INSTITUTO TECNOLOGICO Y DE ESTUDIOS SUPERIORES DE MONTERREY

CAMPUS MONTERREY

PROGRAMA DE GRADUADOS DE LA DIVISION DE COMPUTACION, INFORMACION Y COMUNICACIONES

INTEGRATION OF OUTAGE AND MOBILITY IN WIRELESS NETWORKS

THESIS

PRESENTED AS A PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF

MASTER OF SCIENCE IN ELECTRONIC ENGINEERING
MAJOR IN TELECOMMUNICATIONS

JUAN MANUEL GALLEGOS SIERRA

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ABSTRACT

All the cellular service providers are searching for solutions on how to give a good service to their customers, many factors cause the degradations of the Grade of Service (GoS) affecting its efficiency and good quality. There exist parameters which affect the performance of the system, some of thcy are caused by different scenarios causing different types of problems. Many of these problems can only be described because of their nature and only a few of them may be solved.

Some research has treated the outage performance in cellular systems in terms of averages, effects of cell residence time distribution on the performance of cellular mobile networks, user mobility and channel holding time in mobile communications, we consider that these parameters must be related to one another in just one model, offering the main concepts in a structured way.

Most of the models that treat handoffs and mobility do not treat outage, whereas the models that treat outages do not consider mobility of users. This work relates interference, mobility and handoffs through an analytical Markov model of traffic.

Performance measures are calculated and evaluated considering different parameters inside the network which affect the good service to users.

RESUMEN

Todos los proveedores de servicio se preocupan en ofrecer un buen servicio a sus clientes, muchos factores son los responsables de decrementar el Grado de Servicio (GoS) afectando la eficiencia y la buena cualidad del sistema celular. Existen parámetros que afectan el desempeño del sistema, algunos de ellos son a causa de diferentes escenarios provocando diferentes problemas. La mayoría de esos problemas solo pueden ser descritos ya que la naturaleza es la responsable y solo algunos pueden ser resueltos.

En base a algunas investigaciones que tratan la interferencia en los sistemas celulares en función de promedios, los efectos del tiempo de residencia de un usuario en una red celular, su movilidad y el tiempo de ocupación del canal de comunicación, consideramos que esos problemas podrian estar relacionados en un solo modelo ofreciendo los principales conceptos en una forma estructurada.

Algunos de los modelos que tratan los handoffs y la movilidad no tratan la interferencia, mientras los que tratan la interferencia no consideran la movilidad de los ususarios. Este trabajo relaciona la interferencia, la movilidad y los handoffs por medio de un modelo de tráfico analítico tipo Markov.

Medidas de desempeño se calculan y evaluan considerando diferentes parámetros dentro de la red celular que afectan el buen servicio a los usuarios.

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Chapter 1

Introduction

All the cellular service providers are searching for solutions on how to give a good service to their customers, many factors cause the degradation of the Grade of Service (GoS) affecting its efficiency and good quality. There exist parameters which affect the performance of the system, some of thcy are caused by different scenarios. Many of these problems can only be described because of their nature and only a few of them may be solved.

Some research has treated the outage performance in cellular systems in terms of averages [8], effects of cell residence time distribution on the performance of cellular mobile networks [2], user mobility and channel holding time in mobile communications [3]. It is necessary to consider that these parameters must be related to one another in just one model, offering the main concepts in a structured way.

1.1 Problem Description

In every wireless communication network, there are three fundamental issues affecting availability of resources as well as their allocation techniques, these are the handoff managment, the mobility of the users and the outage. There are several models which include treatments for handoffs such as [9], and [11]. There are also models with treatment for channel outage such as [8]. In general most of the models that treat handoffs and mobility do not treat outage, whereas the models that deal with outages do not consider mobility of the users. In this work, we put together the limiting issues of wireless networks, i.e., blocking and interference, and relate the mobility of the users and handoffs through an analytical model of traffic based on [4], [7] and [11].

1.2 Justification

The presence of outage in the system could cause a drop of any call in some determined channel, in consecuence an increment of the blocking probability affect the grade of service. It is very important the realization of a study which shows the outage related to the blocking probability and the effects of handoffs in the system.

1.3 Objective

To obtain an analytical model that considers the three fundamental issues affecting availability of resources like outage, handoff and mobility in some cellular system, modeling the traffic through a two dimensional Markov chain where the rates of arrival and departure capture the mobility of users.

1.4 Contribution

In [4], a two dimensional Markov model that considers outage and blocking is presented. Any channel can undergo an outage event, if a user is active in one of those channels, then the user will be assigned another channel in order to maintain the call active (*individual repacking*), this procedure could be continued until all the channels are busy, situation under which no call will be reassigned and the call will eventually drop. This model does not consider mobility and handoffs in the network, hence performance such as blocking is not affected by such factors.

We calculate and evaluate the blocking of channels due to occupancy and the outage in a wireless network that considers mobility of users to adjacent cells with certain probability as in [7], [10], [11], and [5]. We model the traffic through a two-dimensional Markov chain as in [4], where the rates of arrival and departure capture the mobility of users. We evaluate the channel reassignment issue when outage of a busy channel occurs as mobility varies. We compute blocking probability for new and handoff calls as mobility increases and outage is varied in order to obtain the trade-off of outage and mobility, as well as that of blocking and mobility. We include measures such as rates of handoffs dropped.

1.5 Thesis Organization

The organization of this thesis is as follows. Chapter 2 presents a general description of a cellular network, concepts associated with this work, a description of the parameters involved in the handoff process, capacities of the cellular network and the outage effects. Chapter 3 introduces the principal bases of analysis of a cellular network as an open queueing system, a model which treats the blocking probability with its performance parameters. The proposed model and the mathematical analysis with the performance measures to evaluate are presented.

Numerical results are in Chapter 4 with different scenarios, Chapter 5 contains the conclusions and further research.

Chapter 2

Cellular Concepts

This chapter explains the main concepts related to a cellular environment, a brief discussion on the problems that affect the good performance of all cellular systems. Emphasis to the tools employed in this work will be mentioned here.

2.1 Elements of a Cellular Network

The design of a mobile-telephone network has established a well known list of objectives that are based on the interest of the costumer and service providers. The objectives that are to be followed in the design are:

- Large system capacity.
- Efficient use of the spectrum.
- Include portable and mobile units.
- Widespread computability.
- Widespread availability.
- Adaptive to traffic density.
- Affordability.

Conceptually, we can think of several systems satisfyng the requirements in the list, except for the first two, capacity and spectrum allocation, because there is a need to grow indefinitely in terms of subscribers but without enlarging continually the allocated spectrum. This has the main issue in the evolution of the cellular concept.

When two or more independent signals, modulated or unmodulated, are transmitted simultaneously in the same frequency band, Co-channel Interference is generated. Therefore, if two customers are to use the same frequency band, they need to be separated from one another at a distance determined by the power strength of the received signal of the customer using the same frequency.

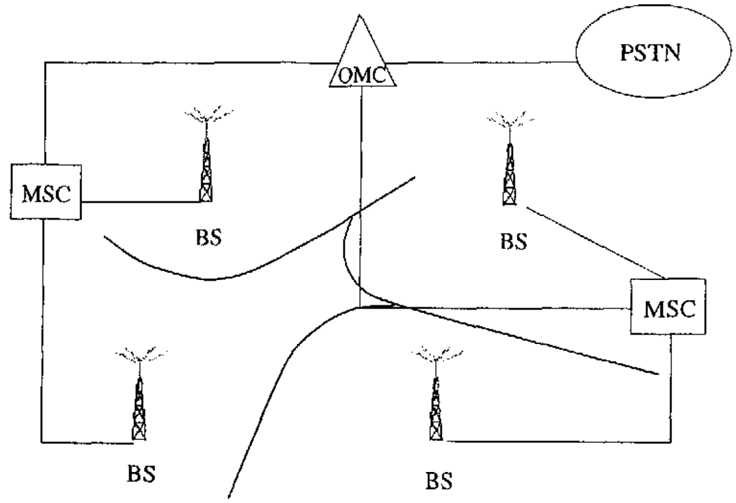


Figure 2.1: A wireless mobile network.

In Figure 2.1 we have a region being served by a network. The region is divided into smaller regions called cells that are controlled by a *Base Station* (BS) with an antenna and a transmitter/receiver whose transmitting power determines the shape of the region covered. The base stations communicate with a *Mobile Switching Center* (MSC) and these with the *Public Switched Telephone Network* (PSTN) and/or the *Operations Maintenance Center* (OMC).

Although the cells have irregular shapes, it is customary to present them through the use of regular hexagons as shown in Figure 2.2.

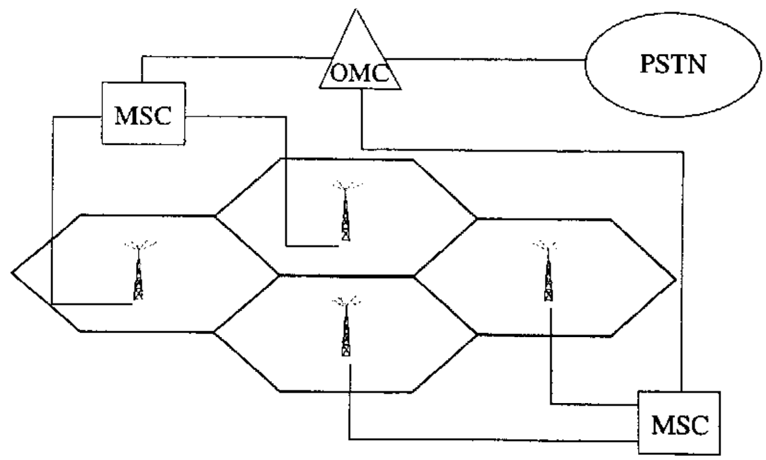


Figure 2.2: A cellular network.

The definition of boundaries between regions brings the problem of a handoff, which is the event of crossing a boundary of a cell when a user is already having a conversation through that BS and the query for service from the new BS of the adjacent cell to which he is moving into. This event needs management tasks to be performed between BS's through MSC's.

The communication between customers and the service provider is done through the establishment of two links or channels, the forward channel is the link from BS to the customer, and the reverse channel is the link from customer to BS.

2.2 Channel Assignment

The channel assignment techniques most widely used are discused here and the main concepts related, it will be a general discussion of the main tools needed in this work.

Fixed Channel Assignment (FCA)

In this case, each cell in the network is allocated a predetermined set of voice channels and that allocation stays during operation of the network. If a user requests service from a cell, it can only be connected if there is a channel available, otherwise, if all the channels are occupied, then the user will be rejected and will be blocked.

A variation of FCA technique is the Channel Borrowing, where a user has been denied service due to full occupancy of the voice channels of the cell, then the corresponding BS tries to borrow a channel from one of the adjacent cells through the MSC that determines the availability of channels and the reuse criteria in order to provide service to the user in question.

Dynamic Channel Assignment (DCA)

In DCA, the channels are managed by the MSC, when a request for service is initiated by the user, the BS sends the request to the MSC allocates a channel according to certain algorithms to verify the reuse distance, the frecuency of the channel and the cost functions. In general, DCA improves blocking since it increases capacity because all the channels are available to all the cells. DCA requires that the MSC carry out some task as keeping channel occupancy levels, traffic distribution and radio signal strength. DCA is better than FCA in light, non-homogeneneous time varying traffic.

Flexible Channel Assignment

In this scheme, we have a combination of FCA and DCA. First, all the cells are assigned a number of channels using FCA, and the remaining channels will be assigned dymamically according to a scheduling criterion or a predictive criterion. The scheduling criterion bases its decisions on traffic demand measures and assigns channels where it is more advantageous for the network performance.

2.3 The Handoff Process

The event of handoff occurs when a mobile is already active (having a conversation through a voice channel) in a cell and moves into a different cell while still active.

The MSC transfers the call from one BS to the other by sending a command to the new BS in order to have a new voice channel assigned to the user.

