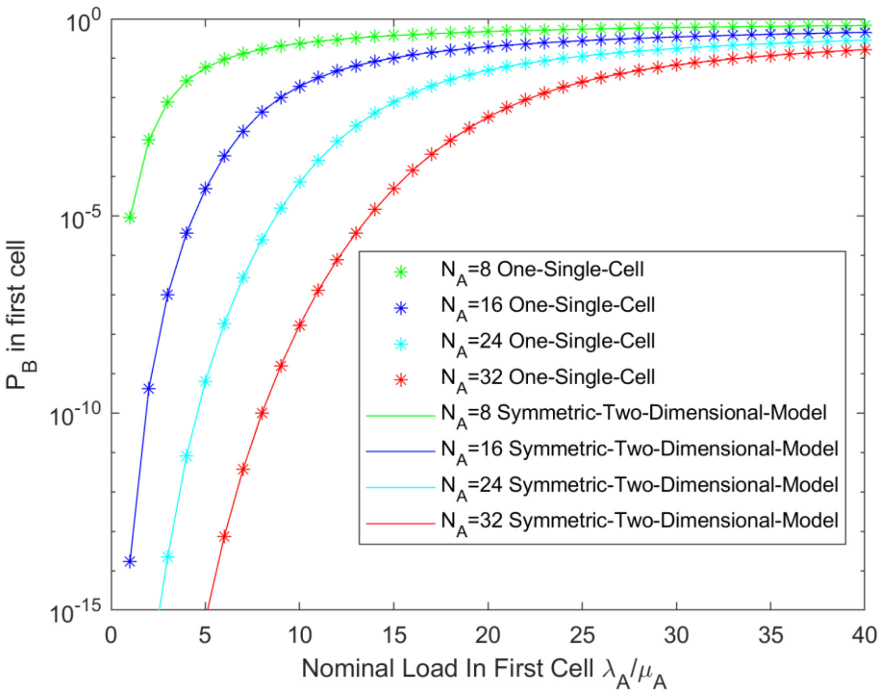
Symmetric-Two- Dimensional Model

In this section, we present some results showing the effect of capacity of cell and mobility rate (outgoing handoff rate).

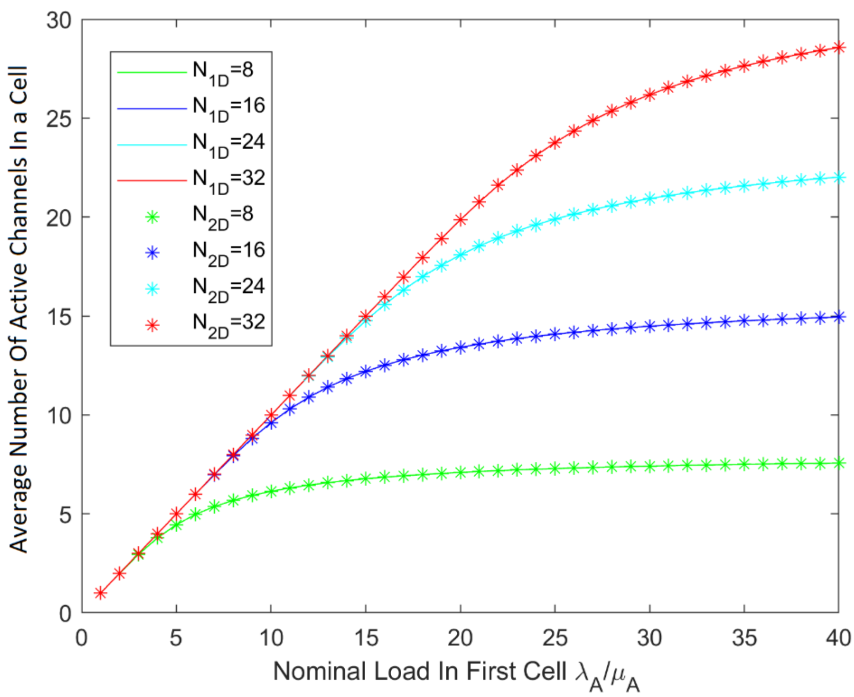
Graph 1 shows the effect of a cell's capacity on the blocking probability. In each cell, new calls arrive according to Poisson process with parameter λ. Average duration time of call is equal to μ=1, average dwell time is equal to μ_h=1 and $\mathcal{E}$ = 0.001. As a comparison with One-Single-Cell Model in similar conditions, it can be observed that Two-Dimensional-Symmetric model has an exact result in terms of blocking probability as same as One-Single-Cell model. With increasing the cell's capacity, both models have a downward trend in probability of blocking.

Graph 2 demonstrates the impact of dimension on the average number of active channels in each cell. This graph has the condition as same as graph 1. new calls arrive according to Poisson process with parameter λ. Average duration time of call is equal to μ=1, average dwell time is equal to μ_h=1 and $\mathcal{E}$ = 0.001. As an expected result, the number of active channels in each cell is increasing when we increase the cell's allocated channels.
Graph3 indicates the impact of mobility rate (average dwell time) on the blocking probability. Here we assume that the number of allocated channels to each cell is N=16, new calls arrive according to Poisson process with parameter λ. Average duration time of call is equal to μ=1 and $\mathcal{E}$ = 0.001. It can be seen when users move fast between cells, the blocking probability in this model will decrease.

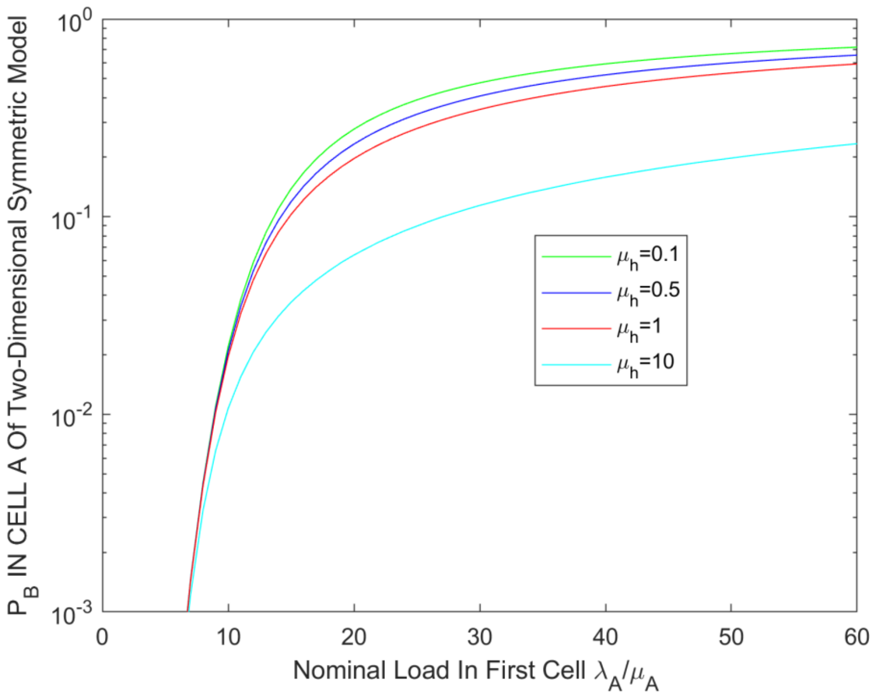
As an overall result Two-Dimensional model in case of symmetric cells has the results as exactly same as One-Single-Cell model. The probability of blocking in two models decrease with increasing either the cell's dimension or the mobility rate while the average number of active channels has an upward trend when the cell's dimension is increasing



Graph 1: P_B VS nominal load in a cell of symmetric 2-D model. In each cell $\mu = \mu_h$=1, λ=1:60. It represents the effect of each cell's dimension and similarity to one-single-cell model



Graph 2: Average number of active channels VS nominal load in a cell in symmetric 2-D model with parameters $\mu = \mu_h$=1, λ=1:60



Graph3: P_B VS nominal load per cell. Effect of different mobility rate in symmetric 2-D model, NA=NB=16, $\mu_1=\mu_2=1$, Ɛ=0.001, $\lambda_1=\lambda_2$= 1:60

Asymmetric- Two-Dimensional Model

For this model, we isolated a group of two neighboring asymmetric cells. All of graphs related to this section can be divided into four parts to present different purposes:

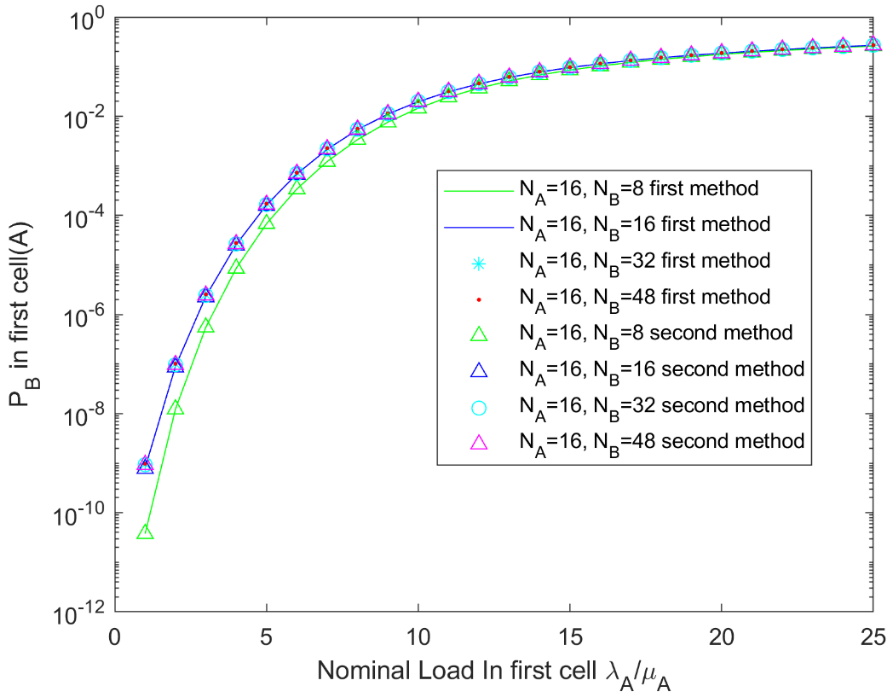
- Different methods used to compute flow of incoming handover calls into a cell in 2-D model
- Effect of second cell's dimension on blocking probability of first cell
- Effect of mobility rate in second cell on the blocking probability of first cell
- Effect of the new arrival rate towards second cell on the first cell blocking probability

Three methods computing incoming handoff calls into a cell in 2-D model

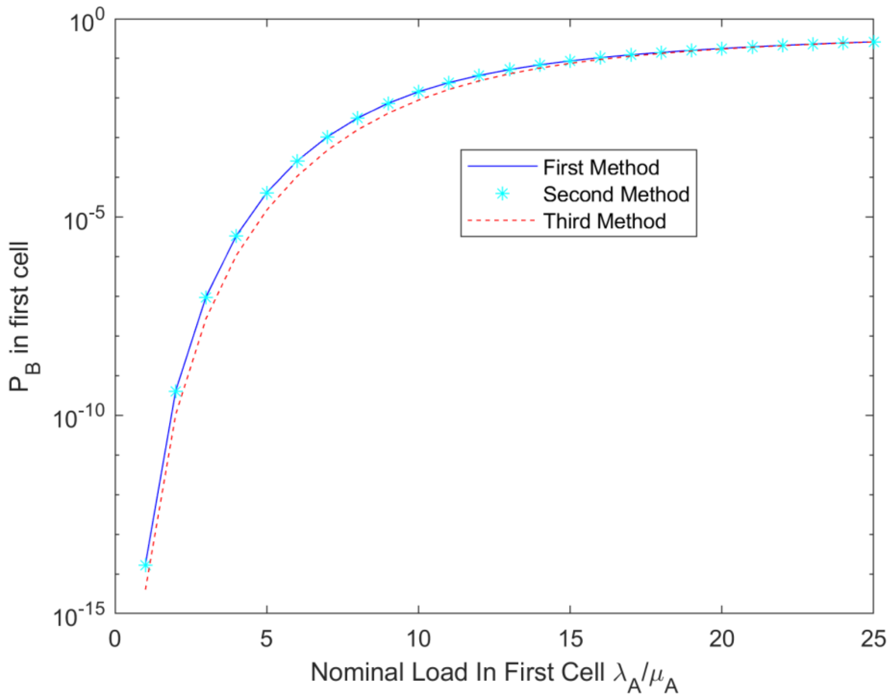
As we said in previous chapter we design three different methods to compute flow of incoming handoff calls into symmetric and asymmetric traditional 2-D model. The first and second methods are completely same. The third one has some ignorable differences but first one has much less complexity so for simplicity we use first method.

