RESOURCE MANAGEMENT IN CELLULAR COMMUNICATION NETWORKS WITH SUBSCRIBER PROFILE PREDICTION

A THESIS SUBMITTED TO
THE GRADUATE SCHOOL OF NATURAL AND APPLIED SCIENCES
OF
MIDDLE EAST TECHNICAL UNIVERSITY

BY

NUSRAT YILMAZ

IN PARTIAL FULFILLMENT OF THE REQUIREMENTS
FOR
THE DEGREE OF DOCTOR OF PHILOSOPHY
IN
ELECTRICAL AND ELECTRONIC ENGINEERING

JUNE 2005

Approval of the Graduate School of Natural and Applied Science

Prof. Dr. Canan Özgen
Director

I certify that this thesis satisfies all the requirements as a thesis for the degree of Doctor of Philosophy.

Prof. Dr. İsmet Erkmen
Head of Department

This is to certify that we have read this thesis and that in our opinion it is fully adequate, in scope and quality, as a thesis for the degree of Doctor of Philosophy.

Prof. Dr. Rüyal Ergül
Supervisor

Examining Committee Members

Prof. Dr. Yalçın Tanık	(METU, EE)	____________
Prof. Dr. Ruyal Ergül	(METU, EE)	____________
Prof. Dr. Mete Severcan	(METU, EE)	____________
Dr. Ali Özgür Yılmaz	(METU, EE)	____________
Prof. Dr. Erdal Arıkan	(Bilkent, EE)	____________

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Name, Last name : Nusrat, Yılmaz

Signature :

ABSTRACT

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YILMAZ, Nusrat

Ph.D., Department of Electrical and Electronics Engineering

Supervisor : Prof. Dr. Ruyal Ergül

June 2005, 168 pages

In this study, a dynamic resource management and subscriber profile prediction scheme for mobile communication systems is presented. The aim is to achieve a high level of QoS for both handoff calls and new calls, while at the same time to improve the utilization of wireless network resources. The simultaneous satisfaction of these two actually conflicting interests will be thanks to two major key features. First, it will be due to the individual subscriber profile based prior information about handoff reservation requests that are provided by the mobile terminals. This information is based on the cell transition probabilities calculated by the mobile itself using collected information during past operations. Second, it will be due to a two-way approach implemented in the resource management processes. The two-way approach controls both the amount of reserved radio channels and the new call admission in a dynamic way, depending on the subscriber mobility and network traffic conditions.

Keywords: QoS, Resource Management, Handoff Call Failure, New Call Blocking, Spectral Efficiency

ÖZ

HUCRESEL ILETISIM AGLARINDA KULLANICI KISISEL BILGILERI DESTEKLI TELSİZ KANAL YÖNETİMİ

YILMAZ, Nusrat
Doktora, Elektrik Elektronik Mühendisliği Bölümü
Tez Yöneticisi : Prof. Dr. Ruyal Ergul

Haziran 2005, 168 sayfa

Bu çalışma, telsiz iletişim ağlarında çağrı aktarma ve yeni çağrı kabul etme işlemlerinde yüksek bir hizmet kalitesini hedeflerken aynı zamanda kısıtlı telsiz kaynaklarının kullanım verimini artırmayı hedefleyen yeni bir yaklaşım içermektedir. Bu her iki hedefin aynı anda gerçekleştirilmesi, iki ana yöntem ile sağlanmaya çalışılmıştır. İlk olarak, hareketli kullanıcı terminallerinde tutulan istatistik bilgileri sayesinde herhengi bir kullanıcının yol güzergahının önceden belirlemesi ve bu şekilde kullanıcının geçeceği bir sonraki hücrede o kullanıcı için kanal tahsisinin yapılması ilkesi. İkinci olarak, radyo kanalı yönetiminde iki aşamalı bir yaklaşım kullanılması ilkesi. Bu iki aşamalı yaklaşımla, ortamdaki kullanıcıların hareketlilik durumuna ve ağ içindeki trafik durumuna bağlı olarak dinamik bir şekide, yeni cağrı başlatma ve geçiş yapan çağrı için rezervasyon ve kabul işlemleri kontrol edilmektedir.

Anahtar Kelimeler: Servis Kalitesi, Kaynak Yönetimi, Geçiş Yapan Çağrı Düşmesi, Yeni Çağrı Engelleme, Spektrum Verimliliği

To My Parents and My Family

ACKNOWLEDGMENTS

The author wishes to express his deepest gratitude to his advisor, Prof. Dr. Ruyal Ergül, for his guidance, advice, criticism and encouragement and insight throughout the research.

The author also would like to thank to, Prof. Dr. Erdal Arıkan and Prof. Dr. Yalçın Tanık, for their suggestions and comments.

The technical assistance of Baki Kuran, and Ercan Yıldırım is gratefully acknowledged.

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CHAPTER I

INTRODUCTION

Next generation mobile communication networks will support high-speed data applications and multimedia services in small cell-size based network architectures. Small cell structures have many advantages. However, they require frequent handoffs for the mobile user due to small cell radius. Handoffs use more resources than a static user due to seamless handoff requirement. The quality of service requirements makes it necessary to give priority to handoff calls to avoid call dropping. Hence, the increased rate of handoff requests in the network environment makes it very difficult for the network to simultaneously satisfy the required Quality of Service (QoS) and effectively utilize the radio network resources.

One of the most common approaches used to guarantee QoS while ensuring high channel utilization is to use channel allocation. Efficient utilization of resources can be obtained if and only if good strategies for channel reservation are employed. This subject has been studied by many researchers and there are several published work related to channel allocation. Their objective was to efficiently manage radio channels in a mobile communication system while reducing handoff failure probability.

Previous works on this subject can be group as a) Fixed Channel Assignment (FCA), b) Dynamic Channel Assignment (DCA), or c) Hybrid Channel Assignment (HCA) strategies for handoff calls. All of these approaches assume that handoff call dropping is highly undesirable, and therefore they attempt to reduce handoff call failures. Channel reservation schemes can reduce handoff failures efficiently, so they have been a preferable choice among various handoff prioritization schemes.

The number of handoff attempts in a cellular network varies according to factors such as user behavior and network traffic conditions. Furthermore, it is a time dependent variable, depending on day and time. Hence, fixed channel reservation schemes efficiency is a time dependent function. It can be efficient during certain time periods corresponding to low traffic and very inefficient during time periods corresponding to heavy traffic.

Handoff attempts do not vary totally randomly and can be predicted using some observations such as time, location and area dependence as well as the traffic conditions in the cells in question. The user mobility, which is a parameter which is strongly dependent on geographical location of cells, needs to be included in these predictions if accurate results are pursued. The call parameters such as call frequency, call duration and mobility of user can be summed up and called user behavior.

Therefore, it is our conjecture that it possible to predict handoff attempts based on call statistics of the cellular network. As an alternative to fixed channel reservation, reservation can be done adaptively, depending on the changes in network traffic conditions and user behavior. The success of adaptive resource management depends very much on the accuracy of the information provided about user behavior, changes in network traffic conditions and on the ability of the resource management algorithm in adapting to those changes. It can be assumed that computational complexity and other considerations that resource management algorithms have to deal with can be handled by the network without causing extra cost in the system.

Many approaches have been proposed in literature to guarantee fast and smooth handoff with low probability of failure and low probability of new call blocking which is required to satisfy a certain QoS level and at the same time to utilize wireless channels as efficiently as possible. They focused on methods like estimating the probability that a mobile terminal will be active in a particular cell at future moments, signal-strength based next cell predictions, signal-strength based handoff decision, user location tracking, signal-strength based handoff prioritization and trajectory predictions. Details of some of the published methods will be presented later in this section. There are several problems or difficulties involved in the methods that have been examined so far. The problems can vary from high computational complexity involved in trajectory predictions to difficulties in next cell prediction based received pilot signal strength information. In some cases, difficulties can not be surmounted and in others, they lead to inaccurate results. Hence, it was believed that some new approaches were needed to obtain significant improvements in adaptive channel reservation strategies.

In this study, a novel approach has been aimed which assumes that each mobile can keep statistical information about its own activities. This information could be shared with the network, enabling network to estimate handoff call probability in a simple and efficient way. Hence, network is enabled to make handoff reservations on per user basis. This is expected to produce very efficient resource utilization since adaptation can be continuous, based on information provided by individual mobiles. This is very different from standard estimation procedures which are based on long term ensemble averages and fail to make accurate estimations valid for short time periods.

The resource management algorithm proposed uses this information both in the channel allocation process and in the new call admission process. The new call admission process is the policy applied by the network to allow new calls admitted by the system or rejected, depending on level of resources available. In telephone network terminology, this is equivalent to delaying incoming calls by sending a busy tone during congestion.

The statistical information kept by the mobile concerns the information based on cells visited, time of visit, calls made, time and duration of calls. This information can be utilized any time to accurately predict the probability that mobile will visit one of the neighboring cells. The accuracy will be improved if some position information in the present cell is also available. This probability will be called cell transition probability. These transition probabilities can be used to predict the next cell along the path of the mobile. Once the next cell is determined, a handoff reservation request will be sent to that cell. It is obvious that the network and the base station controllers involved in this process and they are cooperating. It is further assumed that the mobile has enough computational and storage resources to collect, store and evaluate the necessary information.

This is quite logical considering the capabilities of today's cellular phones marketed.

As a summary, it can be said that the determination of the most appropriate number of channels reserved for handoffs should be based on the estimation of handoff probabilities by individual users since networks are not capable of predicting such probabilities on a per user basis. The only agent that can make this prediction accurately is the mobile itself. Then, the network can collect such information from all potential handoff candidates and can make an intelligent planning of the network resources.

Remaining part of this section presents a summary of published work, their main points, advantages and disadvantages.

One of the most common approaches to guarantee QoS while ensuring high bandwidth utilization is using some bandwidth allocation strategies for handoff calls. In [1] such a bandwidth allocation strategy for wireless ATM networks using predictive reservation is proposed. The proposed approach is based on using mobility patterns and reservation is made dynamically. Paper [1] focuses on performance parameters such as new call blocking probability, handoff drooping probability, and successful call termination probability and bandwidth utilization.

Most of the reservation algorithms proposed in literature make use of the knowledge of mobility patterns (i.e. the probability that a mobile in cell i will travel to cell j) to accurately perform the reservation. Paper [1] tries to predict the mobility patterns by utilizing previous history information of the mobiles. The prediction is then used to reserve bandwidth in the "next cell" in advance. This paper assumes a micro-cell/pico-cell environment, such as WATM networks, in which handoff rate is high. One has to consider the decision in which cell to reserve bandwidth. In some previous studies it is propose to reserve bandwidth for an ongoing call in all neighboring cells. This means of course waste of bandwidth due to unnecessary reservation and thus an unnecessary increase in new call blocking probability as well as a drop in bandwidth utilization. In [1], however authors make use of the fact that mobile traffic does not move totally randomly, instead it moves according to the presence of highways, streets, roads etc and thus are somehow predictable. Therefore, it is possible to correctly predict the movement of a mobile in a particular area with a high degree of accuracy, based on the knowledge of previous history of the mobility patterns in the area. The proposed scheme in [1] will predict the next cell a mobile will travel to, based on the mobility information acquired from previous mobiles in the corresponding area. However, the approach proposed in [1] doesn't make any discrimination between individual mobiles. Thus their approach is area or cell based.