We can see in Figure 2.3 a mobile being active in cell A and moving towards cell B. The mobile is receiving the signal from cell B, but it is not sufficient to cause a handoff, at this moment, the MSC has initiated the identification of the new BS so that it can send the corresponding commands to execute the handoff when necessary. When the mobile has already crossed the boundary between cells and the MSC has determined that it need to be served by the BS, hence the *voice channel* (VC) from BS A has been closed and the new VC from cell B has been assigned to the user.

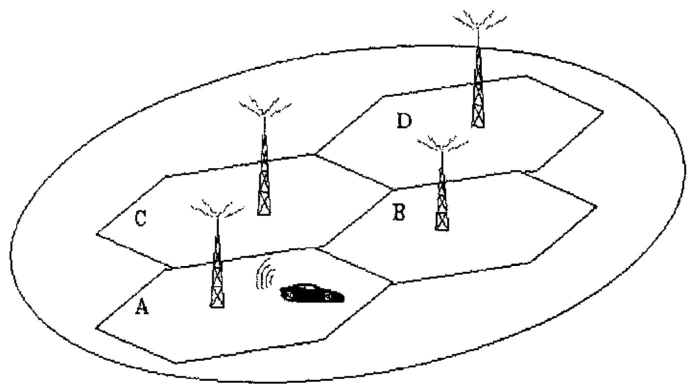


Figure 2.3: Mobile executing a handoff.

2.4 Cellular Network Concepts

The following section describes the main concepts related to networks of queues, some of these parameters will be used along this work.

2.4.1 Application of Networks of Queues

Many networks can be modeled a a set of queues when users arrive with a certain rate and depart from it with another rate. When there is a single server, and users arrive to request service according to a Poisson process to a facility with infinite capacity and one server, and the probability distribution of the service time is exponential we will refer to an $M/M/1$ system.

When we have many $M/M/1$ systems interconnected, they cannot be modeled now as $M/M/1$. Since interarrivals are correlated to service times, but the Kleinrock independence assumption helps restore the independence of arrivals and service times. Now, applying this assumption to a network of queues we can have a Jackson network which is based on Jackson's Theorem, [1].

Consider K single server queues in which customers arrive from outside the network at each queue in accordance to independient Poisson processes at rate r_i. Once a customer is served at queue i, it proceeds to join each queue j with probability q_{ij} or to exit the network with probability

$$1 - \sum_{j=1}^{K} q_{ij}, \tag{2.1}$$

and $q_{ii} = 0$. The total customer arrival rate at queue j, denoted λ_j, satisfies

$$\lambda_j = r_j + \sum_{i=1}^{K} \lambda_i q_{ij} \qquad j = 1, 2, ..., K, \tag{2.2}$$

these equations represent a system of linear equations in which the total rates λ_j, $j = 1, 2, ...K$, constitute a set of K unknows. We assume that they can be solved uniquely to yield λ_j, $j = 1, 2...K$ in terms of r_j, q_{ij}, $i, j = 1, 2...K$. It can be shown that uniqueness is guaranteed under very general assumptions, for instance, if all the departure probabilities $(1 - \sum_{j=1}^{K} q_{ij})$ are positive, $i = 1, 2...K$, or more generally, if for every queue i_1 , there is a queue i with $(1 - \sum_{j=1}^{K} q_{ij} > 0)$ and a sequence $i_1, i_2, ...i_k$, such that $q_{i_1 i_2} > 0$, ...,$q_{i_k i} > 0$, [1].

Jackson's Theorem

Jackson's Theorem states that the number of customers in the queues at a time t, for different queues is an independient random variable. In addition, it states that the steady state probabilities of the individual queues are those of an $M/M/C$ system. This is an amazing result because in general the input process to a queue is not Poisson as was demostrated in the simple queue with feedback discussed in the begining of this section (2.3.1).

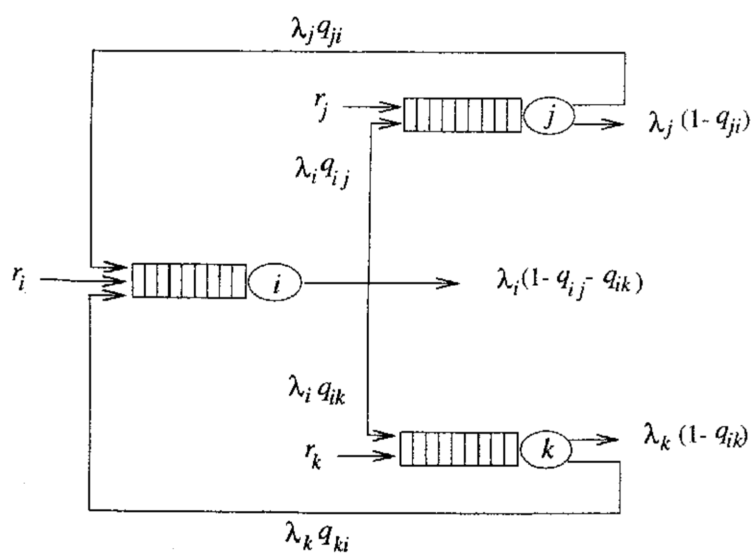


Figure 2.4: Network of three M/M/1 queues.

In the case of a wireless network with cells, we can model the arrival rate of each cell i by considering the external arrival and the handoff's from adjacent cells that move into cell i with certain probability. But cells in the network have a number of channels assigned, C, which is finite and if no channel is available, arriving users will be blocked, hence each cell cannot be modeled as an $M/M/1$ system, but as an $M/M/C/C$ system. We can extend the Jackson's Theorem to the case where the queues are $M/M/C/C$'s .

In a cellular communication network, we have calls that are initiated in a particular cell, say cell i, these calls are considered *New Calls* and the total number of new calls offered to cell i per time unit is the *New Call Arrival Rate* of cell i, λ_i.

Since cells are not isolated and have adjacent cells, users that have a cell in progress can move and cross a cell boundary producing a handoff event. In this case the call in progress is offered to an adjacent cell and is producing a handoff event. The total number of handoff calls offered to cell i per time unit is the *Handoff Call Arrival Rate* of cell i, ν_i. The proportion of new calls and handoff calls that are rejected and blocked in cell i is denoted as B_i. In general, the arrival process of new calls will be determined by a Poisson process with mean λ_i for cell i.

The *set up time* is needed to allocate a VC to a user from the time service it was requested. The *holding time* is the time a call lasts from the moment it was set up until the user hangs up or the call is droped due to handoff or outage. *Outage* is the event when a channel signal to noise ratio is below some prescribed level that determines an acceptable quality of communication therefore producing a drop call or the inability to assign such channel even though it is not occupied by other user. Therefore, we are going to define the number of *free channels* as the set of channels that have an acceptable quality of communication, and the *busy channels* as the channels which are being occupied by the users and the channels that are not in outage. The *dwell time* of cell i is the time that an active user stays within cell i as an active user, and it is an exponential random variable with mean $1/\mu_i$ for cell i.

2.4.2 Grade of Service (GoS)

The grade of service is defined as the number of unsuccessful calls relative to the total number of attempted calls, in other words, it is a measure of inefficiency of the total number of channels to the mobile users. Some cellular systems are designed to have a GoS of 2%, rising to 5%. The GoS is directly related to the blocking probability.

The previous tools here mentioned are very useful to solve the model proposed in the next chapter, each one must be related with another tool. The next chapter presents the global model used to relate the problems before mentioned in the objective of this work. The model proposed will be solved in a specific network cellular system, but this model may be applied to any type of network structure.

Chapter 3

Model Description

There exist some models of traffic in a cellular mobile network, some of they make an approximation with all its parameters depending on the handover requirements like a cellular system modeled as an open queueing network where the number of channels becomes the number of servers in the network, [7]. Other traffic models which treat priority exist, they have grades of reservation for new and handoff calls, [7], [6], [5], [10], [11], and some others treat the interference considering individual repacking [4]. This chapter proposes an analytical model relating the principal issues affecting the good performance of any cellular system, like outage, handoff and mobility of the users, no other work has proposed any relation with the main principal parameters just mentioned.

3.1 Model Proposed

Outage, handoff and mobility are included in the next Markov model, a specific cellular network is proposed in order to study the general model, mathematical expressions represent the behavior of the users in the system, performance parameters are developed to obtain the main characteristics.

Consider an asymetric cellular network with fixed channel asignment where $\mathcal{N}$ is the set of cells and N is the total number of cells. Each cell has C_i channels assigned to it. Let $\mathcal{A}_i$ be the set of cells adjacent to cell i. Assume the new call arrivals and departures are a Poisson process in cell i with mean λ_i, and μ_i, respectively. A call may attempt a handoff to an adjacent cell or leave the network. Let q_{it} be the probability of a call terminating in cell i and let q_{ij} be the probability of an active call causing a handoff to cell j, were $j \in \mathcal{A}_i$. If $j \notin \mathcal{A}_i$, $q_{ij} = 0$.

Let ν_{ji} be the handoff rate out of cell j offered to cell i, for adjacent cells i and j. The handoff traffic that can be offered from cell j to an adjacent cell i depends on the proportion of new calls accepted in cell j that go into cell i, i.e., $\lambda_j(1-B_j)q_{ji}$, and the proportion of handoff calls acepted from cells adjacent to cell j that go into cell i, i.e., $(1-B_j)q_{ji}\sum_{w\in\mathcal{A}_j}\nu_{wj}$. Thus the handoff rate out of cell w offered to cell i is given by

$$\nu_{wi} = (1-B_w)q_{wi}\left\{\lambda_w + \sum_{x\in\mathcal{A}_w}\nu_{xw}\right\}. \tag{3.1}$$

Figure 3.1 contains the representation of the terms involved in Equation (3.1), here we have arrivals of new calls for each cell i with rate λ_i, each cell i has a service time exponentially distributed with parameter μ_i.

The users in the network will need to make a handoff from their origin cell i to another cell j with a determined rate of departure ν_{ij}. If we consider that in determined hours the rate of handoffs may change by different situations, it is necessary to consider another parameter that takes into account the grade of mobility of the users.

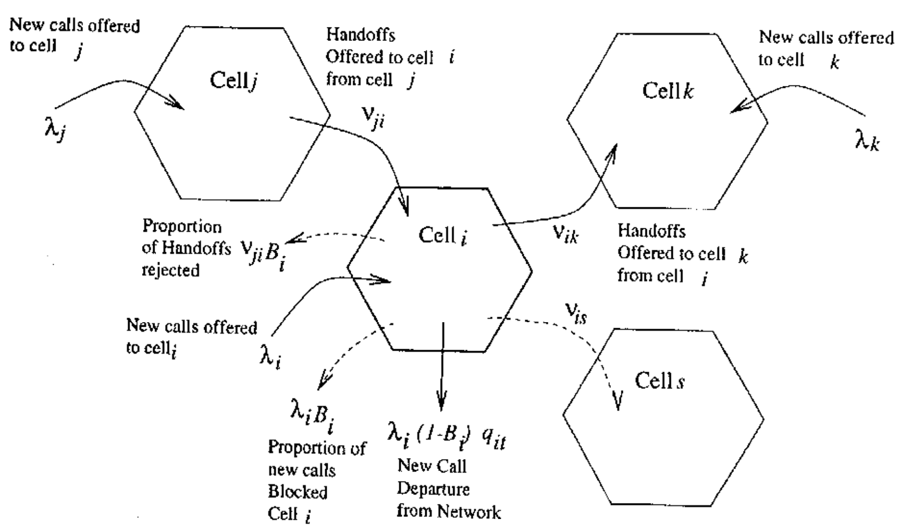


Figure 3.1: Handoff rate offered to cell i from adjacent cell w.