Graph 4 shows the blocking probability in first cell vs nominal load into this cell with using two first methods also this graph illustrates the similarity of first and second method. The first and second cell are asymmetric in terms of new arrival rate and their dimension. The condition of this simulation is N_A=16 (first cell dimension), new arrival rate into first cell is Poisson process with parameter λ_A=1:60 while the new incoming arrival rate into second cell is λ_B=10. The average duration time of each call and the average dwell time for both cells are equal to $\mu = \mu_h$=1 and Ɛ=0.001.

Graph 5 : Two isolated cells in this simulation are asymmetric in terms of their dimension. This graph compares three different methods in the condition of: The average duration time of each call and the average dwell time for both cells are equal to $\mu = \mu_h=1$ and $\mathcal{E}=0.001$. New arrival rate into first and second cell are Poisson process with parameter $\lambda=1:60$. Dimension of first cell is $N_A=16$ while the second cell's dimension is equal to $N_B = 8$



Graph 4: P_B VS nominal load for first cell in asymmetric two-dimensional model using two first method



Graph5: P_B vs nominal load for first cell. Comparing three different methods of incoming handover flow

Effect of second cell's dimension on blocking probability of first cell

Under several simulations, we find the growth of second cell's dimension has an increasing trend on the blocking probability of first cell. This effect can be seen by graph 6.

Graph 6: Two neighboring isolated cells in this simulation are asymmetric in terms of their dimension and new arrival rates. New arrival rate into first cell is Poisson process with parameter λ_A=1:60 while the new incoming arrival rate into second cell is λ_B=10. The average duration time of each call and the average dwell time for both cells are equal to $\mu = \mu_h$=1 and ε=0.001. The dimension of first cell is equal to N_A=16 in contrast we change the dimension of second cell every trial to see the effect of this change.

Effect of mobility rate in second cell on the blocking probability of first cell

Let get started this effect by an introduction to the concept of very slow and very fast mobility

- Very slow mobility: when user moves very slow then μ_h tends to zero
- Very fast mobility: when user moves very rapidly and μ_h tends to infinity [14]

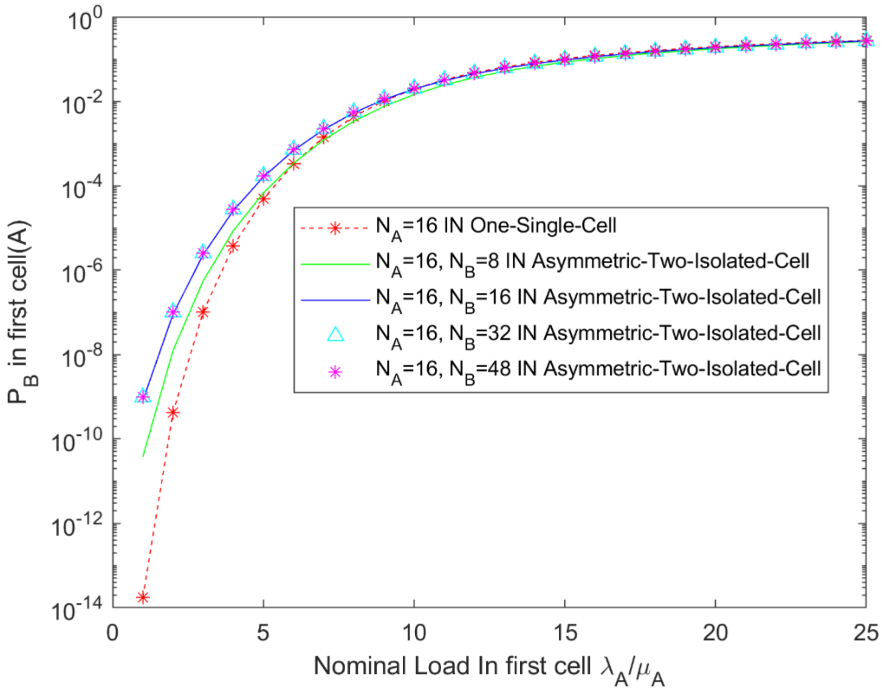
As the graphs 7,7.1, 8 and 8.1 show when the user in second cell moves fast to other cells, It has an increasing effect on the blocking probability of first cell in contrast in the symmetric two dimensional model, we saw that the rate of outgoing mobility in second cell had a decreasing effect on the blocking probability of first cell

Graph 7: This graph indicates the probability versus nominal load in the first cell. The first and second cell have same dimension N_A=N_B= 16. New arrival rate into first cell is Poisson process with parameter λ_A=1:60 while the new incoming arrival rate into second cell is λ_B=10. The average duration time of each call and the average dwell time for first cell are equal to $\mu_1 = \mu_{h1}$=1 while in second cell the average duration time is equal to μ_2 =1 but with variable μ_h . For computing incoming handoff to each cell, we use ε=0.001. from this graph it can be clearly seen that the fast outgoing handoff's rate in the second cell leads to higher blocking probability of first cell.
Graph 7.1 : this graph is exactly as same as graph 7 but we plot the blocking probability of first cell versus the total load in the first cell.

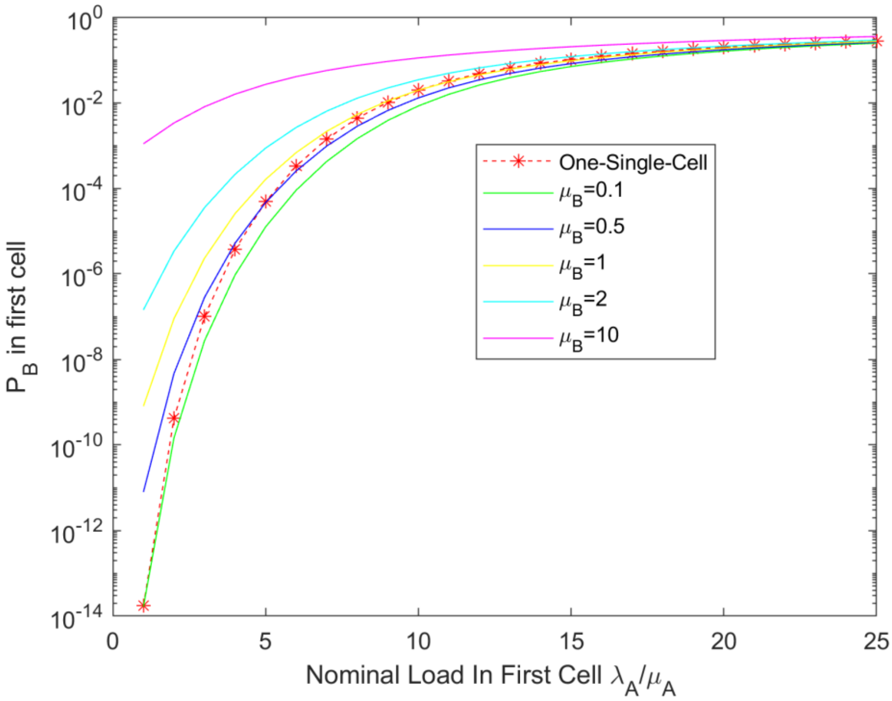
Effect of the new arrival rate into second cell on the first cell blocking probability

The goal of presenting graphs 8 and 8.2 is to show the effect of arrival rate into second cell on the first cell's blocking. As these two graphs illustrate when we increase the arrival rate in second cell, it has a rising effect on the first cell blocking specially in case of low nominal load in first cell.
Graphs 8 represents plot of P_B in first cell versus nominal load into this cell. The applying dimension for both cell in this plot is N_A=N_B=16, new incoming arrival rate into second cell is λ_B=20 and as before new arrival rate into first cell is Poisson process with parameter λ_A=1:60. Both average duration time and average dwell time in first cell are μ_1=μ_{h1}=1 and also average duration time in the second cell is μ_2=1 and for computing flow of incoming handoff in both cell we use ε=0.001.
Graph 8.1: All of condition for plotting this graph is as same as graph8 but the horizontal axis in this graph represents the total load in first cell

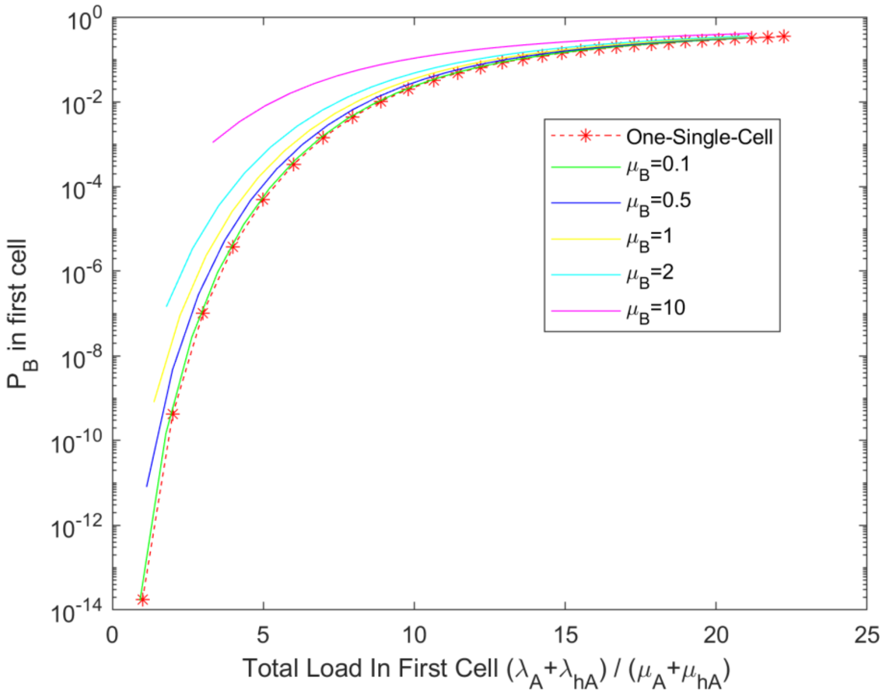
As an overall conclusion of this section in asymmetric two-dimensional case of traditional networks we can see that every changing in the parameter of second cell may leads to significant amount of differences on the blocking probability of first cell.