Besides predicting the next cell based on mobility patterns, [1] proposes also a new approach for the bandwidth reservation in the next cell, once the next cell has been decided. At any time, the total capacity of a cell can be considered to be composed of three parts: the used bandwidth (currently used by active mobiles), the reserved bandwidth (reserved for future handoff calls) and the free bandwidth. When a mobile tries to initiate a connection, it will be accepted if there is enough bandwidth in the free bandwidth portion. When a mobile arrives from a neighbor cell due to handoff, it is allowed to take bandwidth from reserved bandwidth portion if there any amount of bandwidth reserved for it. Otherwise the handoff connection will compete in the free bandwidth portion with the new call connection attempts. There are several ways to reserve bandwidth in the neighboring cells. In [1] the following reservation styles are studied and compared: 1. Reservation in all surrounding cells, 2.Reserve in the neighbor with the highest transition probability, 3. Reserve bandwidth according to the respective value of the transition probability P_j for neighbor j, 5. Reserve in the two neighbors with the highest transition probabilities.

The next generation mobile communication systems will introduce new technologies and services including broadband communications and multi-call/connection services. In [2], first the impact of these new technologies and services on handoff performance is clarified. Then a new handoff method is proposed in which the handoff connection setup is divided into the network connection setup and the radio connection setup parts, with the former taking place before a handoff request. The new network capabilities such as multi-call/connection services and multimedia communications will seriously affect handoff performance in mobile communications systems. The paper proposes a new approach to resolve the handoff performance problem by trying to avoid handoff failure in the next generation mobile communication systems.

When a handoff is required for a mobile terminal that communicates using multi-call/connection services, it is required that all calls and connections are handed over to the new cell in order to continue the service. This means that the multi-call/connection handoff requires more processing than the conventional single-call/connection handoff. In a small cell area handoff occurs more frequently and the permissible handoff processing delay is less than in large cell areas. These facts could result in situations in which the network cannot complete the handoff before the deadline, which is when a mobile cannot communicate with the old BS because of signal degradation. A handoff failure will then follow. Authors in [2] propose some mechanism to support multi-call/connection service handoffs in small cell areas while trying to utilize radio resources efficiently. The main idea of the method proposed in [2] is to divide the network connection setup process into the network connection setup part and the radio connection setup part. The network connection is established before the handoff request is made (referred to as "preprocessing") based on pilot signal levels coming from the surrounding cell. The network connection setup part is started when the difference between the two signal levels (signal level of current BS and possible next BS) falls below a threshold before the handoff request threshold is reached. In [2] it is claimed that with the proposed way, switching the mobile's radio channel from old BS to new BS can be executed earlier than in the conventional method. Thus, the handoff could be completed before the deadline even for a mobile moving with a high speed in small cell areas.

The success of the proposed method in [2] depends very much on the correct selection of the next radio cell since in this method the next cell is selected earlier than in the conventional methods. Without going into details, in [2] some new approaches for the next cell selection are addressed. These are, estimating the signal level variations of the surrounding cells (and using this information in obtaining the speed and direction of the mobile), using transportation information (obtaining cell transition patterns based on map information present in network database), using mobile patterns defined by user, using mobile patterns produced by the network and using cell transition rate. None of these approaches are detailed in [2] and need further study.

To efficiently handle radio channel reservation process in a mobile communication system and reduce handoff failure probability, many studies are performed using special handoff channels for handoff calls. In [3] a new class of adaptive channel management schemes are proposed, aiming to reduce the handoff failure probability below a predefined threshold by adjusting a channel sharing ratio between new and handoff calls. In a resource-limited environment, however, reducing the handoff failure probability increases the new call blocking probability. The proposed schemes in [3] provide a flexible method to control the desired QoS and to strike a balance between the “minimal” handoff failure probability and the “minimal” new call blocking probability by controlling the new call admission rate. The main approach of the schemes proposed in [3] is to adaptively determine, based on current system load and the total number of channels assigned to a cell, the “maximal” number of channels required to guarantee that the handoff failure probability does not exceed a predefined threshold. Two schemes are proposed which differ in the way they are dealing with new calls. The first scheme, randomized Maximal Handoff Channel Assignment Scheme (rMHCA), attempts to provide a better support for new calls by allowing these calls to compete randomly with handoff calls for the remaining channels after satisfying the level of QoS for handoff calls. The second scheme, balanced Maximal Handoff Channel Assignment Scheme (bMHCA) dynamically adjusts the new call admission rate to achieve a desired tradeoff between a “minimal” handoff failure probability and a “ minimal” new call blocking probability. However, since the number of handoff attempts varies according to network conditions, fixed reservation schemes for handoff attempts can be inefficient.

Since handoff attempts can be predicted using some observations such as time dependence of handoff attempts and location or area dependence of handoff attempts, it is possible to predict handoff attempts and to adaptively reserve bandwidth according to these predictions. In [4] such an adaptive channel reservation scheme is proposed to control the size of reservation capacity according to the varying number of “soft handoff” attempts. “Soft handoff” is a term defined and used in some papers like [4], to describe the condition where the mobile finds a new BS with a pilot signal power higher than a predetermined threshold, so that a new link is established to the new BS, while the old link to the old BS is still kept. To maximize the system capacity or resource utilization, a balancing procedure between soft handoff failure and new call blocking is also proposed in [4]. In order to guarantee the QoS of soft handoff attempts, some reservation capacity is required. However, a considerable amount of reserved capacity can result in wasting the bandwidth, for a fixed value of the reservation capacity, because the capacity required for soft handoff is time varying. Therefore, in [4] a reservation method that adapts to the variations in the soft handoff attempt rate is considered. The term “soft handoff” is also used in [4] to represent the case where a mobile finds a neighboring cell with a received pilot signal level higher than a predetermined threshold, T_{Add}. This is the “soft handoff request threshold”, and thus a new link to the new BS is established while the old link is still maintained. If the pilot-signal of either the link to the new BS or the link to the old BS drops below a “drop” threshold, T_{drop}, then the corresponding link is released. One of the key points of [4] is the definition of a new threshold, the “channel reservation request threshold”, T_{Rsrv}, which is lower than the threshold for handoff request. If the mobile finds a BS with a received signal higher than the channel reservation request threshold, then the mobile sends a reservation request message to the associated Base Station Controller (BSC). Afterwards, if the pilot strength drops and stays below the channel reservation request threshold during a predetermined period of time, the mobile asks the associated BSC to release the reserved capacity. On the other hand, if the signal strength drops further and reaches the “drop threshold” then the mobile initiates soft handoff using the reserved capacity. The “reservation threshold” is not an absolute value but rather is a relative value to the soft handoff request threshold. In [4] the handoff request threshold is dynamically determined according to the current link status and thus the reservation request threshold also dynamically determined guaranteeing adaptive channel reservation. This is illustrated in Fig 1, which shows typical pilot strength variation as the mobile moves from one BS area to another area.

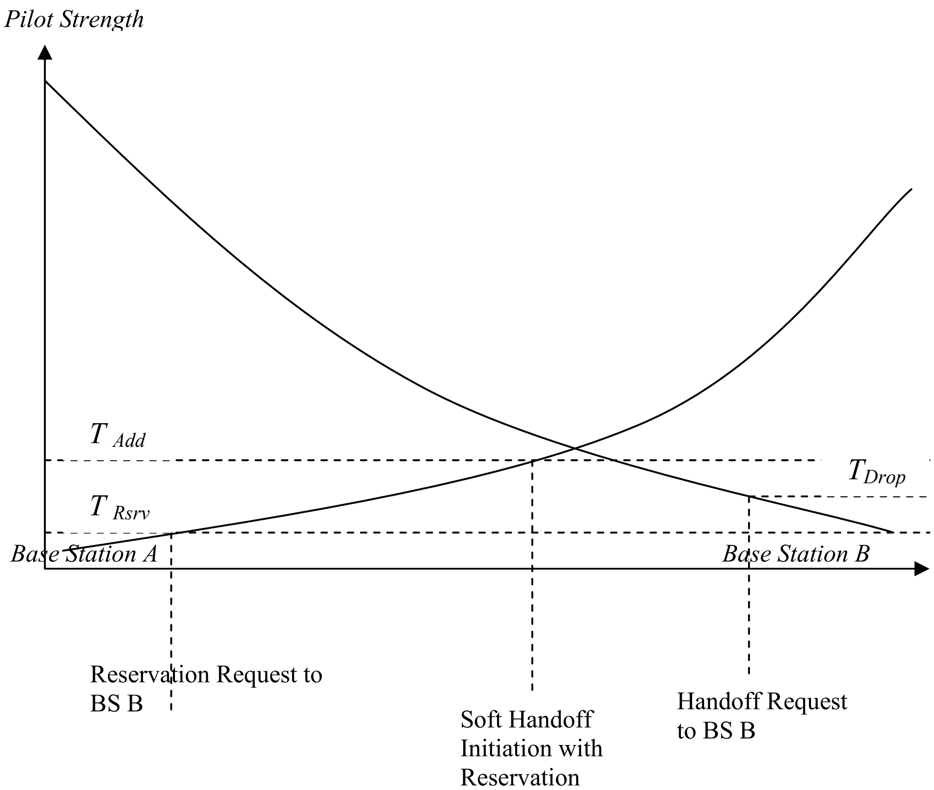


Figure 1. Reservation of channel capacity for soft handoff calls by a threshold mechanism of pilot strength.

The reservation threshold must be adjusted carefully. It should be less than the handoff request threshold so that the reserved capacity is available in the new BS when the mobile actually requests the capacity for soft handoff. However, if it is too low excessive unnecessary reservations can occur.

The proposed pilot-sensing reservation mechanism [4] will reduce unnecessary blocking of new calls with priority on soft handoff calls. However, system capacity also depends on the QoS service requirement difference between new call blocking and soft handoff failures. A weighting factor is used due to the higher relative importance of handoff calls over new calls. For a given weighting factor, system capacity is determined mainly by the new call blocking requirement, if the new call blocking requirement is higher than the weighted soft handoff failure probability requirement. On the other hand, if the weighted handoff failure probability requirement is higher than the new call blocking probability requirement, the excessive soft handoff failure probability requirement limits the system capacity. Thus, the system capacity is maximal when the new call blocking probability is equal to the weighted soft handoff failure probability.

Many studies use different approaches to keep a balance between the new call blocking probability and the soft handoff failure probability. The approach used in [4] is to control the size of minimum reservation capacity β_0, by counting the numbers of new call blocking and soft handoff failures. A "moving window" method is used to estimate the frequencies of new call blocking and handoff failures. In this approach, in successive time intervals, the number of successful/unsuccessful handoff calls and the number successful/unsuccessful new calls are counted and the minimum reservation capacity β_0 is determined accordingly. However, the difficulty in the method proposed in [4] is in selecting a proper size for the window-monitoring interval. Since the offered traffic is time-varying, a short interval may not support a sufficient estimation for determining the size of reservation capacity. On the other hand, the dynamic variation of the offered traffic makes the reservation process inefficient if the monitoring interval is too long.