The set of linear simultaneous equations in ν_{ji}, can be involved to compute the total offered traffic to cell i, which is given by

$$\theta_i = \lambda_i + \sum_{j \in \mathcal{A}_i} \nu_{ji}, \tag{3.2}$$

and

$$Z_i = \mu_i. \tag{3.3}$$

3.1.1 Outage Probability

The other parameter that is useful to evaluate the system is related to cochannel interference (*outage*) that is responsible of degradations of the grade of service. The work that has treated this problem is [4].

Due to the interference caused by adjacent and co-channel cells, a determined call may be affected and dropped out, considering a mean that determines the expected number of calls that ingress in outage per cell, [9], then it can be modeled as an exponential random variable with mean γ, and rate of departures α from an outage state. The outage rate could change in determined cases, different intensities of outage that affect all channels in a determined cell were considered.

In order to evaluate the blocking probability due to the outage we must obtain a model in which the number of channels in outage are presented, the model which brings us all these characteristics is a Markov chain. Figure 3.2 shows the C_i channels in a determined cell i, the arrival rate γ_k of outage and the rate of departure α_i from some state i, for $i = 0, 1, 2...C_i$. Then being in state k means having k channels in outage.

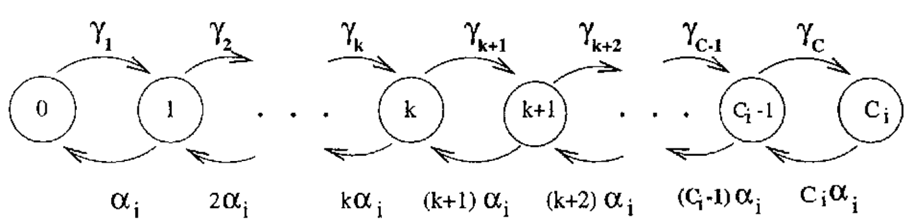


Figure 3.2: Markov chain model having k channels in outage.

Considering an average of arrivals in large cellular systems, this model becomes a single rate model like an $M/M/C_i/C_i$ system.

Let (n_i, k_i) be the state of cell i, where n_i is the number of active calls within the cell and k_i the number of channels in outage in cell i. Considering the total offered traffic to cell i, given by Equation (3.2), the total rate of service of cell i, given by Equation (3.3), the rate of outage γ, and the rate at wich each channel in outage becomes usable, α, we can see that (n_i, k_i) will be a Markov chainn as shown in Figure 3.3.

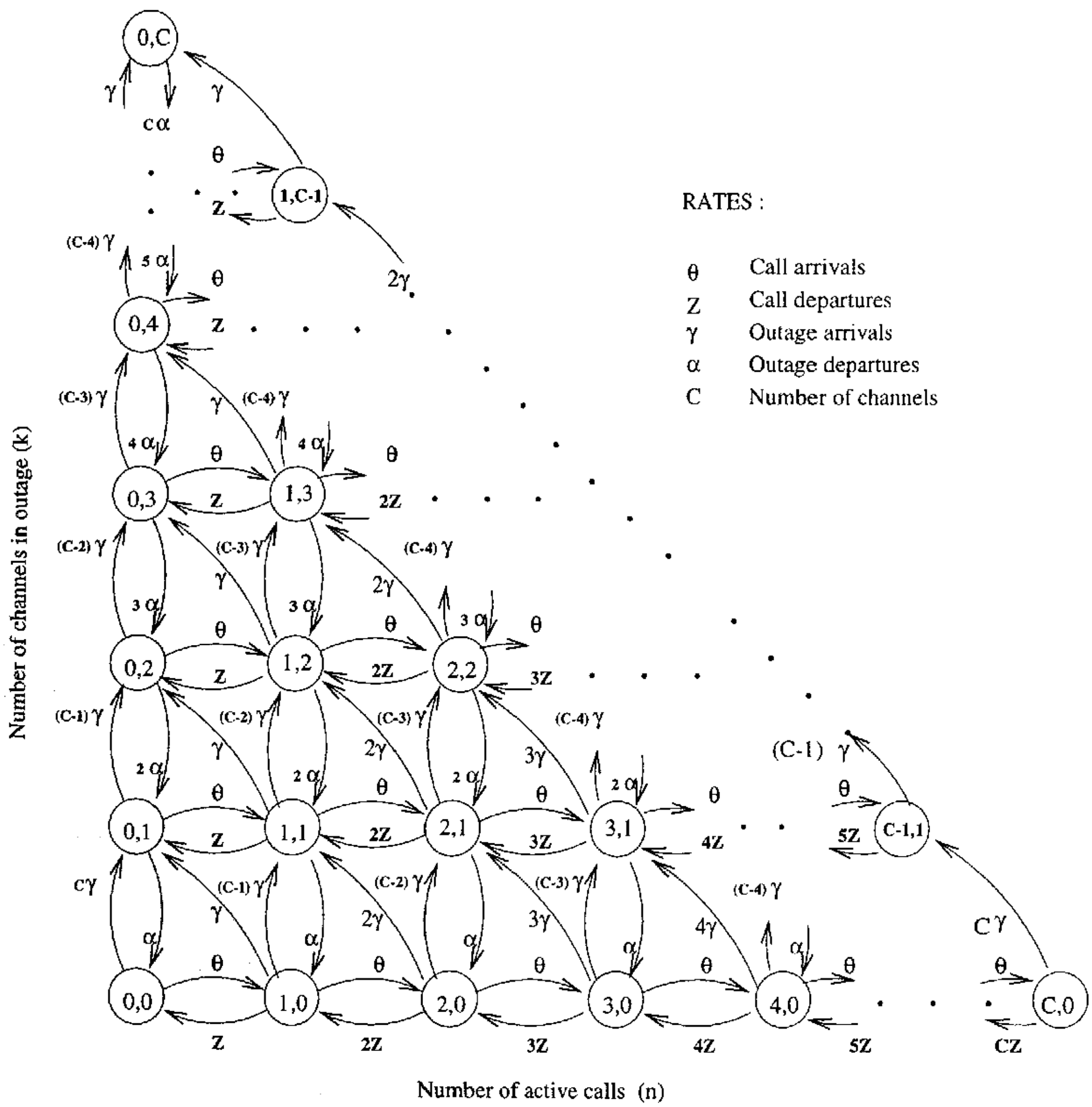


Figure 3.3: Two dimensional Markov chain model proposed for any cell.

Transitions between horizontal states follow the classical model of a one-dimensional queueing system, the vertical transitions are the rates of outage from a determined channel, this transition is divided in two cases because certain calls are in progress in respective number of channels and other idle channels can reach an outage state too.

Let $P_{i_{(n,k)}}$ be the stationary distribution of cell i being in state (n,k). We can find this distribution by solving the system of equations obtained from the global balance equations of the Markov chain in Figure 3.4. This equation is given by

$$\begin{aligned}[n\gamma_i + (C_i - (n+k))\gamma_i + 1_{\{n+k<C_i\}}\theta_i + k\alpha_i + nZ_i]P_{i_{(n,k)}} &= 1_{\{n+k<C_i\}}(k+1)\alpha_i P_{i_{(n,k+1)}} \\ &+ 1_{\{n+k<C_i\}}(n+1)Z_i P_{i_{(n+1,k)}} \\ &+ 1_{\{k>0\}}[(n+1)\gamma_i P_{i_{(n+1,k-1)}} \\ &+ (C_i - (n+(k-1)))\gamma_i P_{i_{(n,k-1)}}] \\ &+ 1_{\{n>0\}}\theta_i P_{i_{(n-1,k)}}, \end{aligned} \tag{3.4}$$

and

$$\sum_{n=0}^{C}\sum_{k=0}^{C-n} P_{i_{(n,k)}} = 1. \tag{3.5}$$

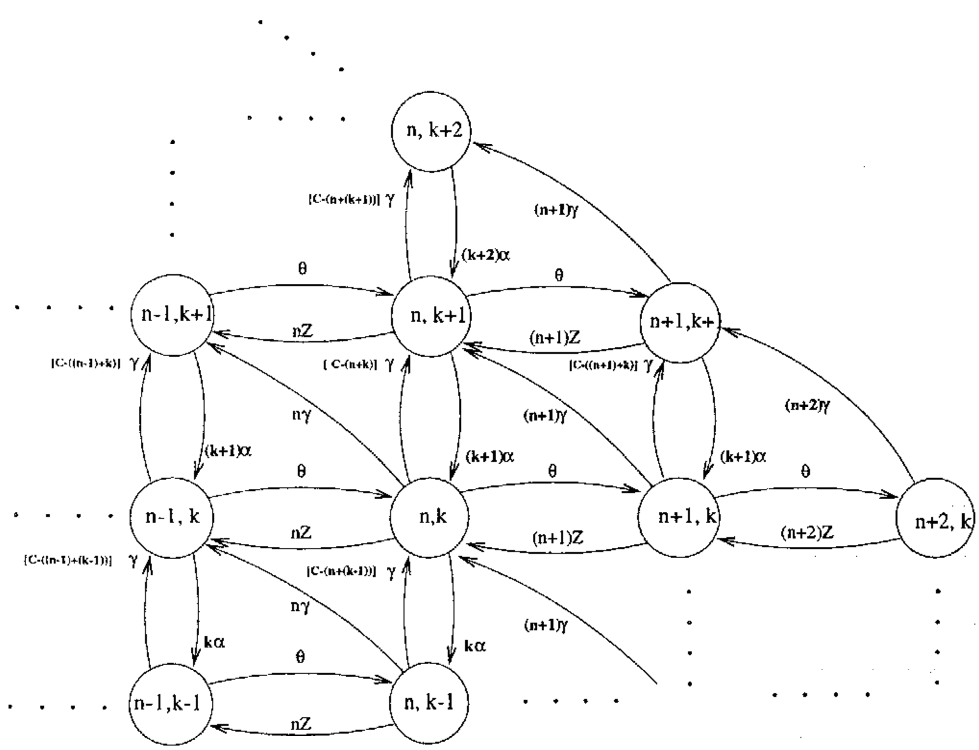


Figure 3.4: Extract of the model relating all the states with its rates.

Where $1_{\{K\}}$ is the indicator function of event K, i.e., whenever event K is true, $1_{\{K\}} = 1$, otherwise, $1_{\{K\}} = 0$.

3.1.2 Performance Measures

In this section we obtain some performance measures establishing the variation with the probability states.

The Blocking Probability B_i for cell i can be found by

$$B_i = \sum_{n=0}^{C_i} P_{i_{(n,C-n)}} \tag{3.6}$$

The calls in progress may be lost due to non-availability of usable channel, then the Rate of Outage is

$$R_{L(i)} = \sum_{n=1}^{C_i} n\gamma_i (\sum_{k=0}^{C_i-n} P_{i_{(n,k)}}) \tag{3.7}$$

Rate of Handoffs Dropped in cell i is

$$D_i = B_i \sum_{j \in A_i} \nu_{ji} \tag{3.8}$$

The Expected Number of Channels in Outage for cell i is

$$N_{O(i)} = \sum_{n=0}^{C_i} \sum_{k=1}^{C_i-n} kP_{i_{(n,k)}} \tag{3.9}$$

The Network Blocking for determined number N of cells in the network can be found as

$$L_i = \frac{\sum_{i=1}^{N} \lambda_i B_{(i)}}{\sum_{i=1}^{N} \lambda_i} \tag{3.10}$$

All these performance parameters show the main characteristics of the network for a determined values in the system like rates of arrival and departure as well as the outage considerations.

3.1.3 System Evaluation

The system is solved having in consideration all the numerical rates involved in a determined cell i and its neighbors in the network, i.e., outage, handoffs, level of mobility, rate of new calls in the system, etc. First it is necessary to solve Equation (3.1), supposing an initial value of blocking probability. The rates obtained from Equation (3.1) are useful in Equation (3.2), then we solve Equation (3.3). Equation (3.4) (*Balance Equation*) is solved with the values of Equations (3.2), (3.3) and (3.5) with a determined number of channels in the cell, levels of outage and outage's departures.