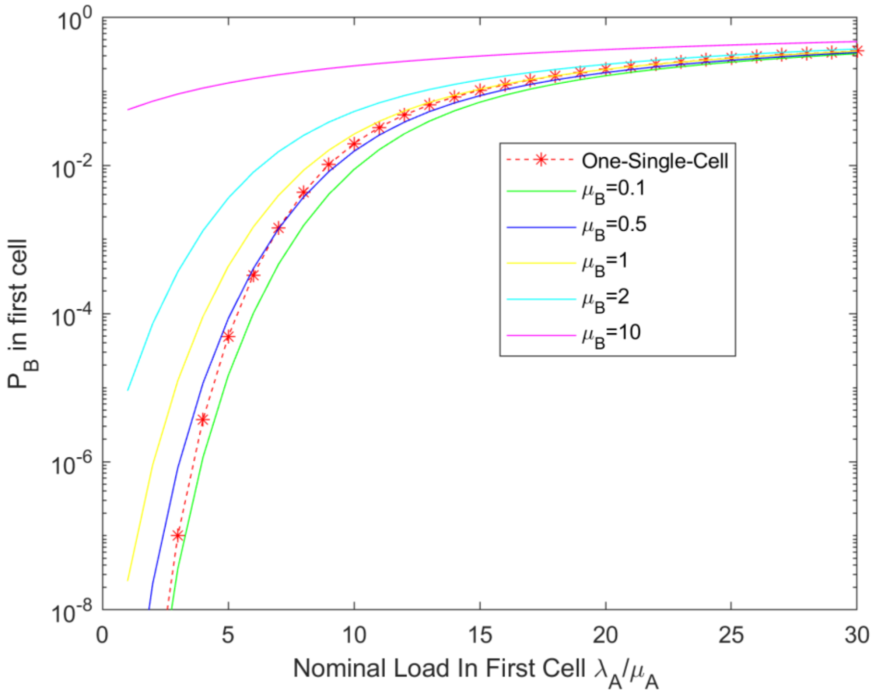
Graph 6: P_B VS nominal load in first cell. Effect of second cell's dimension on the blocking of first cell



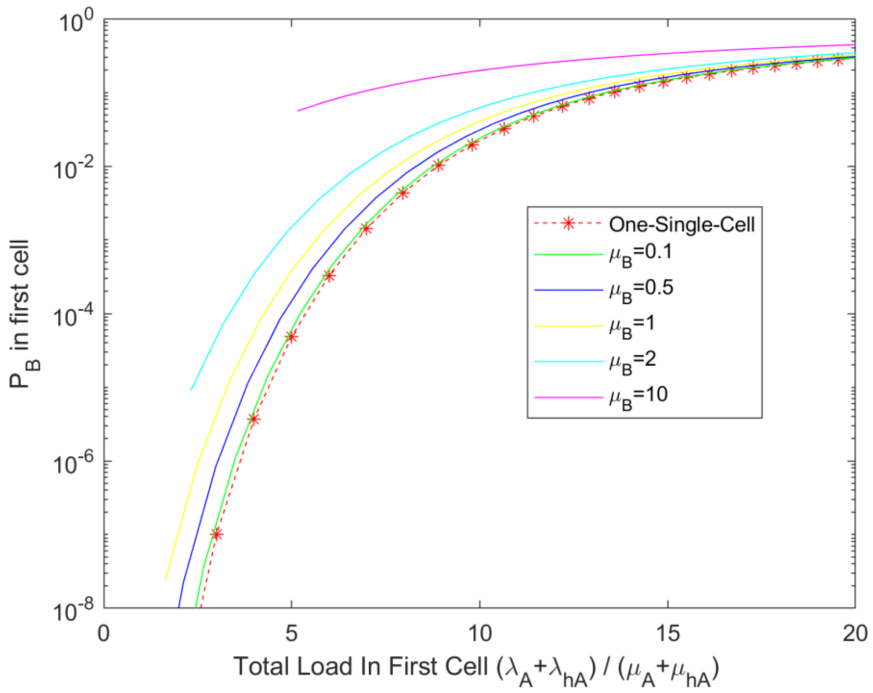
Graph 7: P_B VS nominal load in first cell. Effect of changing μ_h in the second cell with λ_B=10



Graph 7-1: P_B VS Total load in first cell. Effect of changing μ_h in the second cell with λ_B=10



Graph 8: P_B VS nominal load in first cell. Effect of changing arrival rate in second cell λ_B=20



Graph 8-1: P_B VS total load in first cell. Effect of changing arrival rate in second cell λ_B=20

HET-NET WITHOUT RESERVED CHANNELS

As we mentioned in previous computing numerical result of this part is based on the assumption that the probability of moving one handoff call from Macro cell to Micro cell (small cell) is equal to 1/3 while this probability from micro cell to macro cell is supposed to 1 because we investigate the model in which a small cell surrounding just by one macro cell. All of graph of this part is assumed that the dimension of macro and micro cell are NA=16 and N_B=64. The graphs related to this part can be divided into two categories

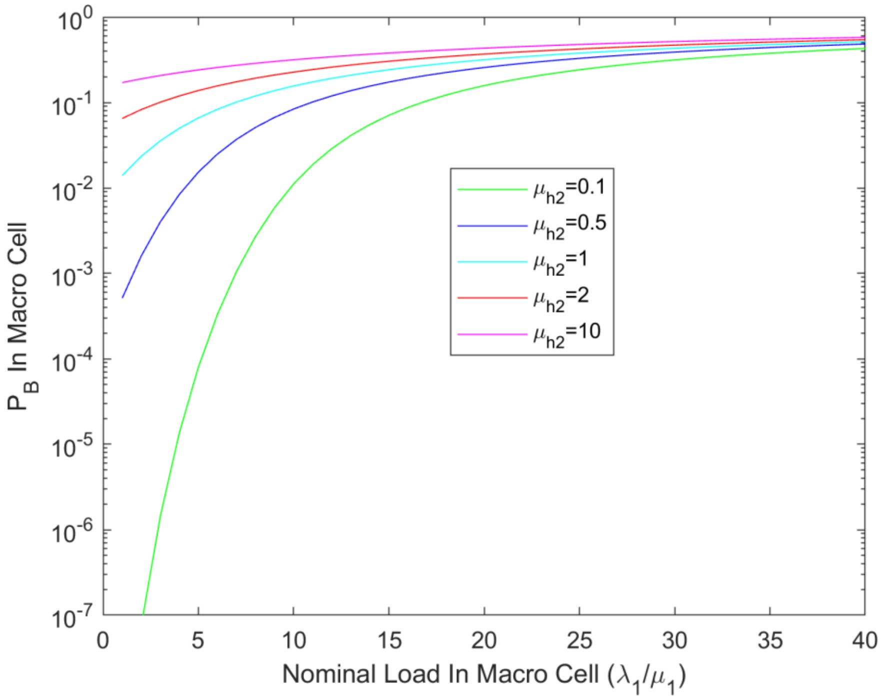
- Representing the effect of inter cell mobility of the small cell's users
- Representing the effect of arrival rate in small cell

The rate of outgoing handoff (inter cell mobility) in micro cell

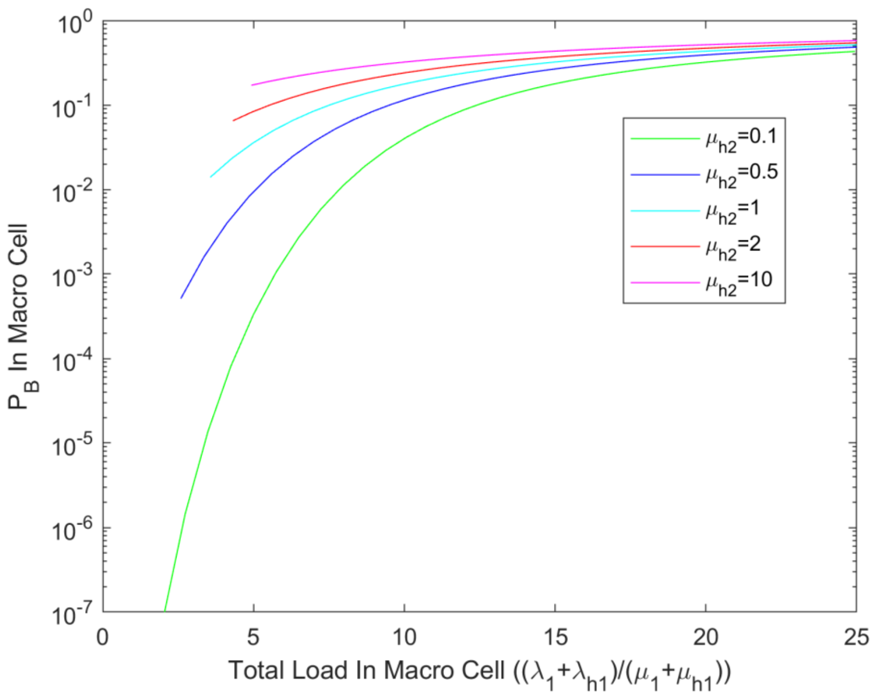
Graphs H1,H1-1, H2,H2-1 and H3 show the effect of inter cell mobility in small cell on the blocking probability of macro cell. From these graphs, it can be clearly seen that as the rate of inter cell mobility of small cell's users increase, the blocking probability of macro cell moves to higher value also we can see much more significant difference for blocking probability in macro cell when μ_{h2}= 0.1 (very slow mobility) rather than other outgoing handoff rates in second cell.

Graph H1 demonstrates the impact of inter cell mobility rate of small cell's users on the blocking probability of macro cell. Number of allocated channels to macro cell is equal to N_A=16 while to small cell is N_B=64. New arrival rate into macro cell is Poisson process with parameter λ_A=1:60 while the new incoming arrival rate into small cell is λ_B=20. The average rate of duration time of a call for both cell is $\mu_1 = \mu_2$=1 also the dwell time in macro cell is μ_{h1}=1.For calculating incoming handoff flow in macro cell we use $\mathcal{E}$=0.001.

Graph H1-1: this graph is exactly same as graph H1 in same condition but we plot vs total load

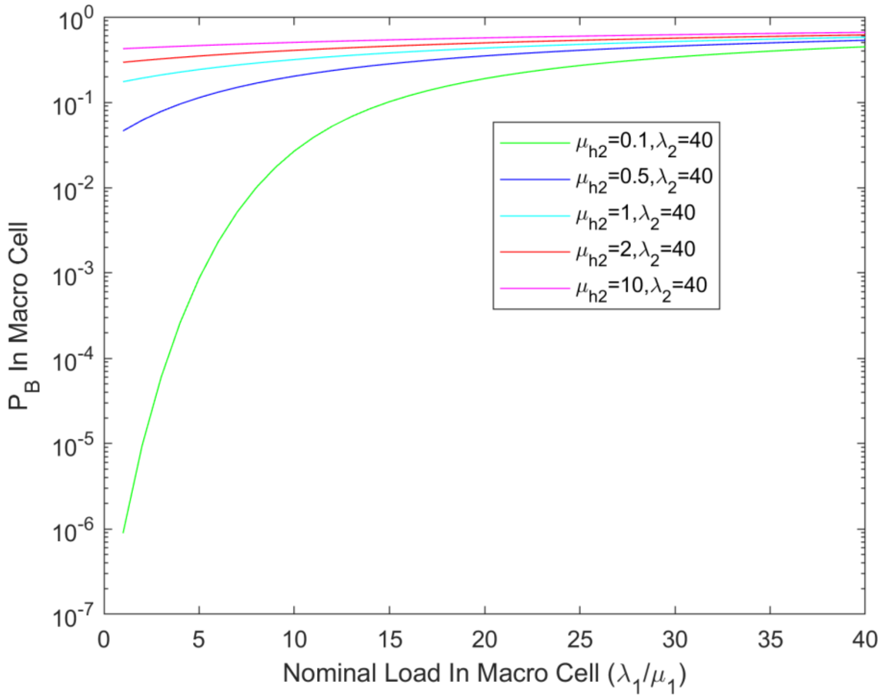


Graph H1: P_B vs nominal load in macro cell in het-net without reserved channels. λ_B=20, μ_1= μ_{h1}= μ_2=1