User mobility profile prediction, i.e. predicting the probabilities that a mobile will be active in other cells in future moments, has gained considerable attention in the field of wireless communications. This information can be valuable for the successful handoff process, especially in those approaches, which use prior channel reservation for handoff calls. The prediction information can be used to assist the BS to maintain a balance between guaranteeing quality of service (QoS) to mobile users and achieving maximum resource utilization. In [5], a novel adaptive fuzzy logic inference system to estimate and predict the probability information for direct sequence code division multiple access DS/CDMA wireless communication networks is proposed. The estimation is based on measured pilot signal strength received by the mobile from a number of nearby BS and the prediction is obtained using the recursive least square (RLS) algorithm.

Previous research efforts in this field are mainly focused on statistics such as user location tracking [17], trajectory prediction, channel holding time, cell boundary crossing rate, mean handoff rate and cell residence time. What is different in [5] is that, the authors are more interested in the probabilities that a mobile user will be active in a particular cell at a future moment.

In general, if a mobile user is closer to a BS, then the propagation path attenuation from the mobile user to the BS is smaller and vice versa. Therefore, if the BS transmits a pilot signal with constant transmitted power then the received signal power at the mobile user carries the information about the distance between the mobile user and the BS. Since the probability that a mobile user will be active in a particular cell at a future moment is a function of the current distance between the mobile and its nearby base stations, the probability can be estimated based on real-time measurements of the received pilot signal power at the mobile. Moreover, the probability depends also on the mobile movement pattern (movement trajectory) since the movement of each mobile has a smooth trajectory most of the time. So, the location of a mobile user at a future moment depends on its location at the current moment as well as previous moments. Making use of these two facts, in [5] it is considered that it is possible to predict the mobility information of a mobile, based on the current and previous measurements of signal strength.

In [5], some important facts about the signal strength measurement technique are pointed out, which are not addressed in papers based on signal strength calculations [1, 2, 4, 9, 16, 20] that use a similar approach in estimating and predicting the next cell. There are some challenges in estimating and predicting the mobility information based on just the pilot signal power measurements because of a couple of facts. Normally there is no one-to-one relationship between the distance and probability. Even if such a relationship would exist, it is very difficult if not impossible to describe such a relationship accurately using mathematical expressions. There are fluctuations in the received signal level due to physical obstacles blocking the transmission path between the BS and the mobile user. Shadowing randomizes the relationship between the received pilot signal power, and the distance between the mobile and the BS.

In [19], the sources of received signal strength variation are addressed. These are, change in mean strength due to changing distance from the antenna, rapid variation due to constructive and destructive interference of signals arriving via different paths to the phone (fast fading), and slower variation due to obstructions (shadow fading). A simple model of the effect of temporal variation in signal strength on active-set membership, is developed in [19] for cellular phone systems that use the soft-handoff algorithm. This model is based on a steady state calculation.

The received signals are distorted by interference due to multiple users and due to background noise. Therefore the measured data are not absolutely accurate. Despite of these disadvantages, in [5] the signal strength measurement approach is still used in estimating and predicting the next cell. However, to handle the difficulty, in [5] an adaptive fuzzy inference system is proposed. The proposed approach deals with the uncertainty inherent in the relation between the distance and the probability, the random shadowing effect by using training data from real measurement or statistical models of practical propagation environments.

To handle the measurement error, the system incorporates the degree of certainty (or accuracy) of measurements by giving a larger degree of importance to the data with higher measurement accuracy. The main concern of [5] is to predict the mobility information of future moments with an adaptive fuzzy inference approach to eliminate the difficulties that arise due to using only signal strength information in determining the possible next cell. However, there some open discussion points about the method proposed in [5]. For example, the complexity of the fuzzy inference system may be a concern, especially when the prediction accuracy is wanted to be high. The increased implementation complexity makes the proposed system impractical for real-time application, which is, of course, not good for next generation mobile communication systems.

Similarly, in [21] fuzzy logic theory and neural networks are used. The intelligent call admission controller (ICAC) proposed in [21] contains a fuzzy call admission processor to make admission decision for a call request by considering QoS measures such as the forced termination (drop call) probability of handoff, the outage probability of all service types, the predicted next-step existing-call interference, the link gain, and the estimated equivalent interference of the call request. Also, the pipeline recurrent neural network (PRNN) is used to accurately predict the next-step existing-call interference, and the fuzzy logic theory is applied to estimate the new/handoff call interference based on knowledge of effective bandwidth method.

Approaches which reserves fixed amount of bandwidth (fixed number of channels) for handoff calls, cannot adapt to changes in the network conditions. This is clearly not suitable in the presence of burst data and emerging multimedia traffic. Therefore, an adaptive and dynamic bandwidth allocation scheme is essential in ensuring the QoS required. Several research studies are performed in the field of adaptive channel allocation. Many of the proposed dynamic bandwidth allocation alternatives involve heavy computational and signaling complexity due to updates in system status, or require complex topology processing [24] for next cell prediction, and information exchange between cells thus making them difficult to be used in actual deployment.

The alternative proposed in [6] as an adaptive and dynamic channel allocation scheme tries to overcome these deficiencies. The main features of [6] are: The estimation is done on-line and periodically, hence it can effectively adapt to changing traffic conditions, which is particularly suitable for multimedia type of services. Bandwidth allocation is implemented by a probabilistic mechanism, which can reserve the bandwidth in an efficient statistical manner. This eliminates the need for reserving bandwidth explicitly for each call setup. The power of this approach is in this periodic and on-line estimation, and in the statistical bandwidth reservation mechanism.

The on-line estimation algorithm of [6] aims to reduce signaling load required in most dynamic call admission algorithms. For example, some approaches require that a cell has to obtain status information, such as channel occupancy and traffic arrival rate, from all cells that have potential handoffs at the beginning of a control period. This requires a significant amount of signaling. To overcome this limitation, an on-line estimation algorithm is implemented, which restricts the use of actual information to those only from the local cell, while the statuses of the neighboring cells are derived by estimation rather than actual signaling.

The adaptive bandwidth allocation algorithm of [6] is executed in a distributed and periodic fashion, each cell executing identical algorithm based on local estimations. At the beginning of a control period, the bandwidth allocation algorithm determines the amount of bandwidth reserved in the next control period for the particular cell by taking the traffic conditions into consideration. So, the bandwidth reservation is done for all *potential handoffs* in a control period, eliminating the need for reserving bandwidth for each call. This enables a more efficient *statistical multiplexing* approach leading to a more efficient usage of the bandwidth.

In [7], another way of dynamic channel reservation scheme is proposed to improve the utilization of wireless network resources while trying to guarantee the required QoS for handoff calls. The wireless channels are dynamically reserved by using the "request probability" determined by the mobility characteristics and "channel occupancy" to guarantee acceptable quality of handoff calls and keep the new call blocking probability as low as possible.

In [7], it is pointed out that handoff will occur more frequently in next generation mobile communication networks because the cell size is much smaller to support high capacity on the limited radio spectrum. As the handoff rate increases, bandwidth management and traffic control strategy, that is, call admission control, handoff procedure etc., become more challenging problems. Dropping probability of handoff calls and blocking probability of new calls are considered also in [7] as critical QoS parameters. From the subscriber's point of view, forced termination due to handoff failure is considered to be less desirable than blocking out a new call. Therefore, just like many other dynamic channel reservation schemes, in [7] it is proposed to guarantee a QoS for handoff calls while allowing a high utilization of wireless bandwidth. The paper [7] describes two of the generic handoff prioritization schemes, among many channel allocation schemes, as recent intensive research areas on channel allocation, namely the *queuing handoff request* and *reserving a number of channels exclusively for handoff requests*. In general, handoff prioritization schemes result in decreased handoff failures and increased call blocking, which in turn, reduces total admitted traffic.

In the handoff queuing scheme (HQS), it is assumed that there is a time interval where the mobile spends some time in the handoff area. Thus, queuing of the handoff request is possible, where it is physically capable of communicating with both the current and the next BS. The fact that successful handoff can take place anywhere during this time interval makes a certain amount of tolerance in the delay for the actual channel assignment to the handoff request. New calls, which originate within the cell, are blocked if all wireless channels are occupied and are served only when a wireless channel is available and no handoff request exists in the queue. Obviously, HQS can reduce the probability of forced termination (so called in [7], other papers usually call this handoff failure), however causes increased call-blocking probability. The reason is that no new call is granted a wireless channel until all the handoff requests in the queue are served.

Another priority scheme is the fixed guard channel schemes (GCS), which gives higher priority to handoff calls by assigning them a higher capacity limit, to reduce the forced termination probability. Fixed GCS shares normal channels between handoff and new calls, and reserves exclusively some *guard channels* for handoff calls. Because fixed GCS is developed under stationary call arrival assumption, it causes a reduction in the total carried traffic under non-stationary traffic patterns due to fluctuation in the mobility.

The approaches studied from [1] to [6], do not take into account the characteristics of network traffic and user mobility. In [7] a dynamic channel reservation scheme (DCRS) is presented to guarantee the required dropping probability of handoff calls while keeping the blocking probability as low as possible. The key point in [7] is that, although the proposed method shares normal channels between new calls and handoff calls, and reserves guard channels for handoff calls, just like GCS, the guard channels reserved for handoff calls can also be used for new calls depending on network status and mobility of calls. The paper [7] defines a *request probability* that is used to allocate guard channels to new calls. This request probability of new calls is adaptively determined according to the mobility of calls, total number of channels in a cell, threshold between normal channels and guard channels, and current number of used channels. The flow diagram of call processing for the DCRS scheme is illustrated in Fig.2.