Once we have the probabilities of the states in the Two-Dimensional Markov chain model for each cell i in the network, we solve Equation (3.6) for each cell, making then a comparison of the new blocking probability with the blocking probability of the previous iteration.

This is repeated until convergence is reached by the blocking probabilities. After this, Equations (3.6)-(3.10) are solved to give the performance measures.

Chapter 4

Numerical Results

This chapter describes the network used with the proposed model, and the behavior of the network obtained through the evaluation of the analytical expressions obtained in Chapter 3.

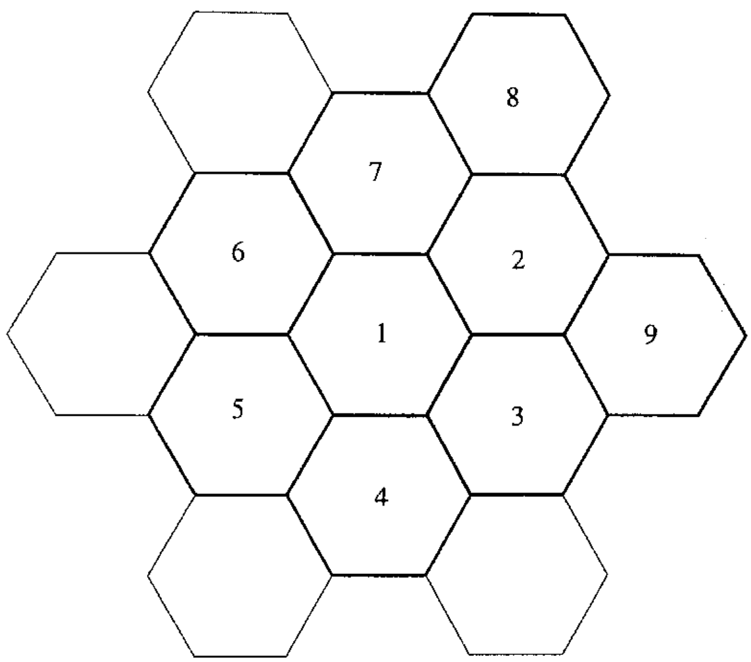


Figure 4.1: Group of cells in study.

Consider a cellular network located in a specific geographic zone in which each cell has a determined number of channels, as it is shown in Figure 4.1 for a network with 9 cells. Numerical results obtained in this work were calculated for this network.

Table 4.1: Values of q_{it}

Types of mobility	q_{it}
NM	1
LM	0.9
MM	0.8
HM	0.6

The cellular network may be influenced by different factors like interference, blocking of new calls due to capacity of the system, mobility of the users in the network, etc; that decrease the Grade of Service(GoS).

4.1 Network Description

In order to consider handoffs in the network, we assumed a probability q_{it} of an active call being terminated in cell i when its dwell time expires. q_{it} is the proportion of active users in cell i that will terminate their call after their dwell time expires. We consider different mobility conditions fixed by this parameter q_{it}, the No Mobility scenario will be when $q_{it} = 1$, meaning that 100% of users will depart from the network after the dwell time expires. For Low, Medium and High Mobility, the value of q_{it} can be seen in Table 4.1.

We assume different levels of outage in the network, from 0% to 40%, which represents the blocking probability in a determined channel. The values in Table 4.2 were obtained considering one specific channel in a determined cell. In order to suppose the total outage experimented in every channel, here we suppose a rate of outage $\gamma_i = 0.00664$, for any cell i which means how many times a channel becomes in outage in a determined period of time. The rate of departure α_i from this state is calculated from the value of γ_i, and the Erlang B table considering the blocking probabilities before mentioned.

Table 4.3 contains the capacity of the cells which was fixed at 10 channels per cell, the rate of departure of each cell, μ_i, fixed at unity and the arrival rate of each cell i fixed at 3.09 (base load) which is chosen by the Erlang B table since for a resource with capacity 10 and input erlangs of 3.09 the blocking is 0.1%.

Table 4.2: Levels of outage proposed

Levels /Rates	% of Outage	α_i
0	0	X
1	5	0.1261
2	10	0.0597
3	15	0.0377
4	20	0.0265
5	25	0.0195
6	30	0.1547
7	35	0.1211
8	40	0.0099

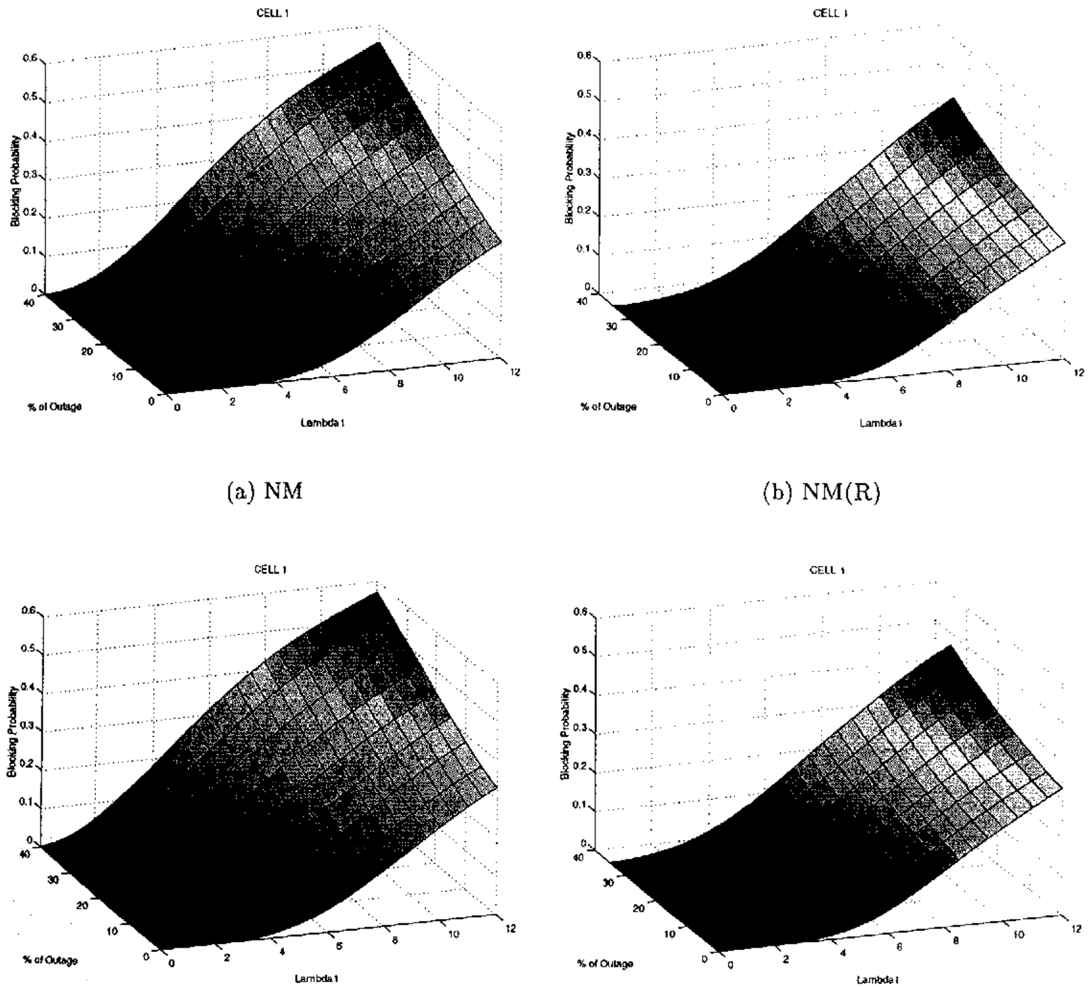
Table 4.3: Values of C_i and rates for each cell

Any cell i	Values
C_i	10
λ_i	3.09
μ_i	1

4.2 Performance Results

The scenarios considered were 2. In the first scenario the arrival rates were kept constant at the base load and only the arrival rate of cell 1, the cell with the most neighbors, was varied from 0 to 12 calls per time unit (scenario 1). The second scenario considers the variation of all the external arrival rates at the same time increasing together from 0 to 12 calls per time unit (scenario 2). Consider cell 1 which is the cell with the most neighbors, some other cell adjacent to cell 1, i.e., (cell 7), and other non adjacent cell to cell 1, i.e., (cell 9). This consideration is to show different behavior varying the outage, new arrivals and mobility. The following figures show the blocking probability for cells 1, 7, and 9 with different types of mobility.

Numerical results are conducted under two outage management conditions. The first is that an active call will be dropped whenever its channel undergoes an outage state, the second is that an active call will be assigned a new channel if its original channel undergoes an outage and capacity is available in the cell, i.e., a partial repacking condition, we denote this condition by (R).

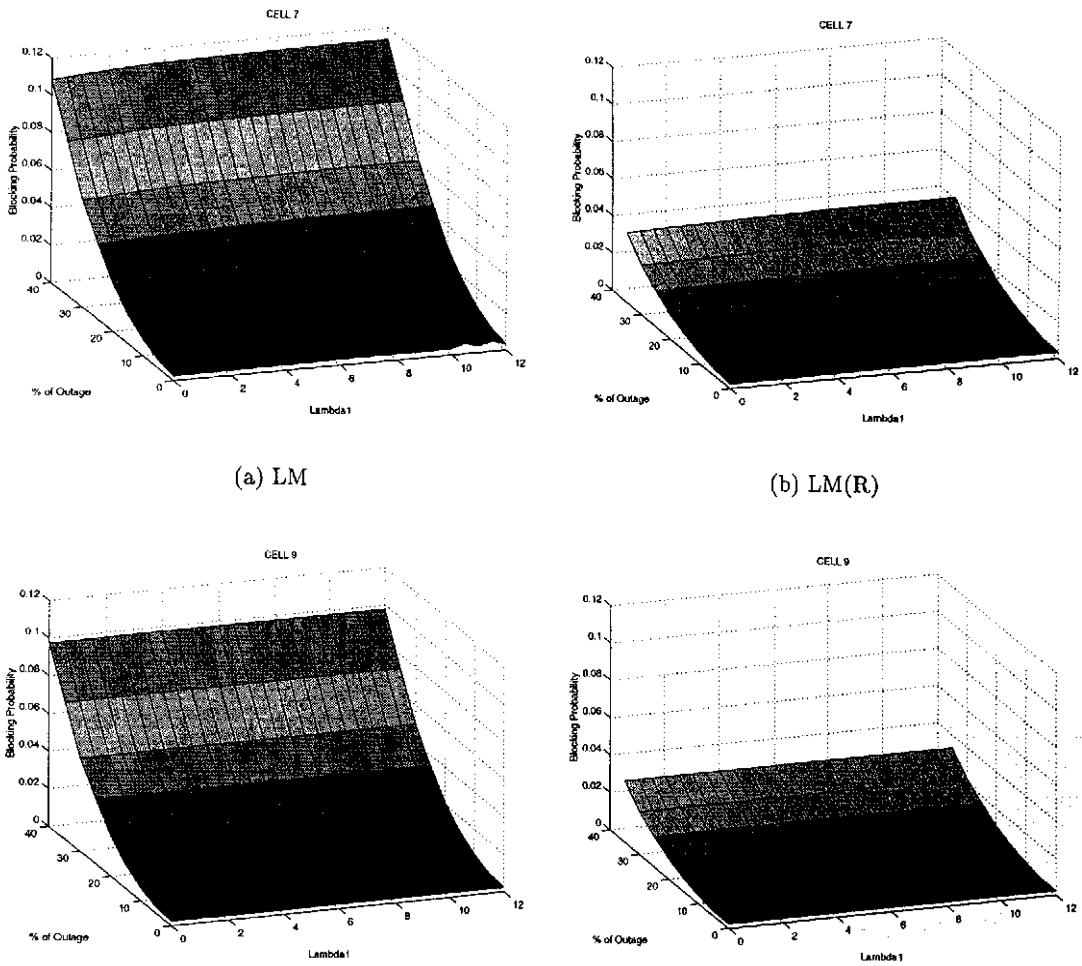


(a) NM (b) NM(R)

(c) LM (d) LM(R)

Figure 4.2: Blocking Probability, cell 1 with effects of λ_1 and Outage.