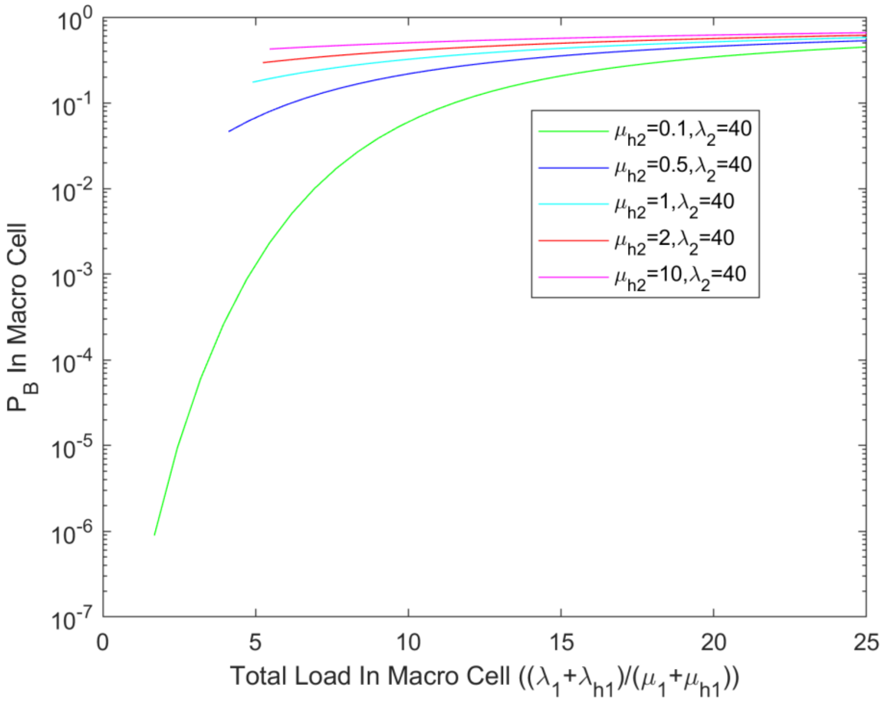


Graph H1-1: P_B vs total load in macro cell in het-net without reserved channels. λ_B=20, μ_1= μ_{h1}= μ_2=1

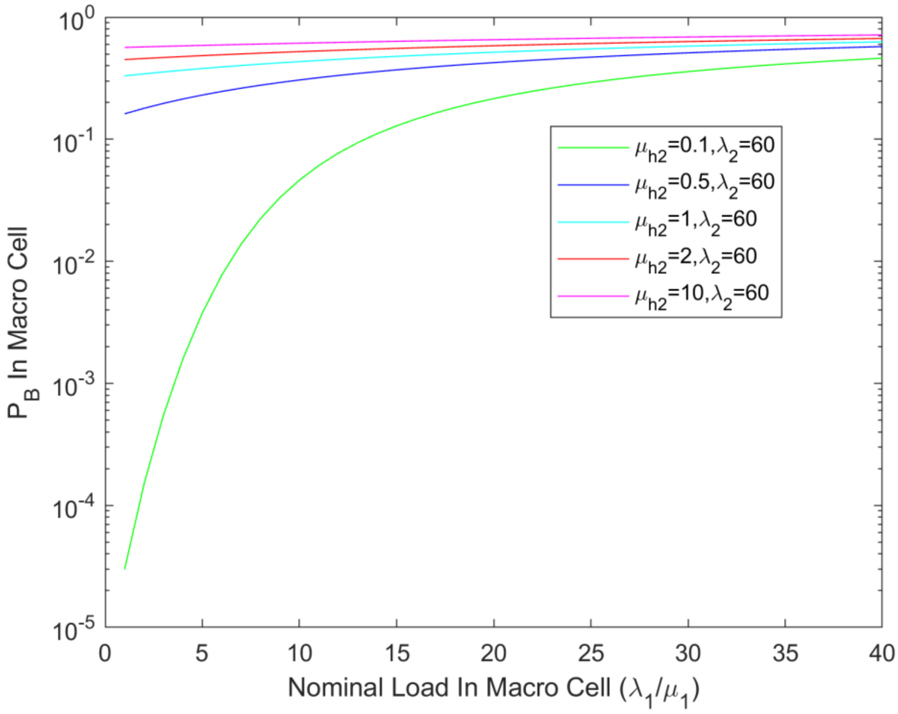
Graph H2 demonstrates the impact of *inter cell mobility rate* of small cell's users along with *increasing new arrival rate into small cell* on the blocking probability of macro cell. As you see in this simulation, we increase the rate of new incoming call into small cell and repeat previous experience. As a result, we can observe that this increasing leads to higher blocking probability in macro cell specially for low amount of nominal load into macro cell. Other incoming result is that the difference between blocking probability in first cell in case of μ_{h2}= 0. 1 and other μ_{h2} is increasing while the amount of difference between macro cell's blocking probability in case of other μ_{h2} is decreasing. Number of allocated channels to macro cell is equal to N_A=16 while to small cell is N_B=64. New arrival rate into macro cell is Poisson process with parameter λ_A=1:60 while the new incoming arrival rate into small cell is λ_B=40. The average rate of duration time of a call for both cell is $\mu_1 = \mu_2$ =1 also the dwell time in macro cell is μ_{h1}=1.For calculating incoming handoff flow in macro cell we use Ɛ=0.001.
Graph H2-1: this graph is exactly same as graph H2 in same conditions but we plot vs total load



Graph H2: P_B vs nominal load in macro cell in het-net without reserved channels. λ_B=40, μ_1= μ_{h1}= μ_2=1



Graph H2-1: P_B vs Total load in macro cell in het-net without reserved channels. λ_B=40, μ_1= μ_{h1}= μ_2=1



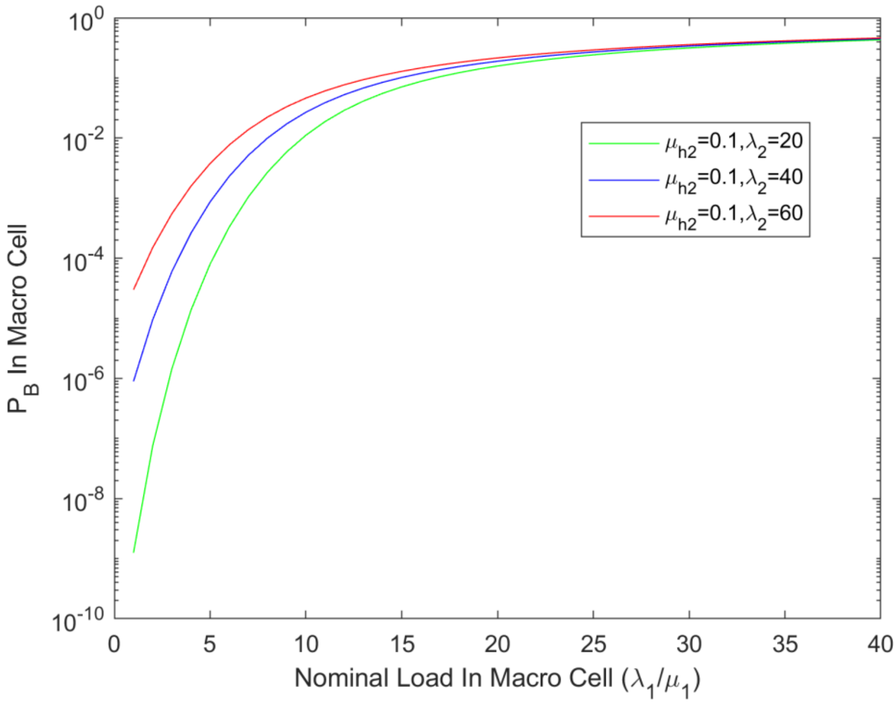
Graph H3: P_B vs nominal load in macro cell. effect of different inter cell mobility rate of small cell's users. λ_B= 60

Graph H3: In this graph, we increase incoming arrival rate into small cell λ_B= 60 and investigate again with different rates of outgoing handoff calls from small cell to see the effect of this changing on the first cell 's blocking probability. As we see in overall this change leads to higher blocking probability of macro cell. In the case $\mu_{h2} \geq \mu_2$ the blocking probabilities of macro cell will be closer to each other, they tend to probability=1. As before we can see big difference between probability of blocking with parameter μ_{h2}=0.1 and other cases.

effect of arrival rate in small cell

Graphs H4, H5, H6, H7 and H8 show the effect of different new arrival rates in small cell on the blocking probability of macro cell. We can see that there is a straight relation between this factor (λ_B) and blocking probability in macro cell. this factor has strong effectiveness specially when the small cell 's outgoing handoff rate increases.

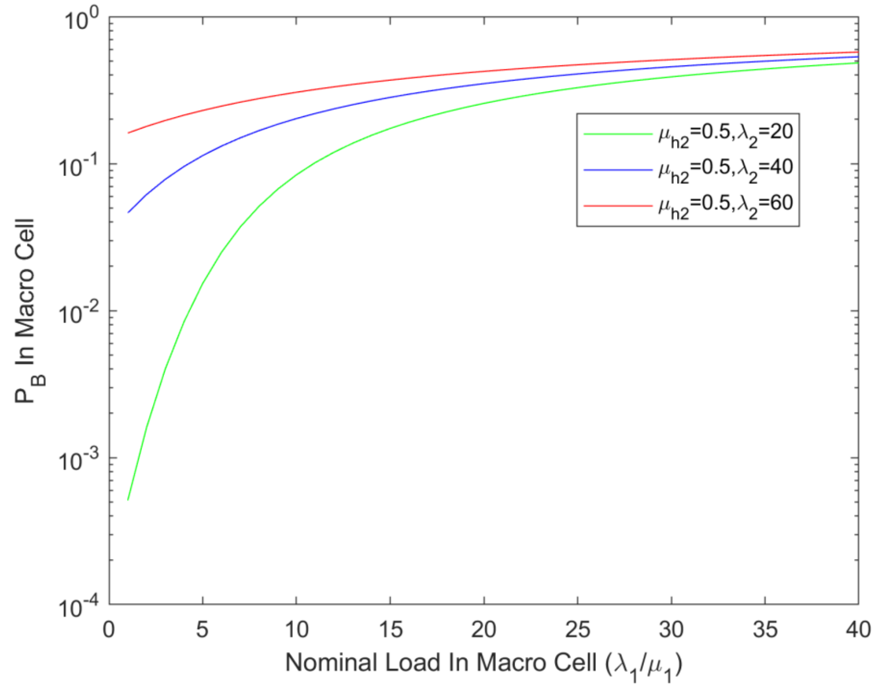
Graph H4 shows the effect of increasing new arrival rate in small cell in het- net when small cell users move slow. Number of allocated channels to macro cell is equal to N_A=16 while to small cell is N_B=64. New arrival rate into macro cell is Poisson process with parameter λ_A=1:60. The average rate of duration time of a call for both cell is $\mu_1 = \mu_2$ =1 also the dwell time in macro cell is μ_{h1}=1 while this parameter for small cell is equal to μ_{h2}=0.1. For calculating incoming handoff flow in macro cell we use Ɛ=0.001