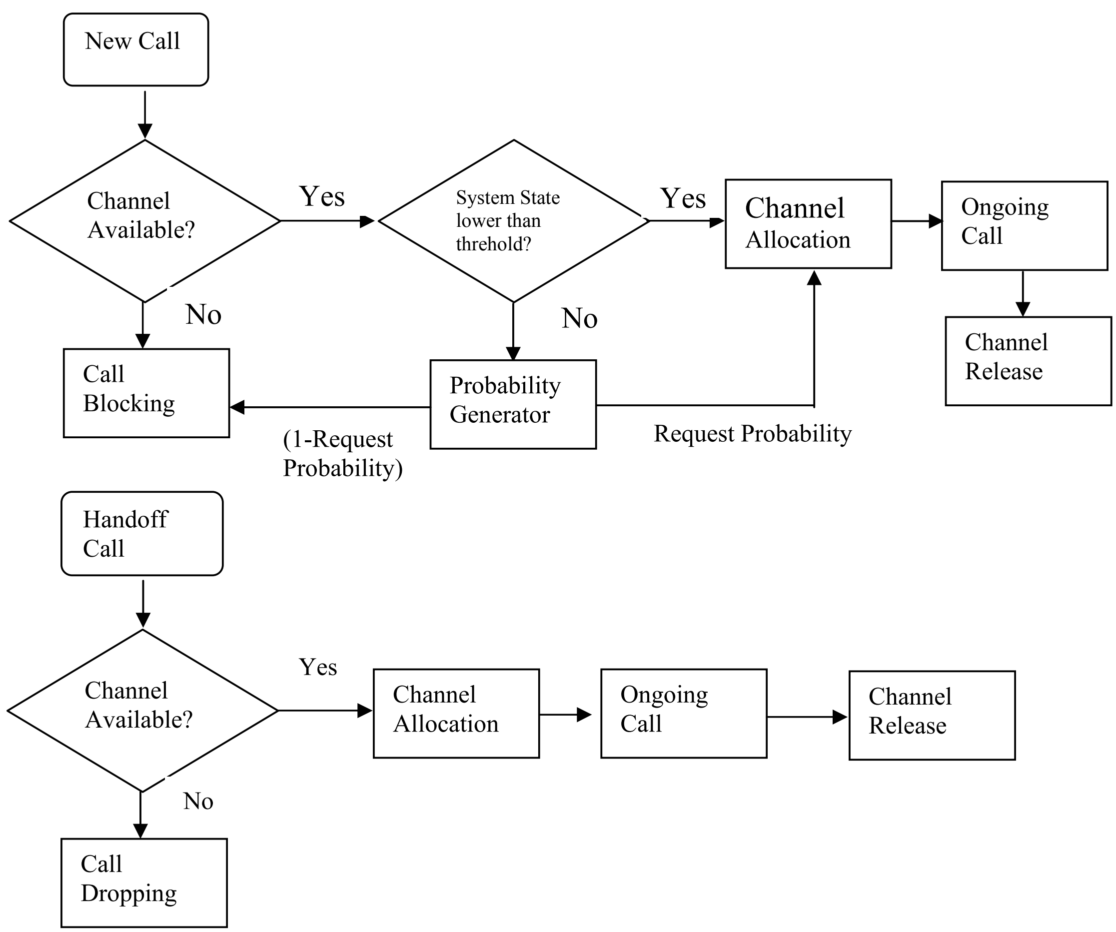


Figure 2. Call processing flow diagram for DCRS

As stated before, the current trend in cellular communication networks is to shrink cell size to accommodate more mobile users in a given area. This results in more frequent handoffs, and makes connection level QoS more difficult to achieve. The important connection-level QoS parameters are the probability of blocking newly requested connections and the probability of dropping handoff calls because of unavailability of channels in the new cell.

Since it is practically impossible to completely eliminate handoff drops, the best one can do is to provide some form of probabilistic QoS guarantees. Several studies have been performed in this field. In [8], five different recent schemes for reserving bandwidth for handoff calls and admission control for new calls are compared.

First two schemes compared in [8] are based on the estimation of handoffs that may occur during a specific time window. In the first scheme, which is referred as CHOI (after the name of the developer), the BS of a cell calculates the required bandwidth to be reserved for anticipated handoffs form adjacent cells upon arrival of a new connection request. The mobility, which is the handoff behavior, of each user is estimated using a history of handoffs observed in each cell. In the second scheme, referred to as NAG (distributed admission control), the BS not only considers incoming handoff from adjacent cells, but also outgoing handoffs to adjacent cells. The BS then calculates the total required bandwidth in its cell for both handed off and existing connections. These schemes were evaluated based on (1) an exponentially distributed time each mobile stays in a cell; (2) the perfect knowledge about the mobility and lifetime of each user connection. However, these two assumptions do not hold in reality.

The third considered scheme is an admission control scheme, referred to as AG (Absolute Guarantee), which guarantees no handoff drop for any existing connection. In the first two approaches it is not possible to eliminate completely handoff call drops. AG on the other hand eliminates totally handoff failure. “No handoff drop” can be achieved by checking bandwidth availability and reserving bandwidth in all cells the mobile requesting a new connection is to traverse in future. It is practically impossible to know all these cells in advance during the call admission phase. In [8], it is shown how costly it is to make the handoff drop probability zero even under the impractical assumption that all the cells that a mobile will visit are known during call admission.

The fourth admission control scheme, known as BHARG (Per connection reservation in next cell after admission), is based on per connection bandwidth reservation. Unlike the first three approaches, this scheme predicts the next cell the mobile will move into and the mobile's per connection bandwidth is reserved in that cell.

The last admission control scheme, referred to as NCBF (Next Cell Bandwidth Reservation First), is similar to BHARG. In this scheme, both the current cell and the predicted next cell along the path of the mobile that is requesting a new connection should have enough bandwidth to accept the request whereas BHARG requires that only the current cell has enough bandwidth. In [8], it is shown that NCBF and BHARG are still costly compared to the first two approaches.

The approaches compared in [8] use mobility estimation based on history of handoffs observed in each cell. However, in predicting the next cell, only a single previous cell is considered.

In [9], a different approach is presented for the handoff problem in wireless networks. Signal strength and next cell prediction techniques are combined to eliminate unnecessary handoffs and reduce the mean number of handoffs in dense urban areas.

Small cell size, like in micro-cell and pico-cell environments, results in more boundary crossings for the mobile, which in turn results in increased number of handoffs between base stations. This, of course, increases the network load and under heavy traffic conditions could cause the call to be dropped. In [9], the starting point is the following fact: If it were possible to determine a candidate BS in advance and then predict the signal strength values from this BS to the mobile, a considerable reduction in mean number handoffs could be achieved. Signal Strength prediction and Next-Cell prediction techniques are used in [9] to determine this next BS correctly in advance. In the proposed approach, the number of handoffs to each BS is recorded and updated recursively. This has the effect of increasing the handoff weight to each BS, a measure that can be used to prioritize and select a Most Likely Cell (MLC). Signal strength estimates from this cell can then be obtained, which are used to predict critical handoff instants.

For the next-cell prediction, [9] uses an approach used in some previous studies. Their approach is to predict the next visited cell, based on history of handoffs of users and cells. These histories are aggregated in a profile server into mobility profiles, which subsequently are expected to reflect the mobility pattern. These are then used in the prediction process. The network is partitioned into zones, with each zone including a profile server. The profile server and BS exchange control messages to build handoff histories of users and cells. The BS has the task of selecting the next-cell for the handoff user.

Once the next cell is found, signal strength estimates will be obtained and utilized to predict the handoff request time instant. The received signal strength from BS on the down link decays exponentially and slow fading associated with this signal strength being highly correlated can be predicted easily. This information is then used to predict the instant of handoff request. It is shown that such a signal strength prediction method can eliminate unnecessary handoffs and in this way can reduce mean number of handoffs. The success of the approach proposed in [9] depends on the order of the predictor. Higher order predictors can detect even deep fades and prevent unnecessary handoff requests under such deep fading cases, at the expense of increased computational complexity.

There are many other working areas dealing with other aspects of the handoff process or handoff procedures in wireless communication systems. These can be grouped as wire-line resource management studies, wire-line bandwidth allocation schemes, call admission control for QoS provisioning, path rerouting, path extension and route optimization upon handoff, guaranteeing loss-less or minimum delay (low latency) handoff, traffic modeling etc. Details of these other areas will not be considered during this study.

However, it is important to point out that new and innovative approaches are needed in order to improve channel utilization in networks where cell sizes are small and there are considerable amount of cell boundary crossings due to high mobility of users. These can be classified as 1- Better estimation of user behavior, 2- improved estimation of user position and user movements. The former requires cooperation of individual mobiles since only the mobile can provide detailed statistical data. The latter implies incorporation of GPS type of capabilities in mobile devices which can provide better information on user position and movements then signal strength measurements or other similar techniques.

CHAPTER II

THE PROPOSED METHOD

As explained in the introduction, new approaches are needed in resource allocation in cellular networks. A novel approach, which employs statistical information collected by mobile terminals, is explained in detail in this chapter. It is presented in three sections. Section 2.1 describes the details of subscriber profile prediction and in section 2.2; details of resource reservation process are presented. Finally, in section 2.3, details of the new call admission process is presented.

2.1 Subscriber Profile Prediction

Previous research effort on mobility information have focused on methods like the probability that a mobile terminal will be active in a particular cell at future moments [5], signal-strength based next cell prediction [4], signal-strength based handoff decision algorithm [20], mobility model [3], user location tracking [17], signal-strength based handoff prioritization [16], and trajectory prediction [2, 22]. All these methods depend mainly on the strength of the pilot signal received by the mobile. Relying just on received pilot signal strength alone cannot provide reliable information about the next cell to be visited. Furthermore, it gives no information about the possibility of call termination before a possible handoff. Depending on several factors like the individual user, called party, service type and cell size, the call may or may not have a high handoff probability before reaching the cell boundary. An illustrative example is the case of mobile from a small town with an active voice call and a mobile along a highway with an active high-speed data application. The mobile on the highway will have high handover probability and possible over several cells whereas a mobile from the small town will have a very small handover probability. To overcome such difficulties, it is proposed that each mobile keeps mobility statistics (that is, cells visited, time of visit, called subscriber and service specific average call durations, call elapsed time for the active call, average distance traveled, average speed etc. Based on this information, the cell transition probabilities, and thus prediction of next cell to be visited, could be obtained for each mobile in a more accurate way.

One way to obtain cell transition probabilities is the following approach. Let C_i denote the cell that the mobile is currently in. Next, the mobile will visit one of the neighbors of C_i. This cell will belong to the set C, where C is the set of all cells visited before and their neighboring cells. Each mobile keeps track of the frequently visited cells in order to avoid C becoming excessively large. Hence, a first time visited cell will be put on a temporary list and if not visited again within a certain time, will be deleted from the list. For each of the cells frequently visited, the mobile keeps transition probabilities form the current cell C_i to the cell C_j, where C_j ε C^K, where C^K ε C is the set of all neighboring cells of C_i. When being in cell C_i, the mobile will pass to one of the K neighbors of cell C_i. Thus,

$$\sum_{k=1}^{K} P_{ik} = 1 \tag{1}$$

In Fig 3, the probability of transition for a mobile, from cell C_i to its neighbor C_{i2} (which is the second neighbor, k=2 among K=6 neighbors) is illustrated.

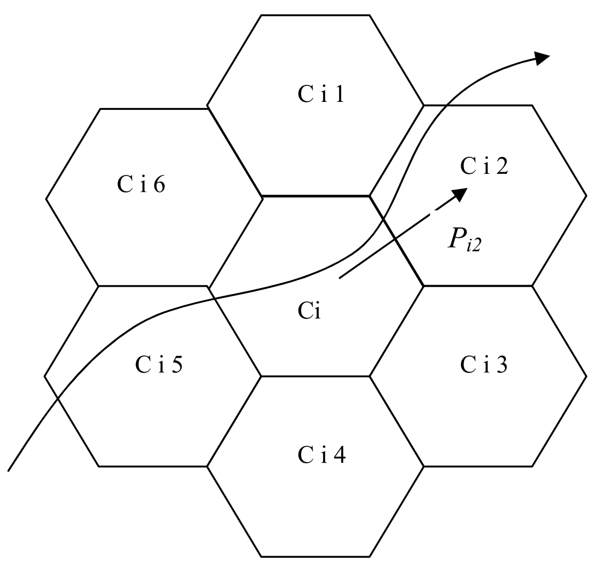


Figure 3. Transition probabilities in a hexagonal cell structure.