The results in Figure 4.2 show the blocking probability of cell 1 affected by the increments of λ_1 (scenario 1) and outage for the No Mobility and Low Mobility cases under conditions of no repacking and repacking. We can see for the case of zero outage for the No Mobility the results are according to the blocking probability obtained by the Erlang B formula for the repacking and no repacking conditions. The effect of repacking causes a less blocking probability for some outage case with respect to the repacking condition due to the assignment of an usable channel to the call in progress. Similar results were obtained for the Low Mobility increasing the blocking probability in cell 1 for any case of outage.



(a) LM

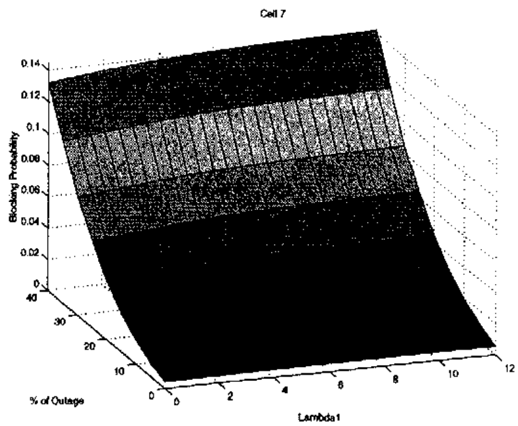
(b) LM(R)

(c) LM

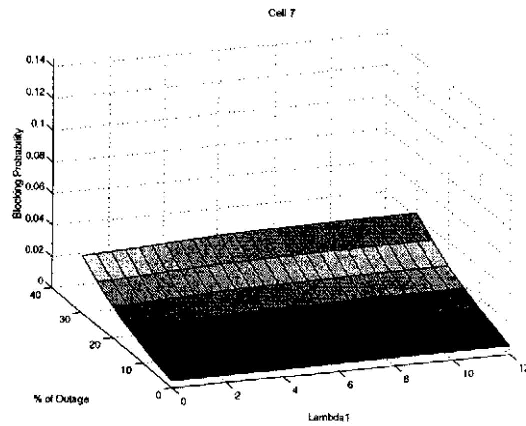
(d) LM(R)

Figure 4.3: Blocking Probability, cell 7 and 9 with the effects of λ_1 and Outage.

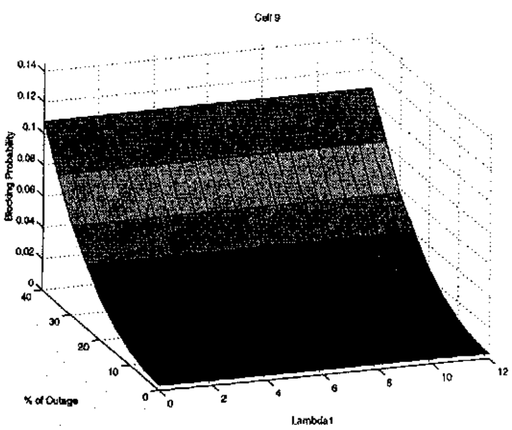
Figure 4.3 is the representation of the behavior of the cells 7 and 9 for the case of Low Mobility in scenario 1 under repacking and no repacking conditions. Cell 7 for repacking condition has a blocking probability less than that for the no repacking condition, similar interpretation, is for cell 9. Cell 9 shows less blocking probability in both conditions than cell 7, due to the location in the network having less number of handoffs. We also see that blocking in cell 7 and 9 has no effect from traffic of cell 1 at Low Mobility, remaining almost constant when λ varies.



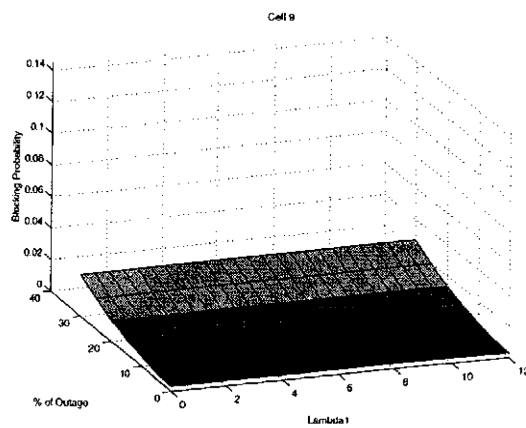
(a) MM



(b) MM(R)



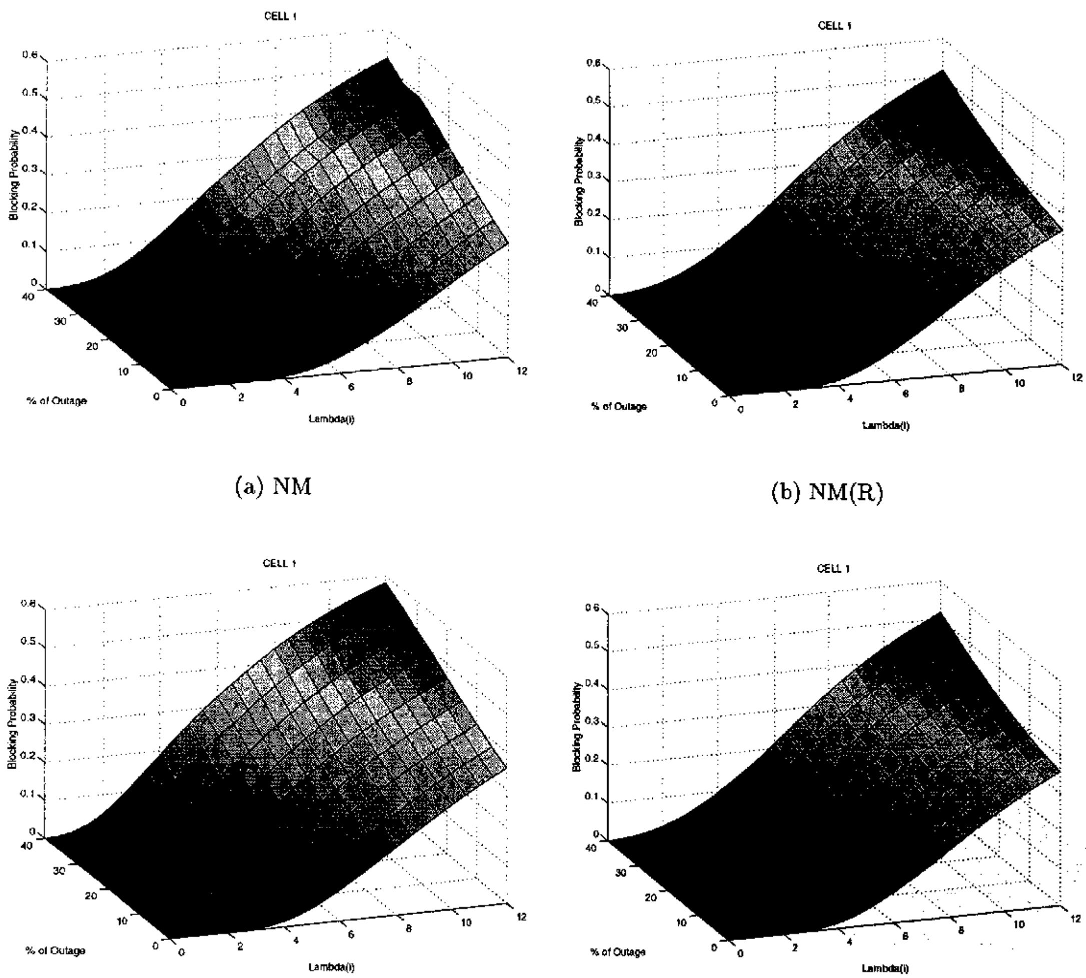
(c) MM



(d) MM(R)

Figure 4.4: Blocking Probability, cell 7 and 9 with the effects of λ_1 and Outage.

Figure 4.4 has similar performance as that in Figure 4.3, here cell 7 and 9 have more blocking probability with respect to cell 7 and 9 for Low Mobility in the conditions of repacking and no repacking. The blocking probability in cell 7 and 9 has no effect from traffic of cell 1 like in the case of Low Mobility.

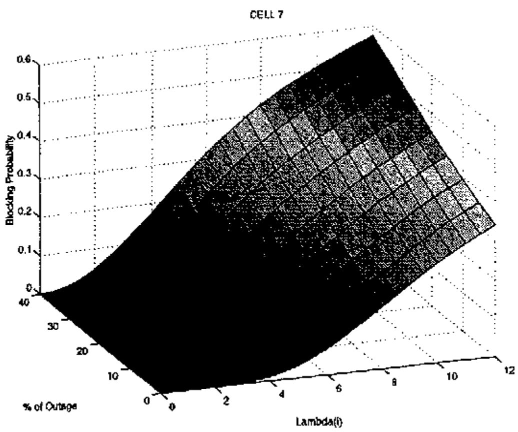


(a) NM (b) NM(R)

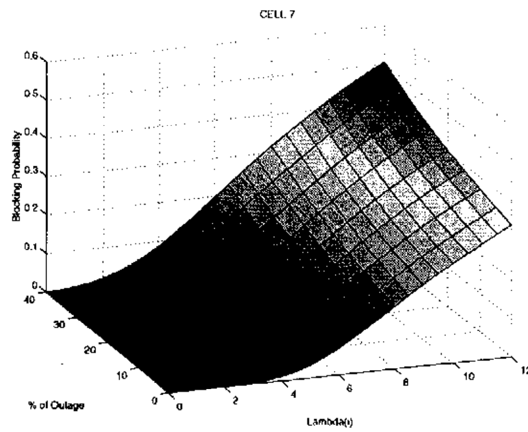
(c) LM (d) LM(R)

Figure 4.5: Blocking Probability, cell 1 with the effects of all λ/s and Outage.

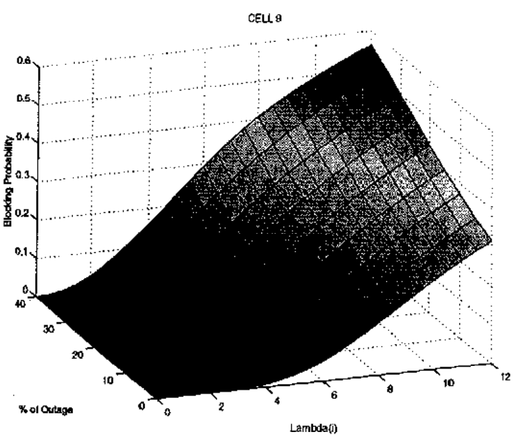
Figure 4.5 shows the blocking probability for cell 1 in scenario 2 with No Mobility and Low Mobility for repacking and no repacking conditions. We can also see that in terms of blocking, for this scenario 2, repacking has no significant gain over no repacking.