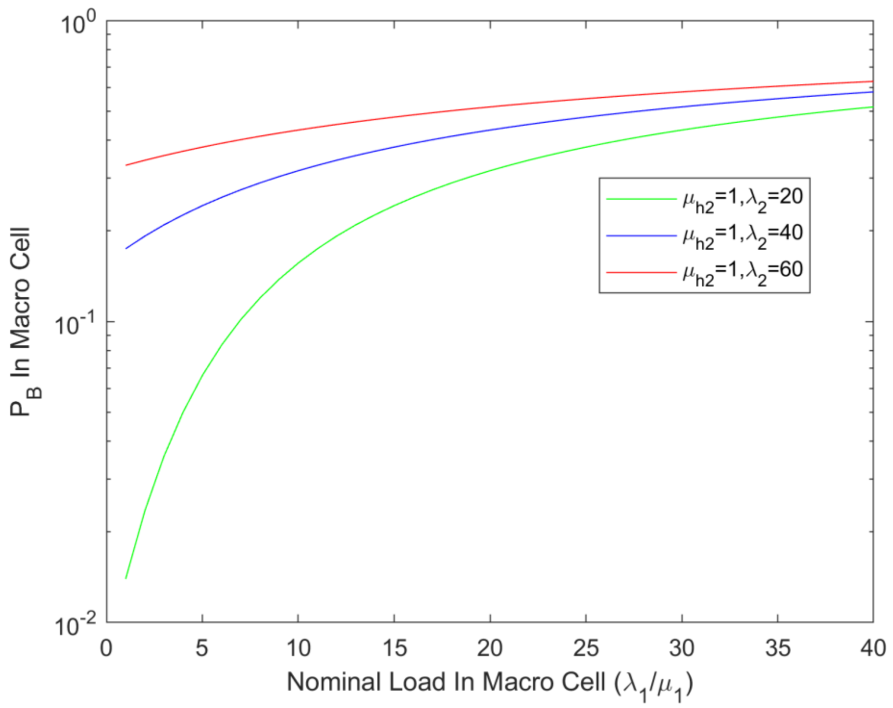
Graph H4:P_B VS nominal load in het -net . μ_{h2}=0.1

Graph H5 shows the effect of increasing new arrival rate in small cell in het- net when small cell's average outgoing handoff rate is μ_{h2}=0.5. Number of allocated channels to macro cell is equal to N_A=16 while to small cell is N_B=64. New arrival rate into macro cell is Poisson process with parameter λ_A=1:60. The average rate of duration time of a call for both cell is $\mu_1 = \mu_2$ =1 also the dwell time in macro cell is μ_{h1}=1. For calculating incoming handoff flow in macro cell we use Ɛ=0.001.

Graph H6 shows the effect of increasing new arrival rate in small cell in het- net when small cell's average outgoing handoff rate is $\mu_{h2}=\mu_2$= 1. Number of allocated channels to macro cell is equal to N_A=16 while to small cell is N_B=64. New arrival rate into macro cell is Poisson process with parameter λ_A=1:60. The average rate of duration time of a call for both cell is $\mu_1 = \mu_2$ =1 also the dwell time in macro cell is μ_{h1}=1. For calculating incoming handoff flow in macro cell we use Ɛ=0.001



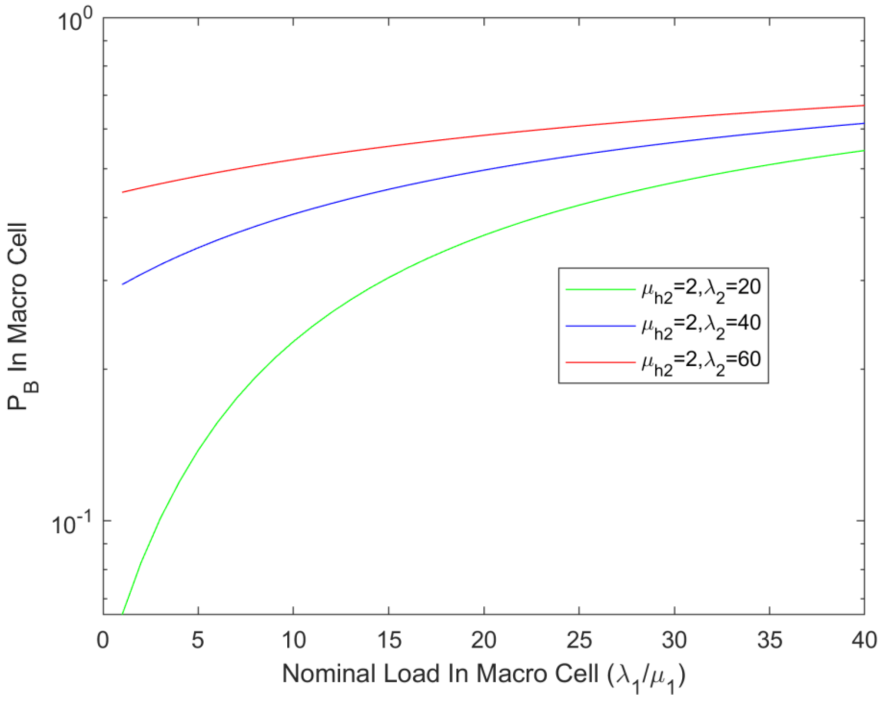
Graph H5:P_B VS nominal load in het -net . μ_{h2}=0.5



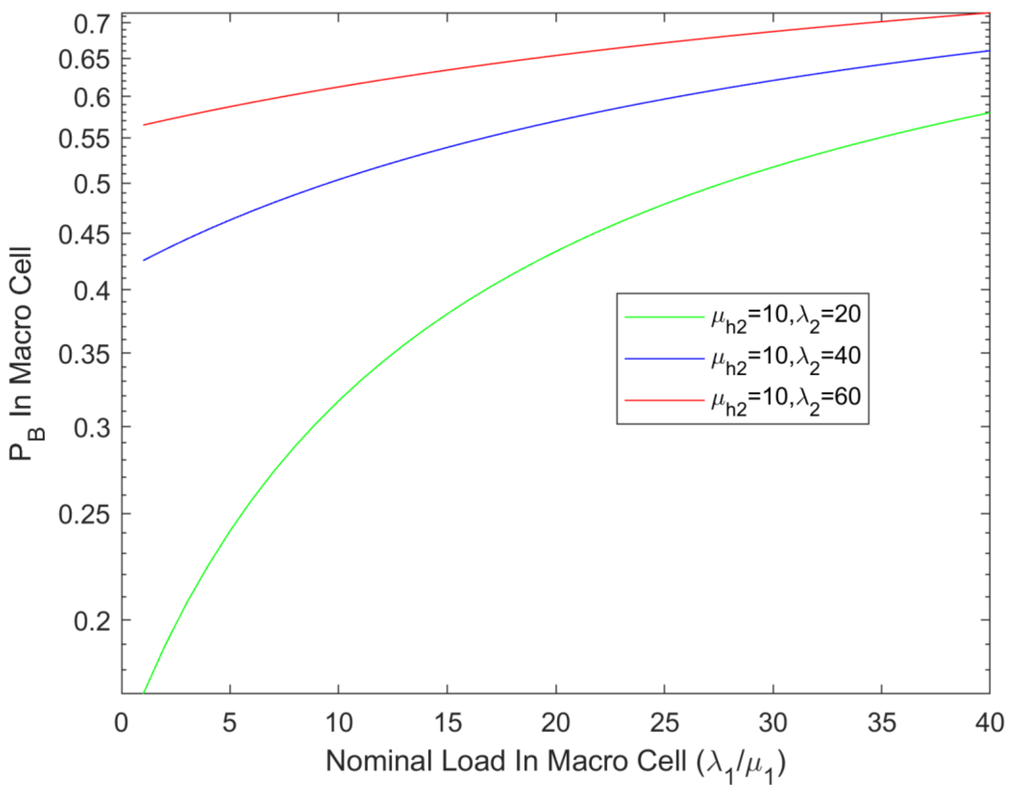
Graph H6:P_B VS nominal load in het -net . μ_{h2}=μ_2 =1

Graph H7 shows the effect of increasing new arrival rate in small cell in het- net when small cell's average outgoing handoff rate is $\mu_{h2} > \mu_2$. Number of allocated channels to macro cell is equal to N_A=16 while to small cell is N_B=64. New arrival rate into macro cell is Poisson process with parameter λ_A=1:60. The average rate of duration time of a call for both cell is μ_1 = μ_2 =1 also the dwell time in macro cell is μ_{h1}=1 and dwell time in small cell is μ_{h1}=2. For calculating incoming handoff flow in macro cell, we use Ɛ=0.001.

Graph H8 shows the effect of increasing new arrival rate in small cell in het- net when small cell's average outgoing handoff rate is $\mu_{h2} >> \mu_2$. Number of allocated channels to macro cell is equal to N_A=16 while to small cell is N_B=64. New arrival rate into macro cell is Poisson process with parameter λ_A=1:60. The average rate of duration time of a call for both cell is $\mu_1 = \mu_2 = 1$ also the dwell time in macro cell is μ_{h1}=1 and dwell time in small cell is μ_{h1}=10. For calculating incoming handoff flow in macro cell, we use Ɛ=0.001.



Graph H7: P_B VS nominal load in het -net . $\mu_{h2} > \mu_2$



Graph H8: P_B VS nominal load in het -net . $\mu_{h2} >> \mu_2$

Reserved Channel Het-Net (RCH)

in previous chapter we describe that our simulation for this model is based on only two reserved channels for both micro and macro cell. Probability of moving one individual outgoing handoff call from macro cell to small cell is equal to 1/3 and we assumed that small cell is surrounded by macro cell. The probability of traveling one handoff call from small (micro) cell to macro cell is equal to 1.

Our purpose of isolating at least two cells and analyzing this group is for the sake of concerning the effectiveness and importance of handover calls. The strategy of reserving channel for handoff calls is an introduction for dividing the probability of blocking into tree different types of blocking. New call blocking, incoming handoff blocking and total blocking

New Call Blocking In Reserved Channel-Het-Net

Under different trials, we became to this conclusion that two significant parameters of small cell which effect more on the new call blocking probability of first cell are the rate of new incoming calls and the dwell time (rate of mobility). The higher value of new arrival calls into micro(small)cell leads the higher probability of blocking in macro cell particularly when small cell's users move between cells rapidly (high value of μ_{h2}) this probability tends to 1. In our simulations, we consider 5 different rates for small cell's mobility (μ_{h2}= 0.1, 0.5, 1, 2, 10), if we compare the amount of new call blocking in the first cell, we can see that the blocking probability of first cell when the rate of mobility in small cell is equal to μ_{h2}= 0.1 is much less than other situations but after a threshold of higher speed mobility in small cell, or at the condition of high load in small cell, the probability of blocking in small cell will be closer to each other, and amount of differences between the blocking probability will be decreased. The effect of amount of load in micro cell is represented by two following graphs (HR1) and (HR2). In graph RH2 and some other future graphs, there is a comparison with the case of Het-Net in which there is no reserved channels neither for macro nor for micro. As we have seen, in comparison between blocking in case of reserved channels and the similar case without any reserved channels, the probability of *new call blocking* in case of Two-Reserved-Channels is greater than the model with no reserved channel. It is all of we expected due to the fact that we reserve two channels of each cell only for incoming handovers so the number of channels devoted for new calls becomes lower than the previous case (Het-Net without any reserved channel).