These probabilities can be represented as a probability array, defined over the subset of neighbors. Let

$$P^{C_i} = \{P_{i1}, P_{i2} \dots P_{iK}\} \tag{2}$$

denote the transition probabilities of the mobile visiting a certain cell C_i. Here, K is the maximum number of neighbors. Hence, each mobile will be required to store a K x M matrix, where M is the number of frequently visited cells. This matrix is defined as the transition probability matrix; H_m. H_m is the "Mobility State" of the mobile. Therefore;

$$H_m = \{P^C0, P^C1, P^C2, \dots , P^CM\text{-}1, P^CM\}^T \tag{3}$$

Entries of the Cell Transition Probability Matrix are the cell transition probabilities P_{ij}, which represent the probability of a transition from cell i to cell j. P_{ij}, represents the probability of passing to cell j when being in cell C_i. Therefore, with each cell transition the mobile derives P_{ij} and puts it into the corresponding fields of H_m. To derive P_{ij}, the mobile keeps counters N_i for each cell C_i, and counters T_{ij} for each cell pair C_{ij}. The mobile will increment the counter $N_{i,}$ with each visit to cell C_i, and will increment T_{ij} for each transition from cell C_i to C_j. The P_{ij} is then derived as:

P_{ij} = (total transitions from C_i to C_j) / (total visits to C_i)

$$P_{ij} = (N_i / T_{ij}) \tag{4}$$

It is important to develop a policy for which cells to keep mobility statistics, which cells to ignore, when and how to reset counters. We propose to ignore all cells, which are not visited at least 3 times during a certain time period, say six months. Moreover, all entries will be kept in FIFO type data structures, to ensure that older transitions are deleted automatically as newer ones are added to the statistics.

By keeping track of the cell transitions, each MT "learns" actually its own mobility pattern. In this aspect, this method is also suitable for a neural network implementation approach and provides more accurate information about the mobility of each individual mobile.

It was demonstrated by simple calculations that, storing mobility statistics and transition probability information does not take much of the resources available in today's mobile terminals, i.e. hand held devices. Therefore, mobile terminals are assumed to have enough resources to handle these calculations.

When entering a new cell, the mobile will inform the new cell, via the signaling channel, about the cell transition probabilities, by transferring the corresponding row of the mobility state H_m to the BS of the current cell. It is just a simple array of data that is sent to the BS of the current cell, in order to inform it about the intent of the corresponding mobile to visit which cell next. No much signaling or computational complexity is involved in this process, and is very simple compared to the methods that were examined so far.

In this way, the mobile informs the BS of the new cell, which cell or cells and with which probabilities it will most likely visit after this current cell. The BS of the current cell will then use this information together with others, to decide on the next cell, and to decide whether to make a reservation request to the corresponding neighboring cell or not. When the mobile leaves a cell H_m must be updated accordingly, to reflect the latest transition. The mobile will increment the corresponding counters and update H_m when making a new transition.

Depending on the relative magnitudes of the transition probabilities P_{ij}, the BS of the current cell C_i can request reservation in more than one cell to improve handoff success probability and thus reduce handoff failure probability. Paper [1] compares different approaches in reserving BW in one or more than one cell to increase success probability. In [1], it was shown that making reservation requests only in the highest probable neighboring cell, compared to other methods, like reserve-uniform or reserve-max2, results in highest resource utilization, with acceptable QoS performance. We will follow a similar approach. Once decided on the next cell, the BS of the current cell will inform the BS of the next cell about the reservation need, using wire-line resources where possible not to consume wireless resources.

Under normal conditions we agree that terminating a handoff call is more critical from the user's (subscriber's) point of view as compared to blocking a new call. All call prioritization schemes are based on this fact and try to guarantee an acceptable QoS (a low handoff failure probability). However, under distressed conditions it might be critical to enable as many new users as possible to get service from the network. This might also be necessary to let the network survive under some special distressed cases like natural catastrophes etc.

Under such conditions, the dynamic structure of the bandwidth management scheme must allow changing the network policy, by for example, restricting calls in duration and enabling as many new calls as possible to get service from the network. The dynamic channel management scheme that is proposed can adapt easily to changing network and user mobility conditions, including distressed conditions. Under such conditions the precautions that is proposed is, first of all, to restrict all calls in duration in the whole network or in the region where such distressed conditions exist. Second, the handoff channels, which were actually reserved for handoff calls, will be handled just like normal channels, enabling them to be used by both new calls and handoff calls without limitations. Since under distressed operation conditions it is important to provide service to a maximum number of users, there is no need to reserve bandwidth for possible handoff calls, some of which may not result in actual handoffs at all, which would cause poor bandwidth utilization.

The expected call duration is an important criterion for the decision whether or not to reserve bandwidth in the next cell for the ongoing call. The expected call duration information, the elapsed time of the current call, the velocity information of the mobile and cell coverage information will be used to decide on whether the call will terminate before the mobile will actually reach the cell boundary or not. In this way, it will be possible to decide whether there will be no request for handoff, or the call will continue beyond the cell boundary and therefore handoff will be requested. If the call will continue also in the next cell, then reservation must be made in the next cell to guarantee a desired value for the handoff failure probability.

The mobile itself, based on the past history of calls that the mobile performs, derives the expected value of a call. Each mobile will store a "Subscriber Average Call Duration, S_{av}" for "n" number of most frequently called and/or calling subscribers, mobile or not, separately. The subscriber average call duration on the initiated or received call by the mobile will be reported to the network as the expected value of the corresponding call. The mobile will store also an "Average Call Duration, D_{av}" which is the average of all infrequently used calls. This average will be used as the expected value of the calls that are performed with users that are not in the list of most frequently called/calling users or users that are called or calling for the first time.

Since the expected value of a service will not only depend on the called/calling party but also on the service type itself, the average call or service duration will be stored and reported to the network by each mobile, for each service type separately. It is obvious that service types like voice, data or multimedia will have different expected service duration. Thus, average values will be kept for different types of services separately. Using call duration information in deciding on the need for reservation is more important for long duration services like videoconference or mobile Internet. It is obvious that, if the service started is a videoconference it will take a longer duration compared to an ordinary voice call. Therefore, the expected call duration is valuable information for the network for the decision whether to reserve bandwidth for the expected handoff call in the next cell or not.

Keeping call averages becomes more important for small cell size environments in which mobiles are moving fast. In such cases, the call may continue in several successive cells, which means there will be many handoffs for the same call. It is considered that, system performance can be improved by requesting bandwidth reservations in successive cells for a call that will continue to get service while the mobile passes through those cells. The improvement is expected to be in terms of handoff failure probability.

It should be noted that, for small cell size environments and high speed mobiles, it is important to get information about the next cell along the path of the mobile, as early as possible. For a mobile that is moving fast in small cell size environments, the sojourn time, that is the time that a mobile remains in a cell, may not be long enough to perform the necessary reservation in the next cell on time. Reservation in successive cells can be considered, as an alternative approach. Such a reservation should be based on accurate next cell prediction. Otherwise, may bring unnecessarily large amount of processing load to the current BS. However, this difficulty can be overcome by transferring more than one row of transition matrix H_m stored by the mobile. Then, the current BS will be able to estimate successive next cells sequentially and request reservation from the BSs of cells in question.

However, just the received pilot signal strength information itself, although being widely used in classical methods to decide on the next cell, is not adequate by itself. Received pilot signal strength information gives a correct and good idea about the next cell only when the mobile is considerably close to the new cell boundary. For today's low-speed data or voice only mobile communication systems this may not be a problem. However, for next generation mobile communication systems, supporting high-speed data and multi-service/multi-connection services, it could be too late to perform efficient resource allocations. Thus, for the next generation systems many studies are performed to find out the next cell as early as possible, without relying just on the received pilot signal strength information.

The received pilot signal strength information alone can also be misleading due to random shadowing effects, interference by other users, fading, geographical obstacles or due to the fact that signal strength will not change much when the motion is tangential to the BS center (actually to the BS antenna) which may result after a while in a sudden cell change, especially when the cell has just a sectored coverage. So, for correctly deciding on the next cell and for making necessary and timely reservation, it is important to have prior information about the next cell, besides the signal strength, long before the mobile actually reaches the cell boundary. In this context, cell transition probabilities, combined with GPS data, whenever available, can bring very powerful tools in next cell estimation in a timely manner. It is our conjecture, that the method we propose based mainly on each mobile keeping its own mobility state and mobile statistics, and using this information in conjunction with the received pilot signal strength information or GPS data, could provide an efficient mechanism for the early and correct next cell prediction.

2.2 Resource Reservation Process

Besides deciding on the next cell along the path of the mobile and performing necessary reservation requests, an efficient resource management algorithm is needed that will take into account the reservation requests, and that will perform resource reservation according to changing user mobility and network traffic conditions. Fixed channel reservation schemes described in literature do not adapt to changing user mobility and traffic conditions. Hence, they either cause high new call blockings, or inefficient utilization of radio channels by reserving more than necessary number of channels. Reported dynamic channel reservation approaches that have been studied, try to adapt to the changes in the current traffic and user mobility conditions, however do not take into account the number of expected handoff calls. Therefore, one of the motivations in this study is to have improved QoS in terms of P_f (handoff failure probability) performance, while at the same time to maintain a high level of resource utilization, by preventing unnecessary new call blockings, which in turn improves P_b (new call blocking) performance. This will be achieved by the resource reservation mechanism proposed, which makes use of the next cell prediction method proposed in section 2.1, and takes into account the reservation requests besides the current mobility figures of the environment. Unnecessary new call blockings that are observed in reported DCR methods, will be handled by the new call accept probability implementation, and is detailed in section 2.3.

To improve performance, we both adjust the number of reserved radio channels and control the admission of new calls to the system, taking into account the network traffic and user mobility conditions. Moreover, we also take into account the handoff reservation request which come from individual mobiles that are, with a high probability, start of a new handoff attempt. We define the user mobility (α) and incorporate the above factors into it by using the equation

$$\alpha = (\gamma_1 \text{ x } \lambda_h + \gamma_2 \text{ x } \lambda_{hrq}) / (\lambda_n) \qquad 0 < \gamma_1, \gamma_2 < 1 \tag{5}$$

Here λ_n, λ_h and λ_{hrq} are the new call arrival rate, handoff call arrival rate and the handoff reservation request rate, respectively. γ_1 and γ_2 are the weighting factors. As seen from this equation, we define α as the ratio of the weighted sum of handoff call arrival rate and handoff reservation request arrival rate to the new call arrival rate. For the weighting factors, different values are considered and evaluated in the performance analysis part. As it will be detailed in the performance analysis part, we believe that this is a fair and realistic definition for our purpose. This user mobility definition is used in both the resource reservation process, and in the new call admission process.