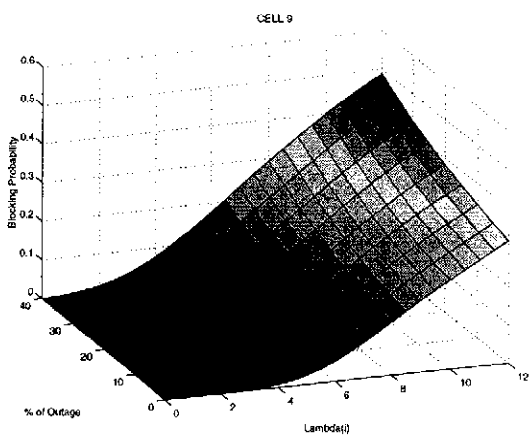
(a) LM



(b) LM(R)



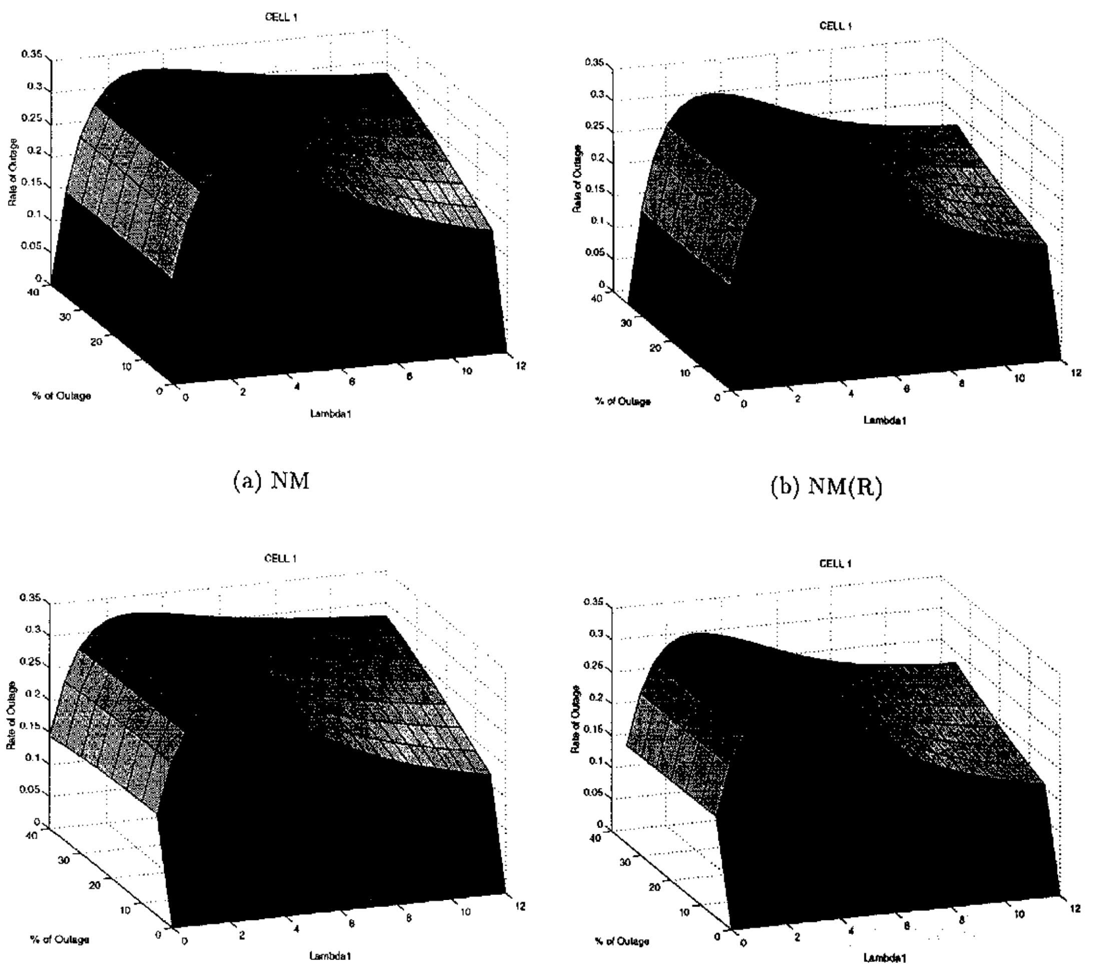
(c) LM



(d) LM(R)

Figure 4.6: Blocking Probability, cell 7 and 9 with the effects of all λ/s and Outage.

In the case of 0% of outage Figure 4.5a and b, show the Erlang B result, the blocking probability is growing up accordingly with outage levels. The Low Mobility in Figure 4.5c, d, cause an increment of blocking probability respect to No Mobility due to handoffs for the repacking and no repacking conditions. For the case of Low Mobility a comparison between cell 7 and 9 is presented in Figure 4.6, cell 7 has a high level of blocking probability compared to that of cell 9 for repacking and no repacking condition in scenario 2.



(a) NM

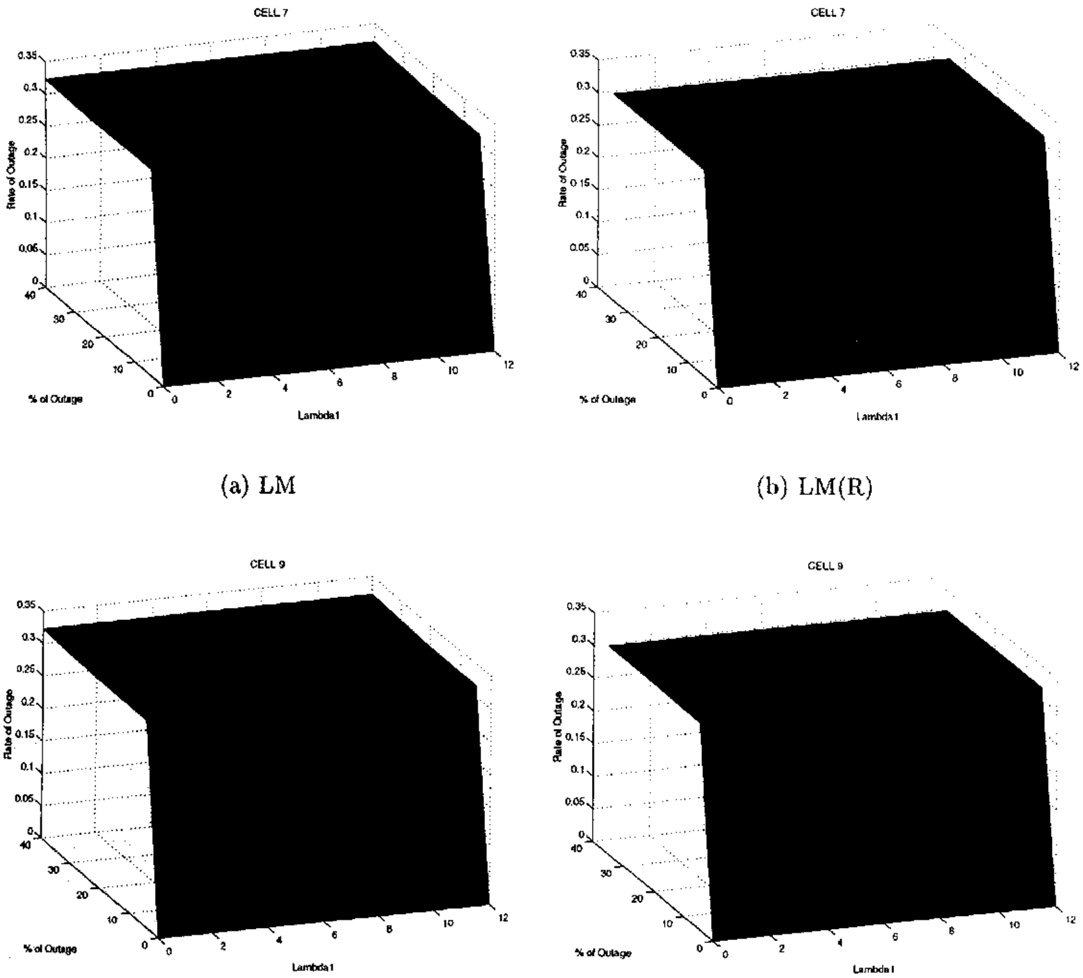
(b) NM(R)

(c) LM

(d) LM(R)

Figure 4.7: Rate of Outage, cell 1 with the effects of λ_1.

Another performance measure is presented in Figure 4.7 where the cell may have a determined rate of outage, or how many number of times in a determined time period a channel becomes in outage. We can see in Figure 4.7a, and the other subfigures in scenario 1 when the outage is zero, the rate must be zero, but this value rises accordingly to the levels of outage.



(a) LM

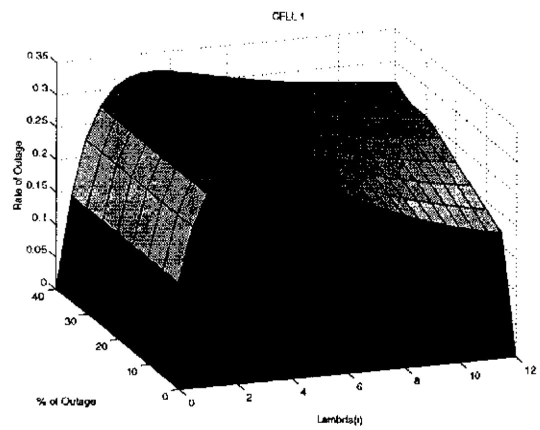
(b) LM(R)

(c) LM

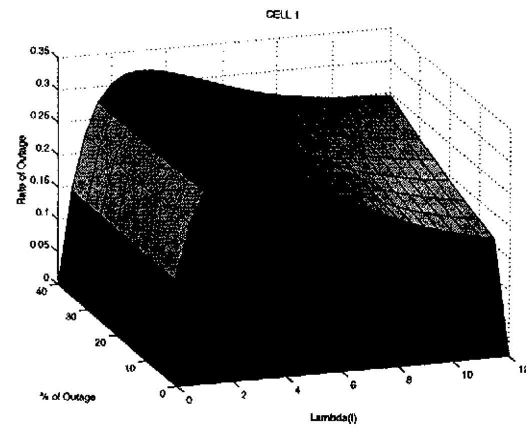
(d) LM(R)

Figure 4.8: Rate of Outage, cell 7 and 9 with the effects of λ_1.

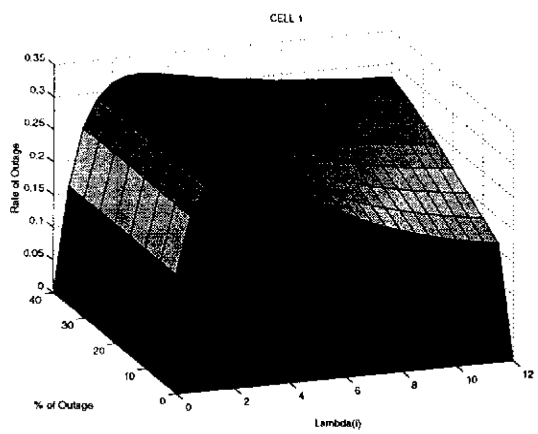
Since the rate of outage depends on the probability of the outage states, in the first values of outage the rate is less than in the other values of outage. The mobility causes the change of the rates of outage in determined points in the figures. For the case of Low Mobility, cell 7 and 9 are compared in scenario 1 for no repacking and repacking conditions. Figure 4.8 shows the rate of outage keeping a constant value. It is easy to see similar figures for both cases for a determined cell, and that the rate of outage is a little dependent on the increments of λ_1 due to Low Mobility.