All of graphs for new call blocking can be divide into three groups

- Graphs representing new call blocking in macro cell with slow mobility in small cell (Graphs HR1 and HR2)
- Graphs representing new call blocking in macro cell with $\mu_{h2} = \mu_2$ (Graphs HR3)
- Graphs representing new call blocking in macro cell with fast mobility in small cell $\mu_{h2} > \mu_2$ (Graphs HR4 and HR5)

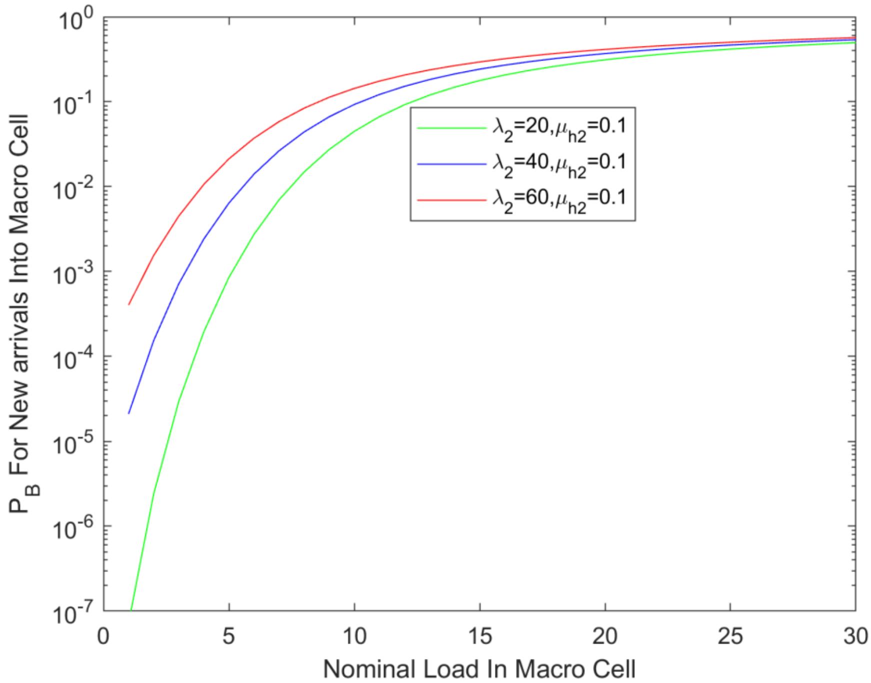
Graph RCH1 demonstrates the effect of new arrival rate in small cell (along with slow mobility) on the blocking probability of new calls in the first cell. This result is reached by: Number of allocated channels to macro cell is equal to N_A=16 while to small cell is N_B=64. New arrival rate into macro cell is Poisson process with parameter λ_A=1:60. The average rate of duration time of a call for both cell is $\mu_1 = \mu_2 = 1$ also the dwell time in macro cell is μ_{h1}=1 and dwell time in small cell is μ_{h2}=0.1. For calculating incoming handoff flow in macro cell, we use $\mathcal{E}$=0.001.

Graph RCH2 : The only constraint which is different with Graph RCH1 is the rate of mobility in small cell equal to μ_{h2}=0.5. other parameter and condition are as same as graph HR1.

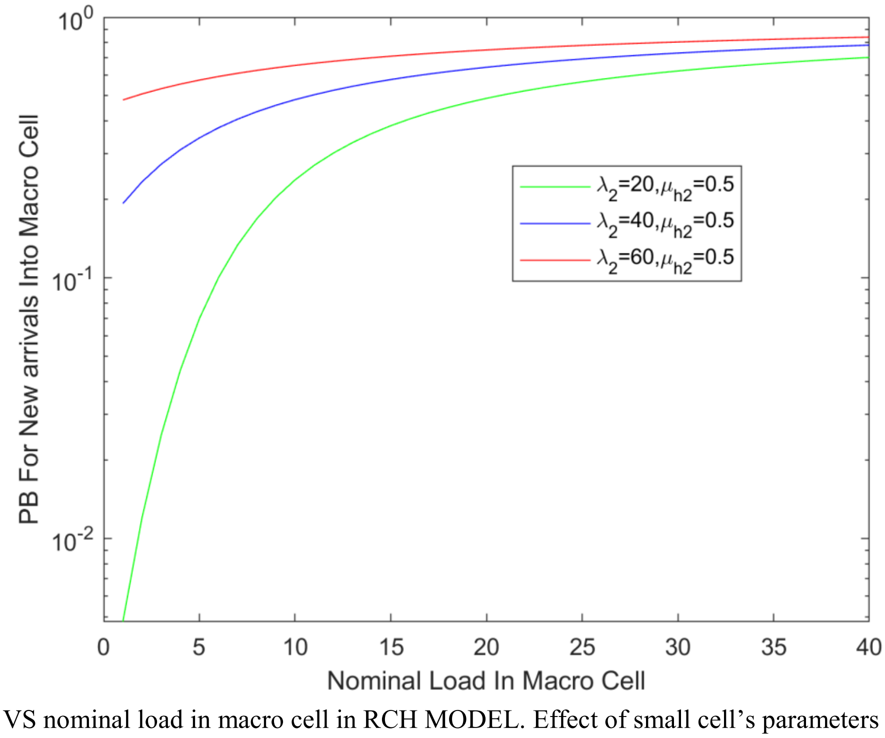
Graph RCH3 demonstrates the effect of new arrival rate in small cell when $\mu_{h2}=\mu_2$= 1, other conditions are as same as graph RCH1.

Graph RCH4 demonstrates the effect of new arrival rate in small cell when $\mu_{h2} > \mu_2$, μ_{h2}=2 and other conditions are as same as graph RCH1.

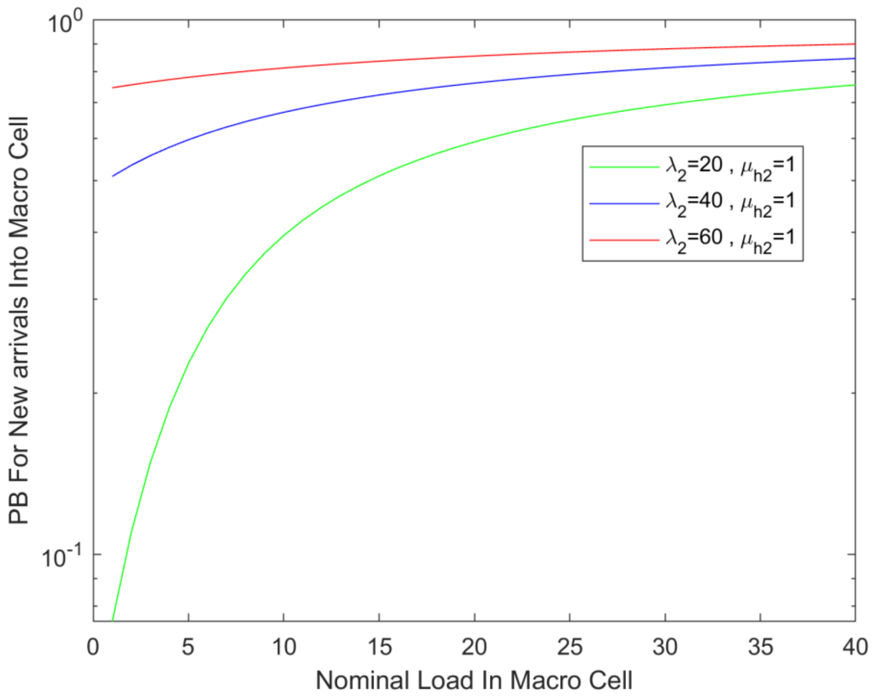
Graph RCH5 demonstrates the effect of new arrival rate in small cell when $\mu_{h2} > \mu_2$, μ_{h2}=10 and other conditions are as same as graph RCH1



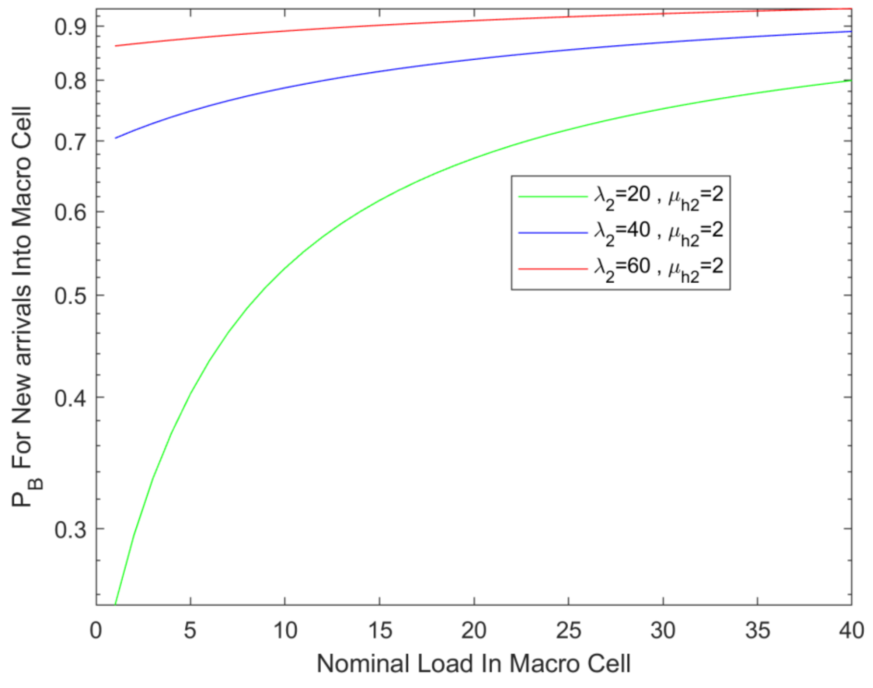
RCH1: P_B VS nominal load in macro cell in RCH MODEL. Effect of small cell's parameters on the new call blocking in first cell when N_A=16, N_B=64, λ_A=1:60, $\mu_{A\ OR\ 1}$=1 , μ_{h1}=1, μ_{h2}=0.1, Ɛ=0.001.



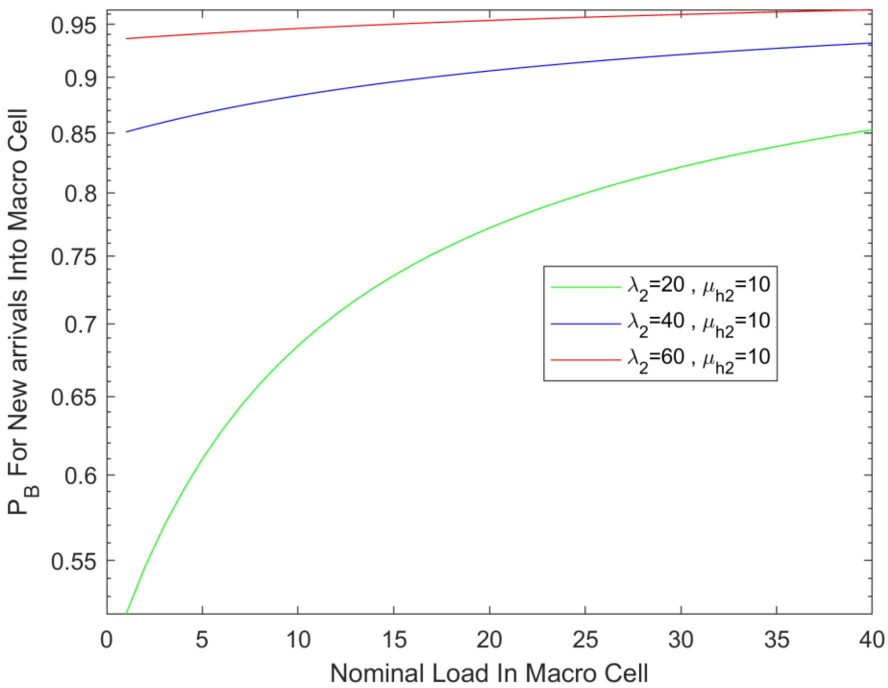
RCH2: P_B VS nominal load in macro cell in RCH MODEL. Effect of small cell's parameters on the new call blocking in first cell when N_A=16, N_B=64, λ_A=1:60, $\mu_{A\ OR\ 1}$=1 , μ_{h1}=1, μ_{h2}=0.5, Ɛ=0.001