All channel reservation methods try to reserve some number of radio channels explicitly for handoff calls. In this study, the number of reserved channels for handoff calls is calculated using the dynamic threshold concept. We denote the dynamic threshold as m. The dynamic threshold, m is defined as the boundary between standard channels and reserved channels. Therefore, m determines the number of regular channels and (C_{max}-m) is the number of channels reserved, where C_{max} is the maximum number of channels. In this study, m is not fixed, as in [7], but changes dynamically depending on changes in the user mobility, network traffic and the relative magnitude of the handoff reservation requests. Those changes are implemented in the α definition, which is used to adjust m. Data collected from real operational environments showed that, from time to time the network traffic and user mobility figures in an operational environment can switch back and forth between some values, instantaneously. Therefore, instead of using directly the α value to adjust m, we use a sliding window average of it. The sliding window average $\alpha_{av,i}$ of α, in the i^{th} time interval is defined as:

$$\alpha_{av,i}=(\beta_{i-1} \text{ x } \alpha_{i-1} + \beta_{i-2} \text{ x } \alpha_{i-2} \ldots + \beta_{i-Nwin} \text{ x } \alpha_{i-Nwin}) / N_{win} \tag{6}$$

Here N_{win} is the number of past α values to be included in the moving average and β_i's are the weighting coefficients. T_{win} is the duration of time interval during which α is updated. α_i is the user mobility measured at the end of the ith time interval using the actual handoff and new call arrival rates. $\alpha_{av,i}$ is the moving average valid for the i^{th} time interval, calculated from the past values, at the end of the $(i-1)^{th}$ time interval. This is illustrated in Fig.4.

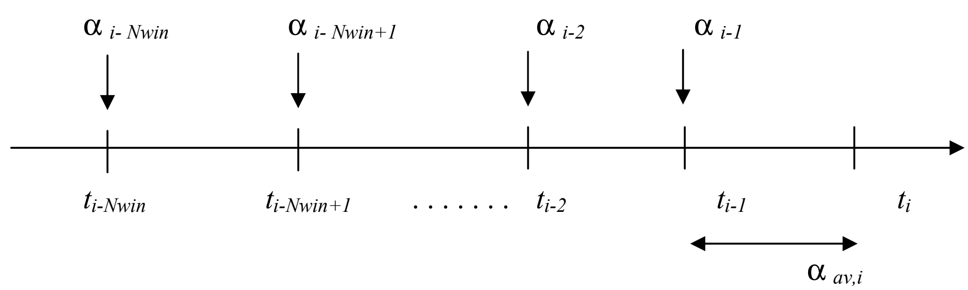


Figure 4. Sliding window average for the user mobility.

It is a very difficult problem to choose appropriate sizes for N_{win} and T_{win}. Since the offered traffic and user mobility are time varying, a short interval and a small number of past α_i values may not support a sufficient estimation for the determination of a proper channel reservation. On the other hand, the dynamic variations in the offered load and user mobility make the channel reservation process inefficient if the monitoring interval is too long. To overcome this difficulty we propose to use a two-way approach in the resource management process. Sufficiently large values are taken for N_{win} and T_{win} so that *m* will reflect the long-term average of the user mobility. More dynamic variations in the user mobility and traffic conditions will be taken into account in the implementation of the new call accept probability concept, as illustrated in Fig.5. The new call admission process is explained in the next section.

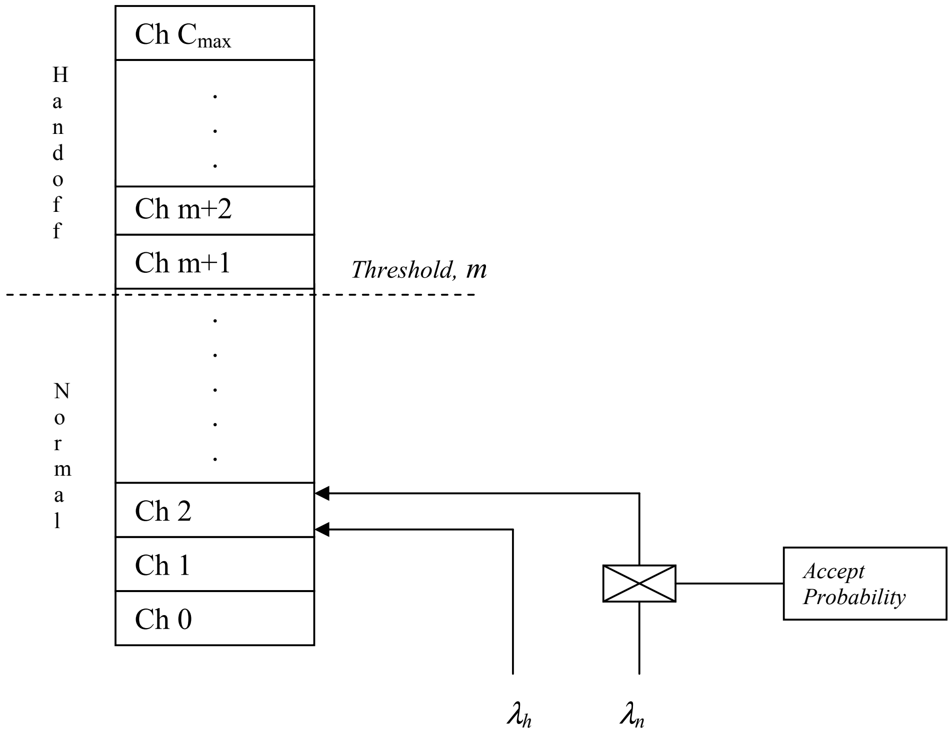


Figure 5. New call admission and resource reservation

The calculated sliding window average value of the α in each time interval is used to adjust the threshold, *m*. The threshold to be used in the next time interval is calculated as:

$$m_{i+1} = Int\ \{m_i - Int\ (((C_{max} - m_{min})/C_{max})\ x\ \log \alpha_i)\} \tag{7}$$

m_{i+1} must be checked each time and kept between C_{max} and m_{min}. Here, the C_{max} is the maximum number of radio channels of the cell (maximum value of the threshold) and m_{min} is the minimum allowed threshold value. The threshold will be adjusted dynamically and kept between these minimum and maximum values.

2.3 New Call Admission Process

In reported work in this field [4, 6, 8, 9], new call attempts are totally blocked when the entire regular (i.e. not reserved) channels are occupied. In these methods, once the system state is above the threshold, independent of the user mobility and network traffic conditions, new call attempts are totally blocked out.

This aims, of course, to increase handoff success. However, it will result in unnecessary new call blockings, which leads to very poor bandwidth utilization, especially when there are only reserved channels free, with relatively many new call arrivals compared to handoff call attempts. In the proposed approach, once the regular channels are full, free reserved channels will be shared between handoff calls and new calls. Under these conditions, a new call will be accepted with a new call acceptance probability P_{ac}, the new calls accept probability. In this study, while the dynamic threshold m reflects long-term variations in the user mobility and network traffic conditions, P_{ac} deals with the short-term variations. This implementation aims to prevent unnecessary blocking of new calls, to increase resource utilization, and to reduce P_b. Following a similar approach as in [7], P_{ac} is calculated as follows:

$$P_{ac}=\mathrm{Max}\{0,\alpha[(C_{max}-i)/(C_{max}-m)]+(1-\alpha)[\mathrm{Cos}((2\pi(i-m)/4(C_{max}-m))]^{1/2}\} \quad (8)$$

Here, α is the user mobility, m is the threshold; C_{max} is the total number of channels in a cell, and i is the currently occupied number of channels, that is the system state. P_{ac} is calculated for each time interval. Handoff calls are always accepted provided that there are any free channels. The case is different for new calls. If the system state is below the threshold ($i<m$), new calls are accepted without any restriction, as in other approaches. However, if the system state is equal, or above the threshold ($i>=m$), then, unlike other approaches, new calls are not totally blocked out and are still accepted by P_{ac}.

The simultaneous use of the dynamic threshold and new calls accept probability leads to high level of QoS and efficient resource utilization. It is important to note that, the accept probability is an instantaneous value that determines how channels are instantly granted to new calls and handoff calls. The threshold, on the other hand, is the limit between normal channels and handoff channels, and is a statistical long-term average determined from the user mobility and traffic conditions in the area. For high user mobility, meaning there are more handoff calls than new calls, P_{ac} drops faster with increasing system state, to give higher chance to handoff calls. On the contrary, for low user mobility, meaning there are more new call attempts than handoff call attempts, P_{ac} drops slower with increasing system state, to give higher chance to new calls.

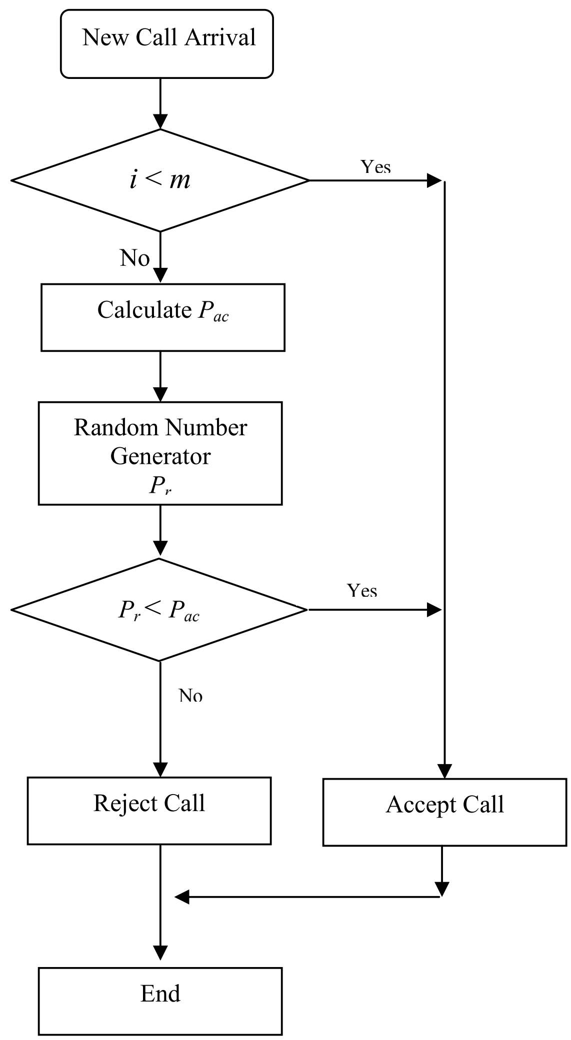


Figure 6. New calls admission process algorithm

In this way, we try to prevent unnecessary new call blockings, which results in very poor bandwidth utilization, especially in such cases where the system state is above the threshold and the user mobility is very low. The new call admission process algorithm is as shown in Fig.6

New call admission process makes use of a probabilistic approach. P_{ac} is a calculated value, which is derived using (8). P_r is the output of a random number generator. The decision criteria whether to accept or reject the new call depends on the relative magnitudes of the calculated P_{ac} value and the generated random variable P_r. The call is accepted if $P_r < P_{ac}$, and rejected otherwise. Fig.7 illustrates this decision criterion.