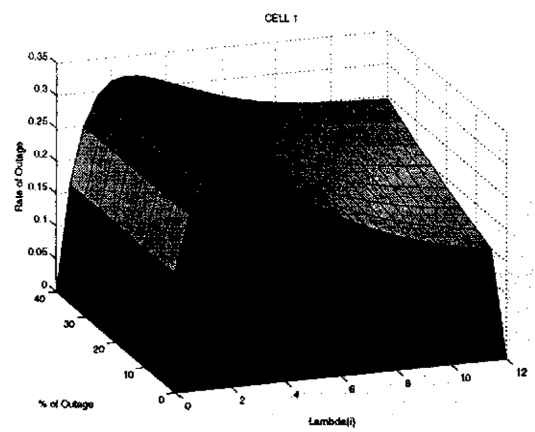
(a) NM



(b) NM(R)



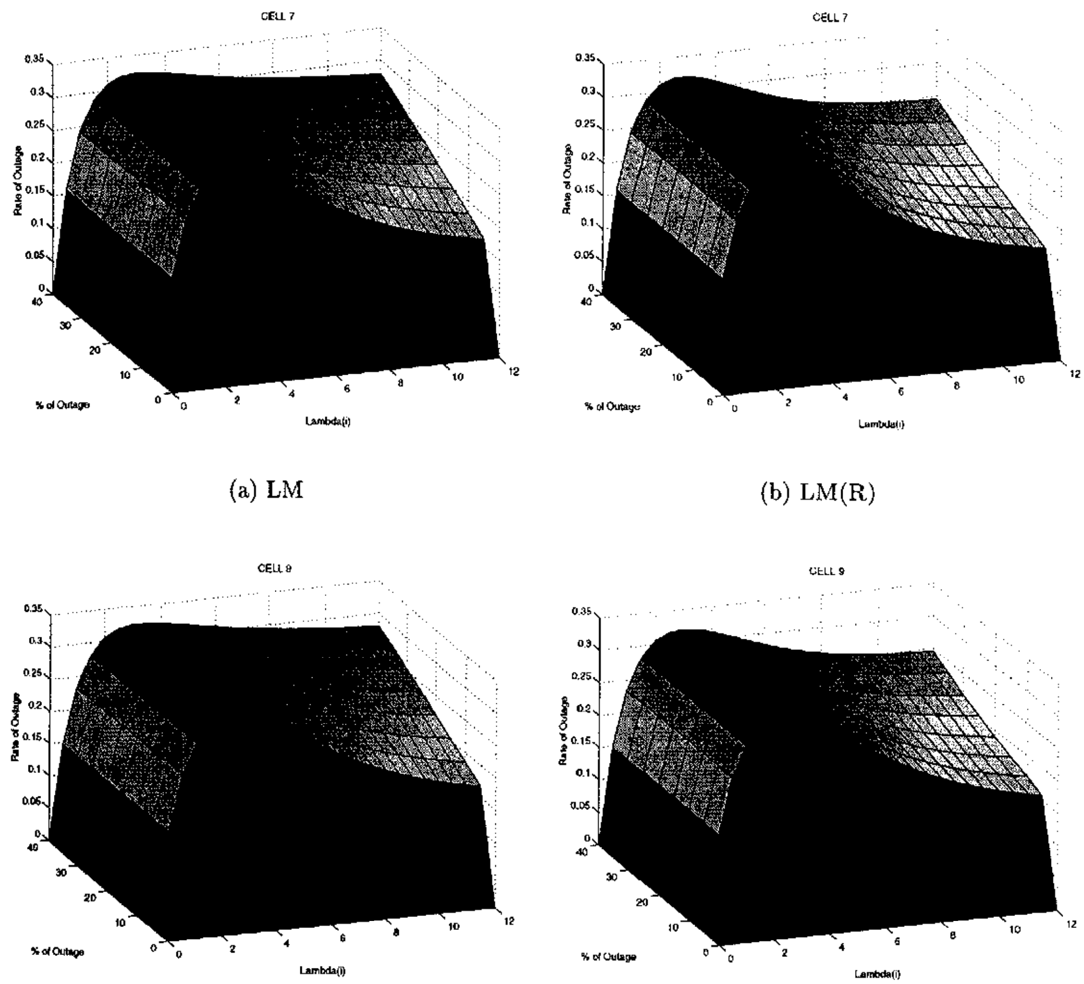
(c) LM



(d) LM(R)

Figure 4.9: Rate of Outage, cell 1 with the effects of all λ's.

The rate of outage for cell 1 is shown in Figure 4.9 for scenario 2 with no repacking and repacking condition, here the effects of rate of outage are zero when there are zero outage, and a little value of rate of outage when there are zero calls in the system. The effects of repacking are visible dimishing the rate of outage, in cell 7 and 9. The curve is affected when the mobility of users is incremented, the curve grows up when the outage is growing up and we have the same interpretation as that of Figure 4.7.



(a) LM

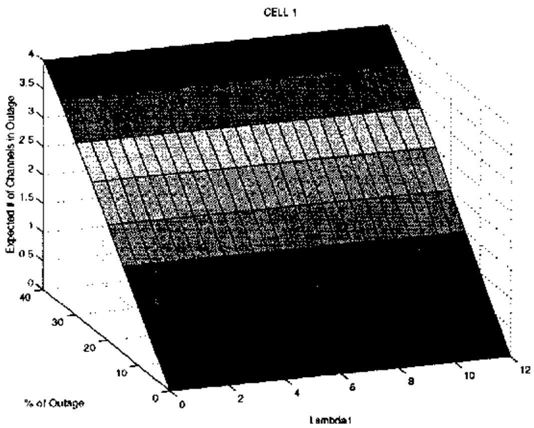
(b) LM(R)

(c) LM

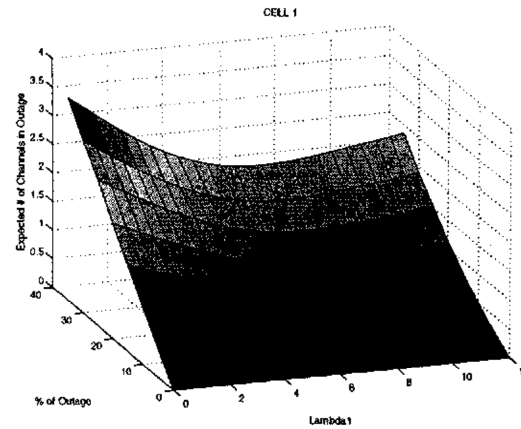
(d) LM(R)

Figure 4.10: Rate of Outage, cell 7 and 9 with the effects of all λ/s.

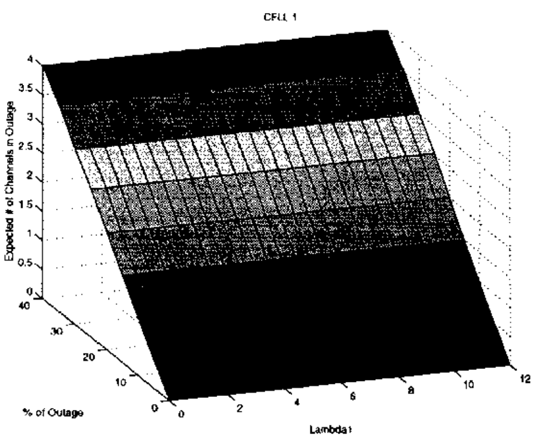
The curves for cell 7 and 9 for scenario 2 having repacking and no repacking condition are shown in Figure 4.10, these figures are affected similarly respect to cell 1 for the conditions of Low Mobility.



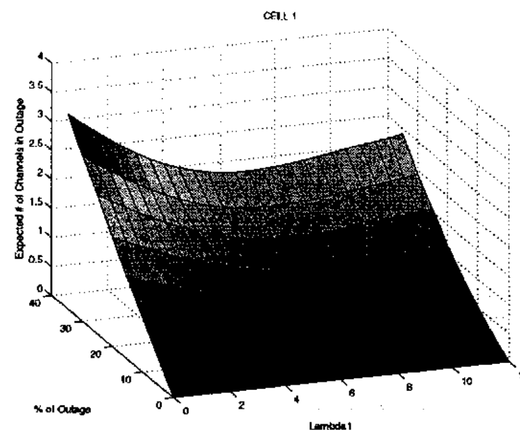
(a) NM



(b) NM(R)



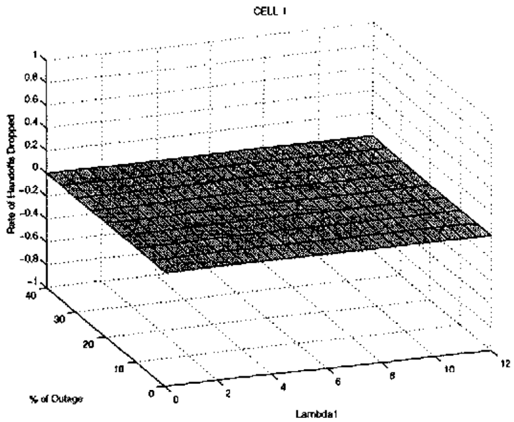
(c) LM



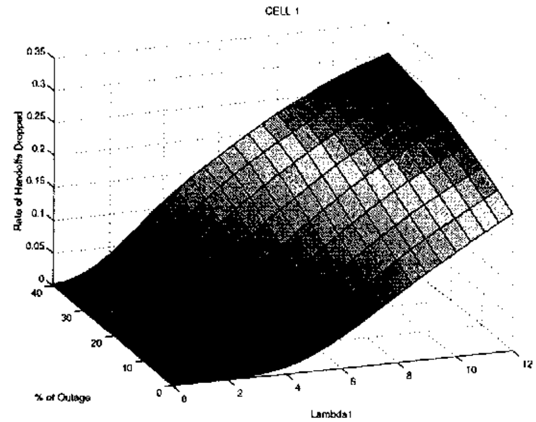
(d) LM(R)

Figure 4.11: Expected Number of Channels in Outage, cell 1 with the effects of λ_1.

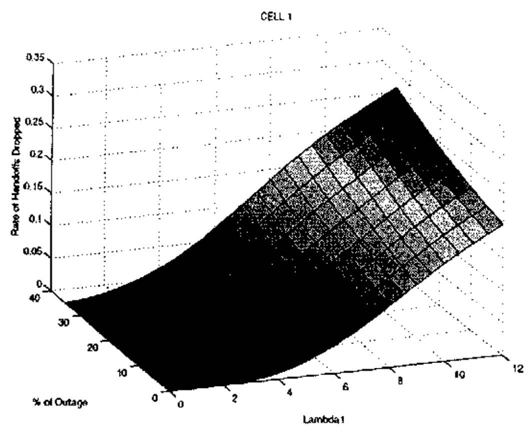
The expected number of channels in outage make a linear curve for all types of mobility for every cell in the no repacking condition due to the proportionality with the outage rate. For repacking condition in cell 1 in Figure 4.11, the expected number of channels in outage decreases when the mobility is increased because the facility of the system to obtain free an accupied channel due to more calls are handed off, whereas scenario 2 keeps this measure constant for any type of mobility. When λ_1 is increased for the repacking condition, the chain has the effect of get none of all channels in outage having a minimum and maximun value of channels in outage.