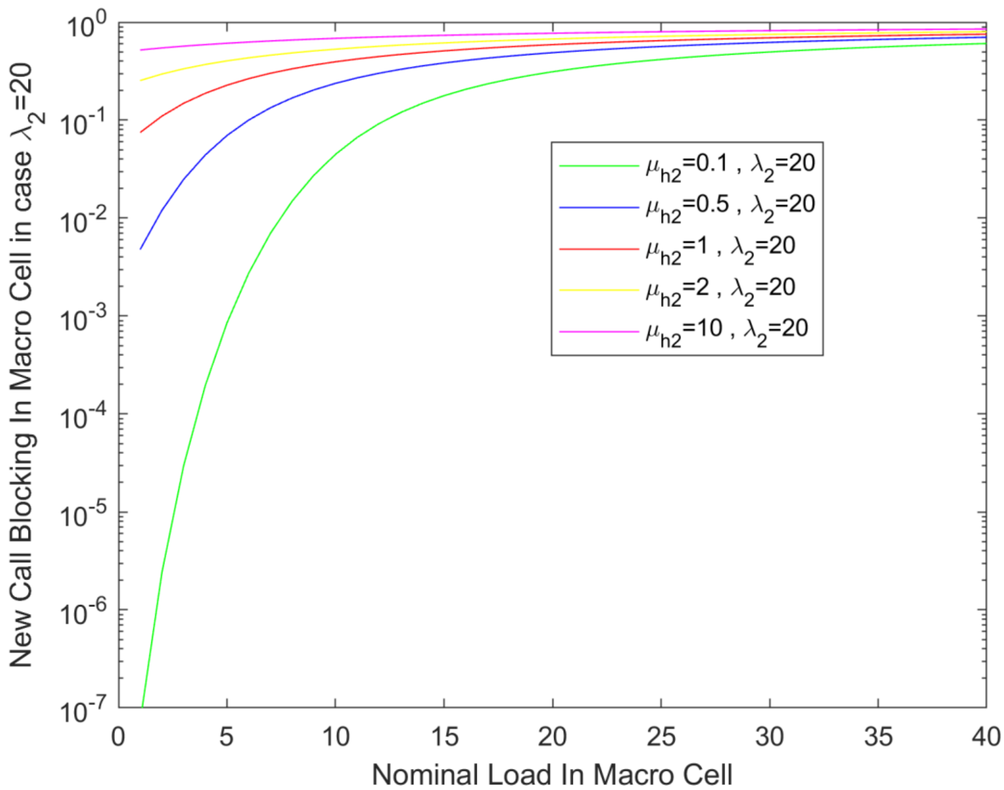
RCH3: P_B VS nominal load in macro cell in RCH MODEL. Effect of small cell's parameters on the new call blocking in first cell when N_A=16, N_B=64, λ_A=1:60, $\mu_{A\ OR\ 1}$=1 , μ_{h1}=1, μ_{h2}=1, Ɛ=0.001.



RCH4: P_B VS nominal load in macro cell in RCH Model. Effect of small cell's parameters on the new call blocking in first cell when N_A=16, N_B=64, λ_A=1:60, $\mu_{A\ OR\ 1}$=1 , μ_{h1}=1, μ_{h2}=2, Ɛ=0.001



RCH5: P_B VS nominal load in macro cell in RCH MODEL. Effect of small cell's parameters on the new call blocking in first cell when N_A=16, N_B=64, λ_A=1:60, $\mu_{A\ OR\ 1}$=1 , μ_{h1}=1, μ_{h2}=10, Ɛ=0.001

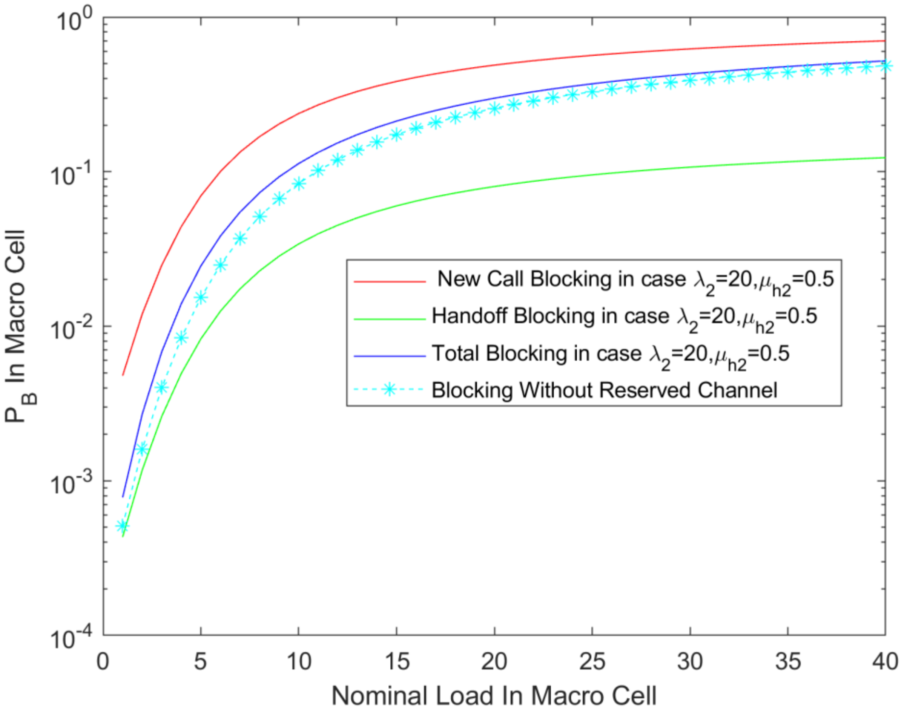


RCH6: P_B VS nominal load in macro cell in RCH MODEL. Effect of small cell's parameters on the new call blocking in first cell when N_A=16, N_B=64, λ_A=1:60, $\mu_{A\ OR\ 1}$=1 , μ_{h1}=1, μ_{h2}=10, Ɛ=0.001, λ_B= 20

Handoff Blocking in Macro Cell for 2RCH Model

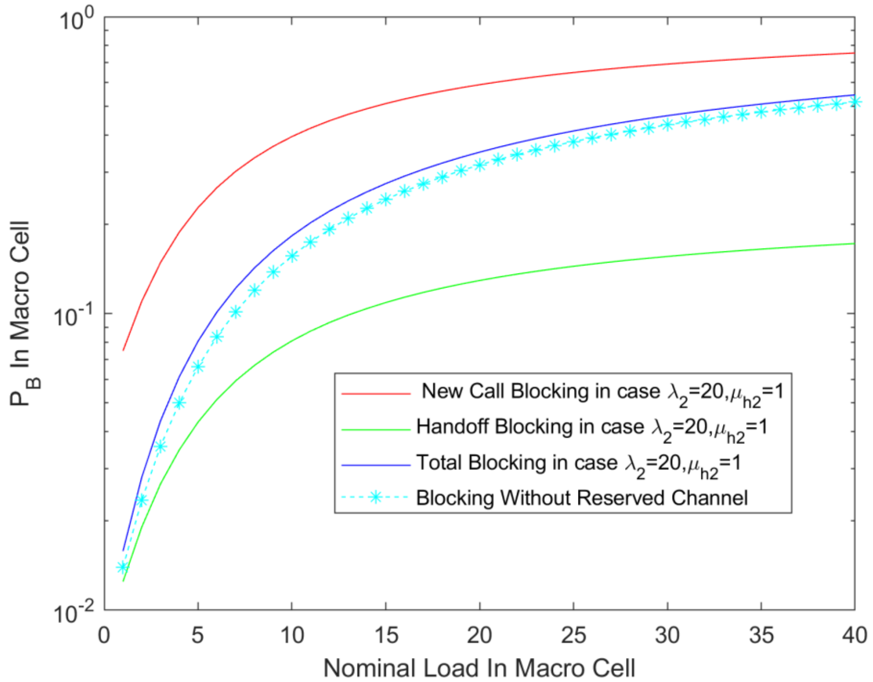
As an overall conclusion, the probability of handover blocking in case of reserved channels must be less than the blocking probability of new arrivals and also less than the case of without reserve channels, but to what extent the parameters of the small cell (new arrival rate, outgoing handoff rate, dimension, etc.) impact the performance of the macro cell. The following graphs show the effect of some parameter on hand off blocking.

Graph RCH7: This graph represents a comparison between tree types of blocking and also a comparison with the het-net model without reserved channel when N_A=16, N_B=64, new arrival rate into macro cell is Poisson process with parameter λ_A=1:60 while arrival rate in small cell is λ_B= 20. The average rate of duration time of a call for both cell is $\mu_1 = \mu_2$ =1 also the dwell time in macro cell is μ_{h1}=1 and dwell time in small cell is μ_{h1}=0.5. For calculating incoming handoff flow in macro cell, we use Ɛ=0.001.

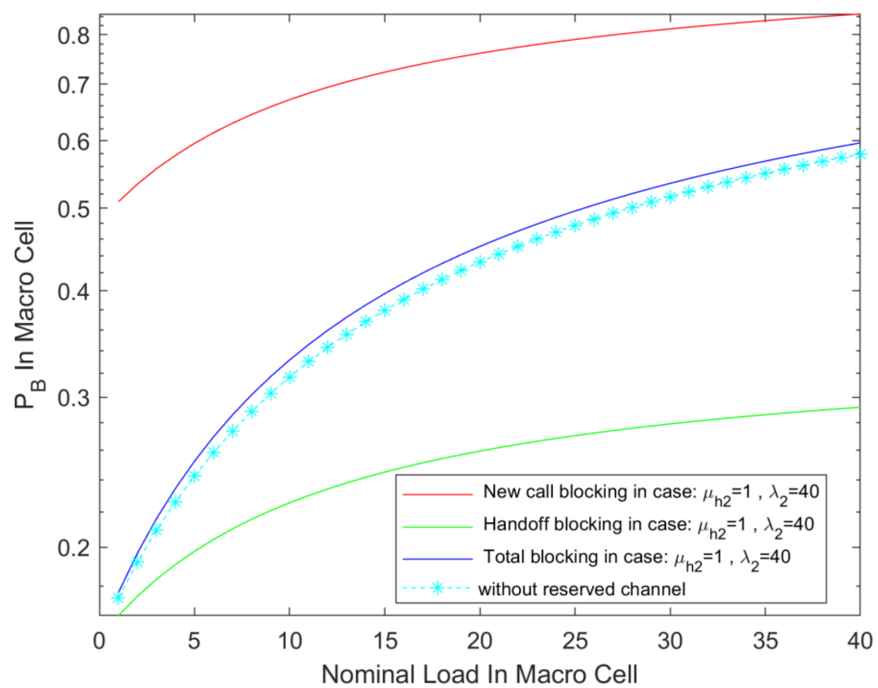


RCH7: P_B VS nominal load in macro cell in RCH MODEL. Effect of small cell's parameters on all kinds of blocking in first cell when N_A=16, N_B=64, λ_A=1:60, λ_B=20, μ_1= μ_2= 1, μ_{h1}=1, μ_{h2}=0.5, Ɛ=0.001.

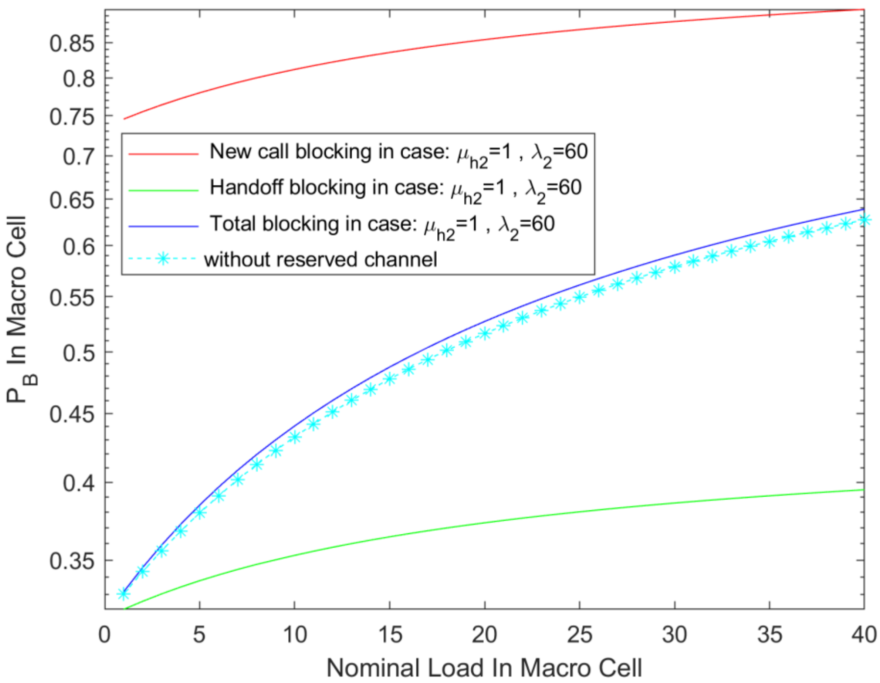
Graph RCH8, RCH9 and RCH10: These graphs are taken when μ_{h2} is equal to μ_2 =1. there are comparisons between tree types of blocking and also a comparison with the het-net model without reserved channel when N_A=16, N_B=64, new arrival rate into macro cell is Poisson process with parameter λ_A=1:60 while new arrival rate in small cell in HR8 is λ_B= 20, in HR9 is λ_B= 40 and in RCH9 is λ_B= 60. The average rate of duration time of a call for both cell is μ_1 = μ_2 =1. For calculating incoming handoff flow in macro cell, we use Ɛ=0.001.