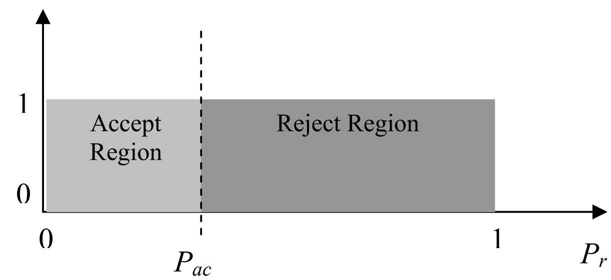


Figure 7. Decision criteria for accepting new calls

Based on this criterion, new calls are accepted with P_{ac} probability and are rejected with (1-P_{ac}) probability. In this way, instantaneous variations in user mobility and network traffic conditions are compensated for. Moreover, free reserved channels that would normally remain empty and unutilized, are granted to new call attempts, as required.

CHAPTER III

OPERATIONAL FIELD DATA

The proposed approach and any other approach presented in published works, assumes certain operating conditions in cellular networks. However, none of the approaches studied do not base their analysis on actual statistical data of network operators. In order to investigate the validity of proposed technique, it was felt necessary to study the real operating data from one of the operators in Turkey. Once this data is analyzed, then, the results could be used as guide lines in our studies.

For that purpose, data that was collected by one of the 1800 MHz GSM service providers in Turkey was obtained. The received data from the operator were categorized into two sets:

1. The first set consisted of recorded data on a 24-hour basis from 6790 cells nationwide. This data set covered a wide range of information, such as new call arrivals, handoff call arrivals, number of successful new call assignments, number of successful handoff establishments, number of blocked calls, number of dropped calls, mean call holding times and total network traffic in Erlang.
2. The second set consisted of data that was recorded from a cluster of cells located in a business area (Kızılay) in the downtown region of Ankara. This set consisted of non-stop data collected over one-week duration, with per hour averages of total network traffic, blocked calls, dropped calls, handoff traffic, successful handoff attempts, and handoff failures.

The figures of the real operational field data analyzed are included in Appendix-A, as reference. In Appendix-A.1, we have presented the figures of the one-week data from the cluster of cells located in the downtown region. These are related to total traffic in Erlang, and include blocked new call attempts, and dropped calls. In Appendix-A.2, we have presented the figures of the one-week data from the cluster of cells located in the downtown region. These are related to handoff traffic and include successful handoff attempts, and handoff failures.

In Appendix-A.3 to Appendix-A.6, statistics about nationwide 24-hour data are presented. The analyzed actual reports cover the whole 6790 cells. Since the actual reports are very large, in Appendix-A.3 to Appendix-A.6, we have presented just some samples. Appendix-A.3 shows total cell to cell handoff report. Appendix-A.4 shows the cell to cell handoff type report, and Appendix-A.5 shows the cell to cell handoff reason report. Finally, in Appendix-A.6 we have presented the cell TCH traffic channel report, which covers very detailed information about total cell traffic.

Careful categorization and detailed analysis of this data showed some important facts. These are summarized as follows:

1. Network traffic, in terms of new calls and handoff calls, is time and location dependent, and shows a wide range of variations, including instantaneous step variations.

2. Depending on the area where the cell is located, very high user mobility figures are observed.

3. Even on a Sunday, Handoff failure rates in the today's GSM network can reach high values that would normally be not acceptable in the next-generation mobile communication systems.

4. Handoff call statistics were derived from the nationwide 6790 cells, on 100.865 cell intersection. During 24-hours, a total of 2.290.249 handoff attempts were observed, with 138.573 unsuccessful handoffs attempts, or 6,05% handoff failure.

5. The overall network traffic is observed to be somehow predictable and periodic on a 24-hour basis.

6. Noticeable utilization of the mobile network starts at around 07:00, in general.

7. Handoff arrival rate reaches as high as “eight calls/minute”. Large variations in handoff arrival rate, as much as 150% increments in one hour, or 50% decrease in one hour was observed.

All these observations prove the need for a highly dynamic bandwidth management approach. The need is more critical for the next generation mobile communication systems, because it is expected that 3G mobile networks will support applications with a wide range and unbalanced nature of network traffic (biased towards the downlink for multimedia traffic), and will face to diversified traffic load between cells, like hot-spot cells, and instantaneous step variations in user mobility and bandwidth demands.

The nationwide 24-hour data, as well as the one week data from the highly utilized cluster of cells, showed that even for the current GSM network which have larger cell size compared to cell sizes in next generation mobile communication networks, the handoff call arrivals can be really high. Moreover, both the new call arrivals and handoff call arrivals are very much time dependent. An efficient resource management algorithm must be able to cope with all these important facts. Therefore, we have done the performance analysis under such conditions that will cover the user mobility and network traffic conditions from real operational field.

CHAPTER IV

PERFORMANCE ANALYSIS

The radio spectrum used by the current cellular networks is both expensive and limited. In third generation systems, the radio bandwidth is increased. But, finite capacity will probably continue to be a bottleneck. Present and future networks have to preserve minimum level of QoS during their operations. There are two important QoS parameters that can be used as a measure of QoS. These are the handoff dropping probability P_f, and the new call blocking probability P_b . The performance analysis done in this section was based on these QoS parameters. Section 4.1 details the key aspects and parameters of our study. In section 4.2, the derivations of the analytical model of the system are obtained and the theoretical analyses are based on these system models. Section 4.3 gives information about the software simulations. The results of both the mathematical approach and the software simulations are given in chapter 5.

4.1 Definition of Parameters

4.1.1. New call arrival rate, λ_n

We consider a homogeneous system where the arrival of new calls forms a Poisson process with the arrival rate λ_n per cell. The Poisson process arrival rate approximation for the new calls emerging in a cell is a valid approximation provided that the number of non-communicating mobiles in a cell is much larger than the number of available channels. For performance analysis purposes, number of available channels is assumed to be, for example, 20 in [3], and 5 in [8] with a total 50 non-communicating users. However, in this study we use much larger range of values for λ_n. This range of values for λ_n is taken from real operational environment, as explained in section 4.3. Moreover, we will analyze the performance of the proposed solution, even for unrealistic values of λ_n, to be able to cover extreme operational cases. This will enable us to investigate the system performance under distressed operational cases as well.

4.1.2. Handoff call arrival rate, λ_h

Handoffs in cellular communication systems cause interactions in mobile communication systems that can be modeled using multi-dimensional birth-death process approaches and the concept of System State. However, exact numerical calculations of traffic performance characteristics are hindered by unmanageably large system state space, even for systems of modest size [15]. Many studies come around this difficulty by isolating a cell and invoking a Poisson process assumption for the handoff arrivals to the cell. In ref. [2] of [10] it is shown that handoff arrival process is Poisson. There are some studies, like [10], that examine the interactions among cells in more detail. However, in [10] it is shown that more complex handoff arrival rate models do not generate significant difference in performance when compared to the simple "single isolated cell, Poisson handoff arrival rate model" which is sufficient for most planning and analytical purposes. Therefore, we use the "single isolated cell, Poisson handoff arrival rate model" in this study. So, the arrival of handoff calls forms a Poisson process with the arrival rate λ_h per cell. As in the case of new call arrivals, we will consider typical values for the handoff call arrival rate taken from real operational environment. Besides, we will analyze the performance of our solution for a much wider range of λ_h values, even for unrealistic values to be able to cover extreme operational cases. This will enable to show the system performance under distressed operational cases as well.

For performance analysis purposes, we will cover a very wide range of values for both absolute and relative magnitudes of λ_n and λ_h. This wide range of values will include all practical values taken from real operational environment, and will also include any practical value that a typical subscriber behavior modeling tool could provide. We have covered a wide range for relative magnitudes of λ_n and λ_h. This will enable us to evaluate the performance of the compared methods under a wide range of user mobility figures. The definition of user mobility α was given in equation (5) in section 2.2.

4.1.3. Mean Call holding time, $1/\mu$

The call holding time, or average service time, is exponentially distributed with mean $1/\mu$. Many papers in literature are using exponentially distributed call holding time values with given mean values. Typical mean values are between 100 sec and 300 sec. For example, service duration is assumed to be 300 sec in [1], 120 sec in [2], 200 sec in [6], and 100 sec in [8]. We will use a similar value for this parameter.

In reality, we proposed to keep service specific call duration statistics for each mobile itself. However, for performance analysis purposes, we will use typical values as service duration as in [2] and in [8].

4.1.5. Service Type

For performance analysis purposes, we will consider single service type. This can be considered as the voice service requiring single radio channel with specific mean service duration. However, this assumption can be easily extended to cover multi-service/multi-connection applications, by assuming multiple radio channels and longer service duration per call.

4.1.5. Transition Probabilities, P_{ij}

To derive the Mobility State of users, we use a statistical, previous history based mobility state derivation approach, which was detailed in section 2.1. We will use C_i to denote the cell that the mobile is currently in, where $C_i \in C$ (where C is the set of all possible cells). Each mobile keeps track of the most visited M cells. For each of these most visited cells, the mobile keep transition probabilities form the current cell C_i to all its k neighboring cells. The probability array in (2) denotes the transition probabilities of the mobile when being in cell C_i. These arrays are actually the rows of the probability transition matrix, H_m defined in section 2.1.

4.1.6. Subscriber Behavior (User Mobility), α

In section 2.2 we have defined the user behavior, α as the ratio of the weighted sum of “handoff call arrival rate” and “handoff reservation request arrival rate” to the “new call arrival rate”. Therefore, the mobility of calls or user mobility α is defined in such a way that it will include not only the effect of handoff calls and new calls, but also the effect of handoff reservation requests. This was given in (5). The weighting factors γ_1 and γ_2 in (5) are used to adjust or control the effect of handoff reservation requests on the user mobility.

For performance analysis purposes, we consider different γ_1 and γ_2 values. However, in real life the weighting factors γ_1 and γ_2 can be adjusted recursively, using an error feedback loop. The error feedback loop can monitor the handoff reservation request arrival rate and the handoff arrival rate. Then, depending on the degree of how much reservation request turn into actual handoffs, the magnitudes of γ_1 and γ_2 can be adjusted.

We consider that it is important to include the handoff reservation request in the definition of user mobility. In this way, the reserved bandwidth becomes ready to the changes in the traffic and user mobility conditions, instead of following the changes.

4.1.7. Maximum number of channel, C_{max}

The maximum number of channels of a cell is C_{max}. As typical value taken from real operational environment, maximum number of channels is assumed to be 44 user channels in the performance analysis.

4.1.8. Dynamic Threshold, *m*

The threshold, *m* is the limit between normal channels and handoff channels. It is expressed in number of channels. The derivation of m was given in detail in section 2.2. It is an important parameter that must be carefully decided on. Most suitable number of handoff channels must be determined based on mobility and traffic patterns in the area. We propose a method in which the threshold is not fixed, as in [7], but changes dynamically depending on changes in the user mobility conditions. In this way, we aim to reach a dynamic channel reservation scheme, which can better adapt to changes in network dynamics. This will result in increased bandwidth utilization, and an improved QoS in terms of handoff failure probability and new call blocking probability. The threshold as stated in the equation (7), is used in the mathematical analysis part, as the dynamic threshold value of the proposed DRCM method. Similarly, in the software simulation part, the dynamic threshold adjustment process, continuously determines the value of the threshold, and the number of reserved channels is adjusted accordingly.