(a) NM



(b) LM

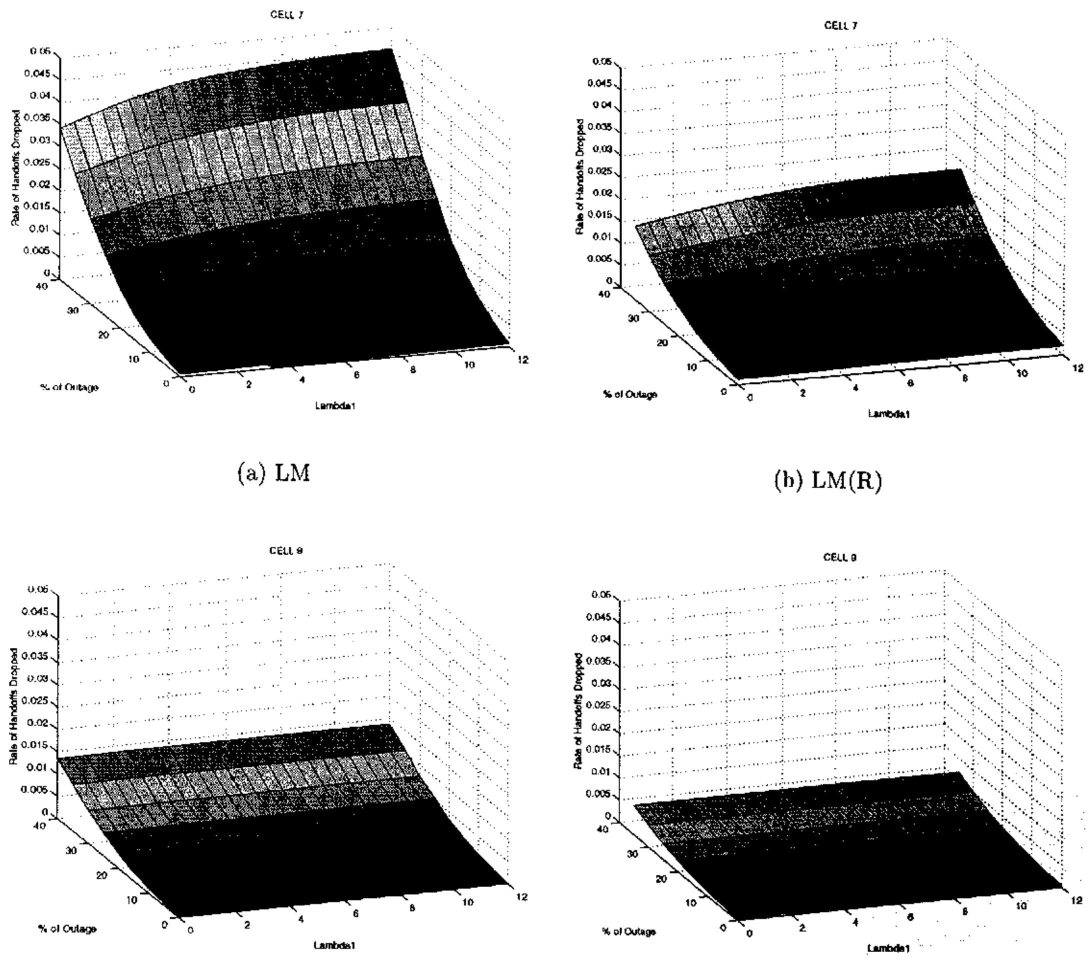


(c) LM(R)

Figure 4.12: Rate of Handoffs Dropped, cell 1 with the effects of λ_1.

The rate of an unsuccessfull handoff for cell 1 in scenario 1 is ploted in Figure 4.12, the curve grows up when the intensity of mobility is experimented in the network and is increasing with more percentage of outage in the system.

Figure 4.12c, shows the repacking condition and we can see a dimishing of rate of handoffs dropped relating to no repacking condition due to disponibility of the system to have all the calls active.



(a) LM

(b) LM(R)

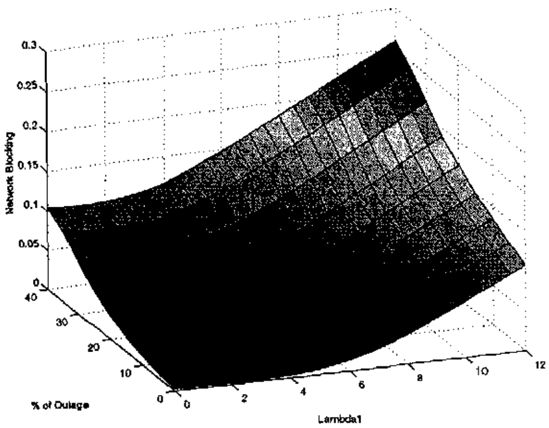
(c) LM

(d) LM(R)

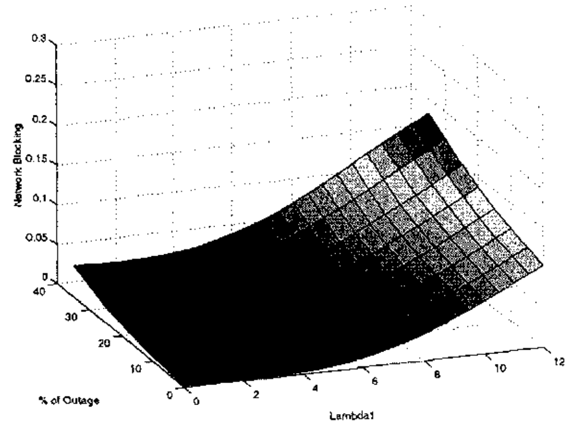
Figure 4.13: Rate of Handoffs Dropped, cell 7 and 9 with the effects of λ_1.

Figure 4.13 show the adjacent cell 7 having more rate of handoffs dropped due to the number of neighbors around, while cell 9 has more reduction of rate of handoffs dropped due to the minimum number of neighborhoods.

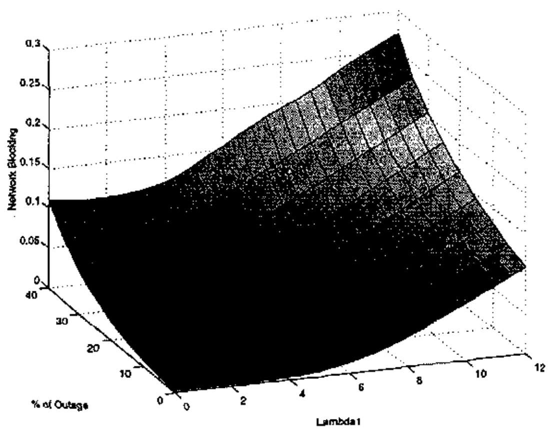
The repacking condition makes a better behavior reducing the rate of handoffs dropped to near of 50% respective to the no repacking condition.



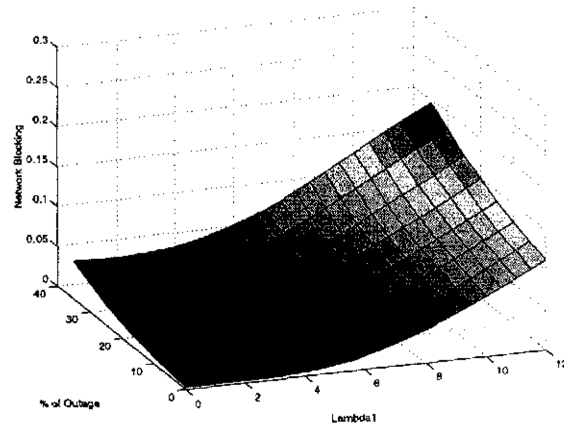
(a) NM



(b) NM(R)



(c) LM

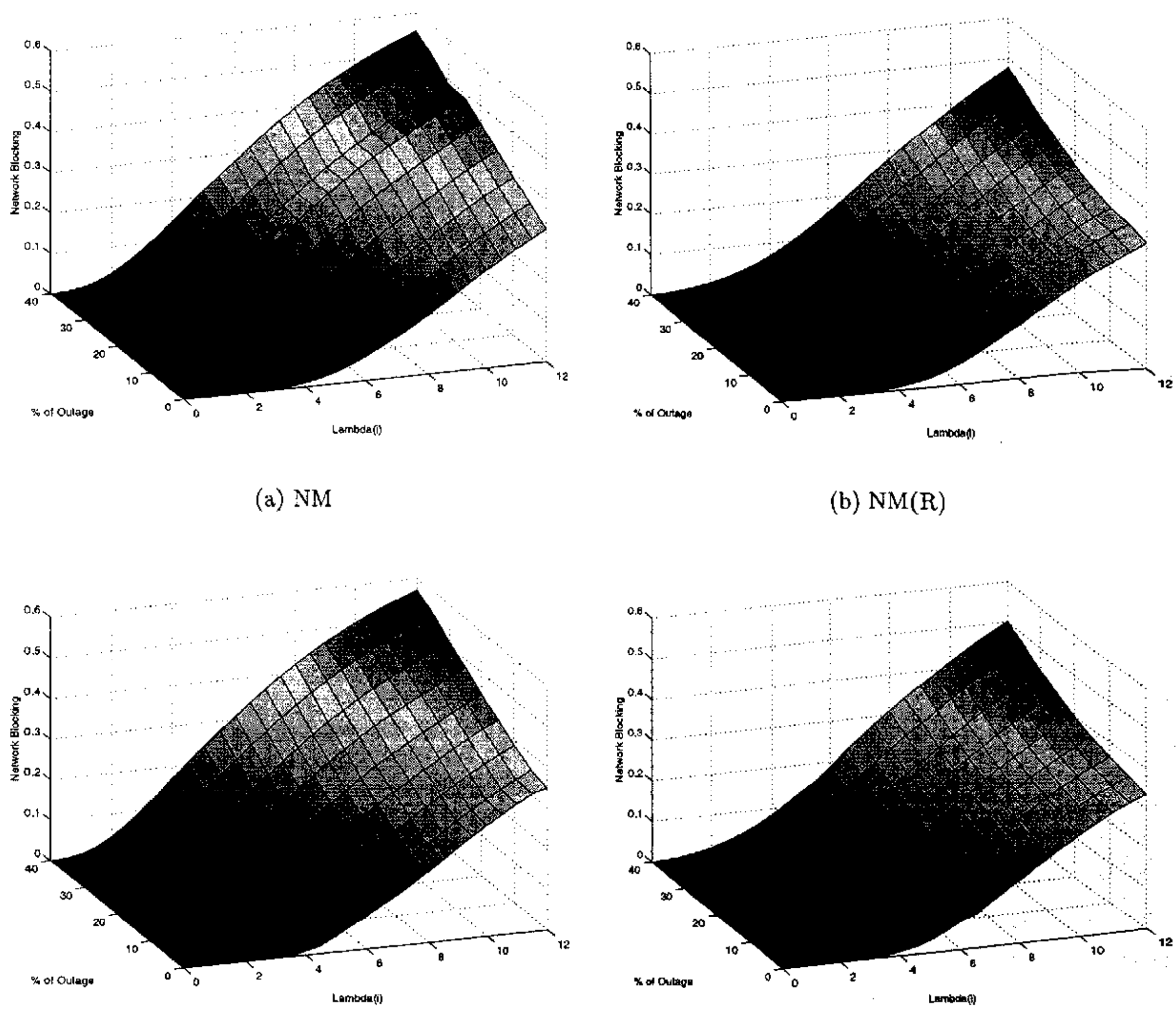


(d) LM(R)

Figure 4.14: Network Blocking, effects of λ_1 over the network.

All the system can be analized with the network blocking probability, as seen in Figure 4.14, this performance measure relates all the λ's with its respective blocking probability. The network blocking has the same tendency of growth as in the scenario 1 and increments of outage in the system.

The repacking condition makes a better performance of the network reducing the blocking probability for any point in the curve with respect to the no repacking condition.



(a) NM

(b) NM(R)

(c) LM

(d) LM(R)

Figure 4.15: Network Blocking, effects of all λ's over the network.

Scenario 2 is shown in Figure 4.15, the effects of network blocking are more drastic than those in scenario 1, but the repacking condition makes the effect of reducing the network blocking, for any type of mobility with respect to the no repacking condition.

Chapter 5

Conclusions and Further Research

5.1 Conclusions

This work has related the outage and mobility of users in a wireless network, a two dimensional Markov model has been proposed and calculated different types of performance measures in large cellular systems.

The two dimensional Markov model may be applied to any cell i in a determined wireless network, with any number of channels C for each cell, different characteristic of rates, i.e., arrivals ,outages , departures, may be considered for each cell and different types of mobility like No mobility (NM), Low Mobility (LM), Medium Mobility (MM), and High Mobility (HM) may be applied for a specific cell i inside the network in study.

The rates of arrival and handoff are a function of the number of neighbors to cell i, and the rates of outage are a function of the geographic zone in study.

The performance measures show the efficiency of the model verifying some basic considerations like the blocking probability must agree with the Erlang B table when outage equals zero. This work has shown that the outage effects cause more problems of blocking probability than the mobility effects. The repacking condition has been assigned to the network showing a best performance in the different performance measures here presented, making the repacking condition a lower bound of blocking probability in the network.

5.2 Further Research

The proposed model may be applied in further research like:

- To continue this work with considerations like reservations and priorities.
- To make a reliability approach in the network with the costs implied.
- Could hysteresis in the Markov model for the outage assumptions be considered?
- To extend to consider Soft Handoffs.

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