RCH8: P_B VS nominal load in macro cell in RCH MODEL. Effect of small cell's parameters on all kinds of blocking in first cell when N_A=16, N_B=64, λ_A=1:60, λ_B=20, μ_1= μ_2= 1, μ_{h1}=1, μ_{h2}=1, Ɛ=0.001.



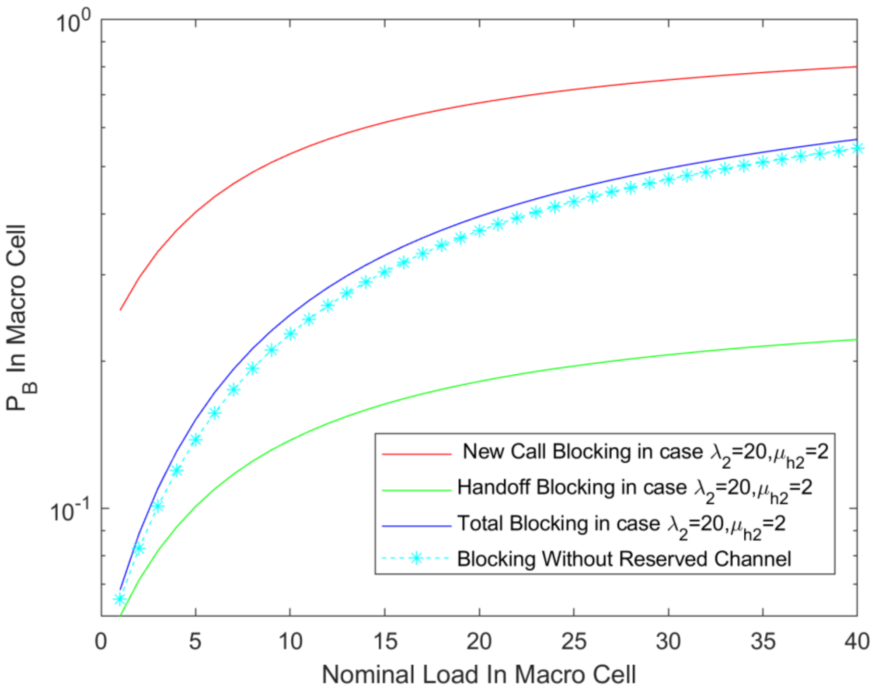
RCH9: P_B VS nominal load in macro cell in RCH MODEL. Effect of small cell's parameters on all kinds of blocking in first cell when N_A=16, N_B=64, λ_A=1:60, λ_B=40, μ_1= μ_2= 1, μ_{h1}=1, μ_{h2}=1, Ɛ=0.001



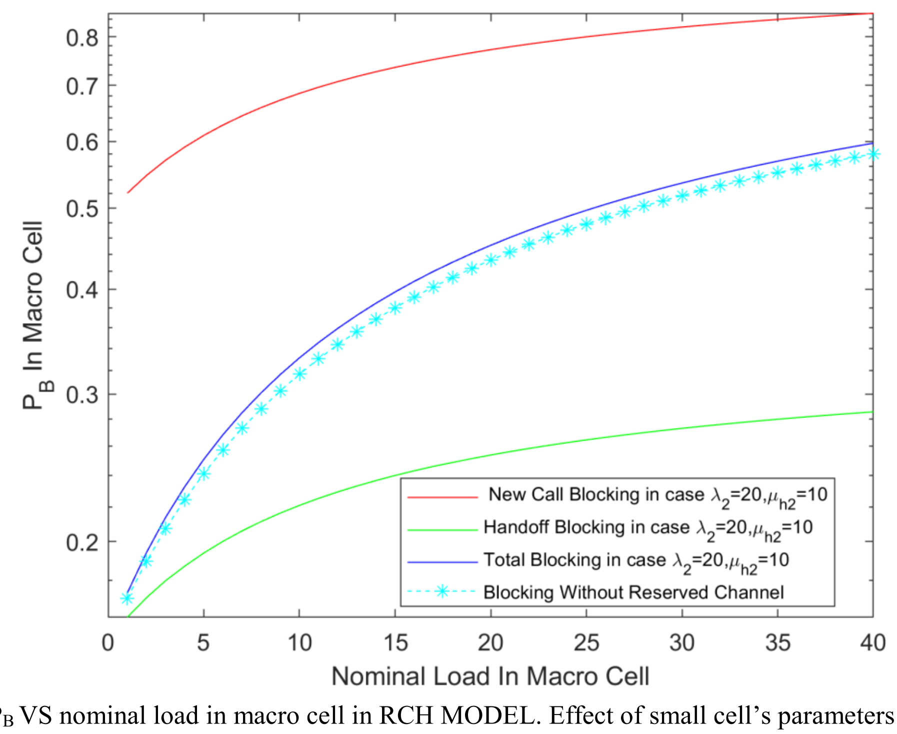
RCH10: P_B VS nominal load in macro cell in RCH MODEL. Effect of small cell's parameters on all kinds of blocking in first cell when N_A=16, N_B=64, λ_A=1:60, λ_B=60, μ_1= μ_2= 1, μ_{h1}=1, μ_{h2}=1, $\mathcal{E}$=0.001.

Graph RCH11 and RCH12: These graphs are taken when μ_{h2} (for RCH11 μ_{h2}=2 and for RCH12 μ_{h2}=10) is greater than μ_2 =1. There are some comparisons between tree types of blocking and also a comparison with the het-net model without reserved channel when N_A=16, N_B=64, new arrival rate into macro cell is Poisson process with parameter λ_A=1:60 while new arrival rate in small cell is λ_B= 20. The average rate of duration time of a call for both cell is $\mu_1 = \mu_2$ =1. For calculating incoming handoff flow in macro cell, we use $\mathcal{E}$=0.001.

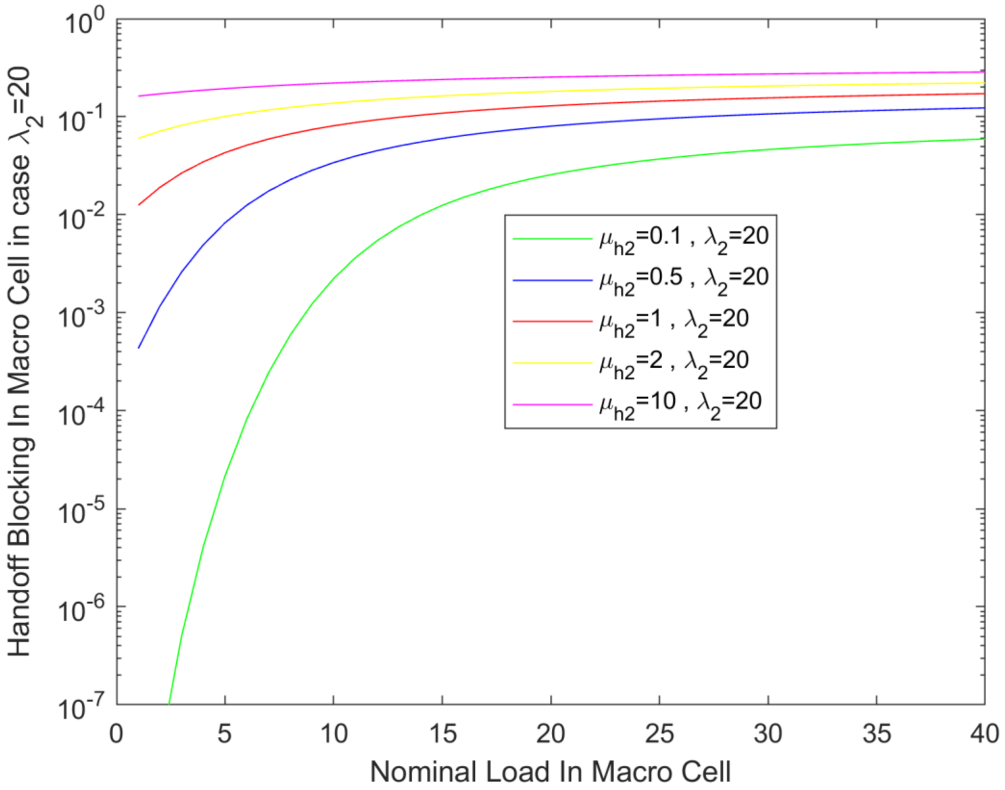
Graph RCH13 shows numerical result for different mobility rate in small cell and their effect on handoff blocking in macro cell when N_A=16, N_B=64, new arrival rate into macro cell is Poisson process with parameter λ_A=1:60 while new arrival rate in small cell is λ_B= 20. $\mu_1 = \mu_2$ =μ_{h1}= 1. For calculating incoming handoff flow in macro cell, we use $\mathcal{E}$=0.001.



RCH11: P_B VS nominal load in macro cell in RCH MODEL. Effect of small cell's parameters on all kinds of blocking in first cell when N_A=16, N_B=64, λ_A=1:60, λ_B=20, μ_1= μ_2= 1, μ_{h1}=1, μ_{h2}=2, Ɛ=0.001



RCH12: P_B VS nominal load in macro cell in RCH MODEL. Effect of small cell's parameters on all kinds of blocking in first cell when N_A=16, N_B=64, λ_A=1:60, λ_B=20, μ_1= μ_2= 1, μ_{h1}=1, μ_{h2}=10, Ɛ=0.001



RCH13: P_B VS nominal load in macro cell in RCH MODEL. Effect of different mobility rates in small cell on handoff blocking probability in first cell when N_A=16, N_B=64, λ_A=1:60, λ_B=20, μ_1= μ_2= 1, μ_{h1}=1,, Ɛ=0.001

5-Discussion

This thesis has demonstrated that the usual assumption made in the literature for One-Single cell analysis is correct only for symmetric cells. As we have seen by graph 3, in One-Single-cell model and Symmetric-Two-dimensional model, by increasing the rate of inter cell mobility in a cell, the blocking probability of another cell is going to decrease but this fact is completely different for Asymmetric cells.

In our simulation for a group of two neighboring isolated cells, in case of asymmetric cells case, the blocking probability of one cell (first cell) increases when the outgoing handoff rate in other(second) cell increases specially when the amount of load in second cell tends to high value.

Other result is that the difference between three kinds of blocking is particularly significant when the users move fast.

But there are some questions such as

what is the result by increasing number of isolated cells?

What will happen about Het-Net when we investigate more than one small cell in a macro cell and there was interaction between small cells located in macro cell?

In theory by increasing number of isolated cell, the blocking probability of one cell must be decrease but to what extent?

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