The channels reservation process is driven by the long-term average of the user mobility. The new call admission process manages more dynamic variations in the user mobility and traffic conditions. The *"new call acceptance probability"* concept implemented in the call admission process was explained in section 2.3. Due to this two-way approach used in resource management, the proposed approach tries to provide an improved solution in terms of adaptability to changing user mobility and traffic conditions, bandwidth utilization and improved QoS.

4.1.9. New Call Acceptance Probability, P_{ac}

While the threshold adjusts itself into long-term variations in the user mobility and network traffic conditions, the *"new call acceptance probability"* deals with the instantaneous variations.

Once the system state is above the threshold value, new calls are still able to get access to available channels according to the accept probability, instead of being totally blocked out. The calculation of the *"new call acceptance probability"* was given in section 2.3, in detail. The accept probability of new calls P_{ac}, is dynamically calculated depending on the mobility of users, channel occupancy, total number of channels and the threshold between normal channels and handoff channels, as shown in equation (8). Among these parameters the most effective one will be the mobility of users. Thus, our α definition directly affects the accept probability, and in this way will control the channel reservation and channel allocation process.

4.1.10. System State, i

The System State is defined as the occupied number of channels in a cell. Decision criteria, like the dynamic threshold in the channel reservation process and P_{ac} in the call admission process, depend on the system state.

4.1.11. Performance Parameters, P_f, P_b, U_{BW}

The performance parameters of this study will be the handoff call dropping probability or handoff failure probability P_f, the new call blocking probability P_b, and the bandwidth (i.e. radio channel) utilization, U_{BW}. *Handoff call dropping probability or handoff failure probability,* P_f is the probability of forced call termination due to unavailability of any channels. Any existing handoff and normal channels can be allocated for handoff calls. The *New call blocking probability,* P_b is the probability of blocked new call attempts due to unavailability of any free channels that can be allocated for new calls.

4.2 System Models

We consider a homogeneous system in which the new call arrivals and handoff call arrivals form a Poisson Process with arrival rate λ_n and λ_h, respectively. The call holding time is exponentially distributed with mean $1/\mu$. We assume that there are C numbers of radio channels in each BS; therefore each BS can support at most C simultaneous calls. Thus, the whole system can be treated as a *M/M/C/C* model, in which the first and second M represent that both the customer arriving and leaving rates obey the Markov processing policy; the first C is the maximum number of calls that can be handled concurrently in the system; and the second C represents that there is no waiting queue allowed in the system, i.e. a call can either be accepted or rejected.

In this study four different methods are examined and evaluated; the no channel reservation (NCR) method where all channels are treated equally, the fixed channel reservation (FCR) method in which the number of channels reserved for handoff calls is fixed, the dynamic channel reservation (DCR) method in which the number of channels reserved for handoff calls is varying; and finally the solution that we propose, namely the Dynamic Radio Channel Management scheme (DRCM). For all the four cases derivations of the handoff call dropping probability or handoff failure probability P_f, and the blocking probability of new calls P_b is provided separately in the following sections.

4.2.1. No Channel Reservation (NCR)

In this method there are no channels dedicated for handoff calls. Therefore, the total call arrival is the sum of the λ_n and λ_h independent of the system state. The NCR method can be considered as the baseline, which provides no improvement to the handoff call success. If we let *i* denote the system state, then

$$\lambda_T = \lambda_n + \lambda_h, \qquad 0 \le i < C \tag{9}$$

Since a busy channel is released with a rate of μ, the effective call departure rate in system state *i* is given as,

$$\mu_i = i \times \mu, \qquad 0 \le i < C \tag{10}$$

where i = 1,2,3,…..C. Therefore

$$\sum_{i=0}^{C} \pi_i = 1 \tag{11}$$

where π_i is the probability that the Markov process is in the state *i*. Therefore, the steady-state transition probability in state *i* is derived from Fig. 8 as follows:

$$\pi_i = \pi_0 \times ((\lambda_T/\mu)^i \; / \, i!) \tag{12}$$

and substituting (12) in (11), we get

$$\pi_0 = \left(\sum_{i=0}^{C} (\lambda_T/\mu)^i \; / \, i! \right)^{-1} \tag{13}$$

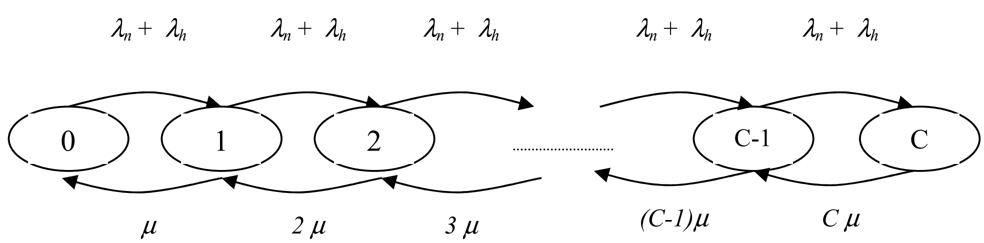


Figure 8. State transition of Markov Process for the NCR

From Fig. 8 we get

$$P_b = \left((\lambda_T/\mu)^C \; / \, C! \right) / \left(\sum_{i=0}^{C} (\lambda_T/\mu)^i \; / \, i! \right) \tag{14}$$

Since there are no dedicated channels for the handoff calls, same expression is valid for the handoff failure probability in the NCR method.

4.2.2. Fixed Channel Reservation (FCR)

From a cell point of view, Fixed Channel Reservation (FCR) is considered to be a channel assignment scheme where a BS reserves a fraction (r) of its total channels, as guard channels for handoff calls. If the total number of in-progress calls in a cell, denoted as i, exceeds a predefine threshold m = ((1-r) x C), then the BS accepts handoff calls only and denies totally the new calls. This is studied in [7].

The total effective call arrival in this case is the sum of the λ_n and λ_h, and it is state dependent. If we let i denote the system state, then the effective call arrival rate will be;

$$\lambda_T = \begin{cases} \lambda_n + \lambda_h , & 0 \leq i < m \\ \lambda_h , & m \leq i < C \end{cases} \qquad (15)$$

Since a busy channel is released with a rate of μ, the effective call departure rate depending on the system state i is given as,

$$\mu_i = i \times \mu , \qquad 0 \leq i < C \qquad (16)$$

where i = 1,2,3,…..C. Therefore, we have

$$\sum_{i=0}^{C} \pi_i = 1 \qquad (17)$$

where π_i is the probability that the Markov process is in the state *i*. Therefore, the steady-state transition probability in state *i* is derived from Fig. 11 as follows:

$$\pi_i = \begin{cases} \pi_0 \times ((\lambda_n + \lambda_h)^i / (\mu^i \times i!)), & i \leq m \\ \pi_0 \times (((\lambda_n + \lambda_h)^m \times \lambda_h^{i-m}) / (\mu^i \times i!)), & i > m \end{cases} \qquad (18)$$

Substituting the above equation in (17), we get

$$\pi_0 = \left(\sum_{i=0}^{m} ((\lambda_n + \lambda_h)^i / (\mu^i \times i!)) + \sum_{i=m+1}^{C} (((\lambda_n + \lambda_h)^m \times \lambda_h^{i-m}) / (\mu^i \times i!))\right)^{-1} \qquad (19)$$

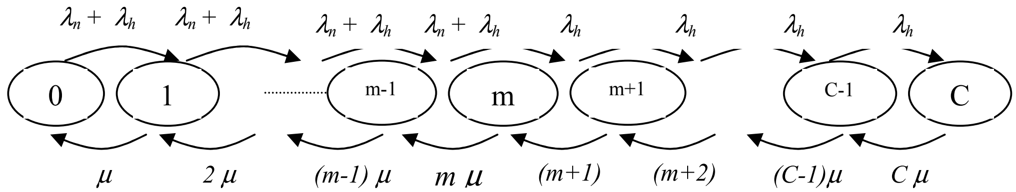


Figure 9. State transition of Markov Process for the FCR

Therefore, from Fig.9 for the new call blocking probability we have,

$$P_b = \sum_{i=m}^{C} \pi_i \tag{20}$$

Similarly, from Fig.9 for the handoff call dropping probability we have,

$$P_f = \pi_0 \text{ x } \left(\left((\lambda_n + \lambda_h)^m \text{ x } \lambda_h^{C-m} \right) / \left(\mu^C \text{ x } C! \right) \right) \tag{21}$$

4.2.3. Dynamic Channel Reservation (DCR)

The DCR is a channel assignment scheme where the reserved number of channels for handoff calls is not fixed as in the case of FCR, but changes depending on the user mobility. That is, the fraction (r) is not fixed. Thus, the threshold m = ((1-r) x C) is not fixed and adapts to changes in the user mobility.

Performance analysis of the DCR will follow same derivations as in the case of FCR; with the exception that the value m is not fixed and depends on the relative magnitudes of new call and handoff call arrival rates. Therefore,

$$P_b = \sum_{i=m}^{C} \pi_i \tag{22}$$

Similarly, from Fig.9 for the handoff call dropping probability we have,

$$P_f = \pi_0 \text{ x } \left(\left((\lambda_n + \lambda_h)^m \text{ x } \lambda_h^{C-m} \right) / \left(\mu^C \text{ x } C! \right) \right) \tag{23}$$

4.2.5. Dynamic Radio Channel Management (DRCM)

The last approach that we will analyze and evaluate is the Dynamic Radio Channel Management Scheme that is proposed in this study. We compare the performance of the DRCM with the other three approaches.

In DRCM, the fraction (r) of the total radio channels that will be reserved for handoff calls is determined in a highly adaptive fashion. This was described, as the threshold value, in detail in section 2.2. Section 2.2 provides the detailed derivation of the threshold, *m*. If the total number of in-progress calls in a cell, denoted as *i*, exceeds the threshold m, then the DRCM does not totally block out the new calls. Instead, once the system state is above the threshold value, new calls are still able to get access to available channels according to the accept probability, instead of being totally blocked out. The accept probability of new calls P_{ac}, is dynamically calculated depending on the mobility of users, channel occupancy, total number of channels and the threshold between normal channels and handoff channels. P_{ac}, was described in section II.3, and formulated as in (8).

In equation (8), *m* is the threshold, *C* is the total number of channels, *i* the currently occupied number of channels, that is the System State, and α is the user mobility, as presented in equation (5). Therefore, the total effective call arrival in the DCR case is as follows;

$$\lambda_T = \begin{cases} \lambda_n + \lambda_h, & 0 \leq i < m \\ P_{(k)\,ac} \times \lambda_n + \lambda_h, & m \leq i < C \end{cases} \quad (24)$$

Since a busy channel is released with a rate of μ, the effective call departure rate in system state i is given as,

$$\mu_i = i \times \mu, \qquad 0 \leq i < C \quad (25)$$

where i = 1,2,3,…..C. Therefore, we have

$$\sum_{i=0}^{C} \pi_i = 1 \quad (26)$$

where π_i is the probability that the Markov process is in the state *i*. Therefore, the steady-state transition probability in state *i* is derived from Fig. 11 as follows:

$$\pi_i = \begin{cases} \pi_0 \times ((\lambda_n + \lambda_h)^i / (\mu^i \times i!)), & i \leq m \\ \pi_0 \times ([(\lambda_n + \lambda_h)^m \times (P_{ac}(i) \times \lambda_n + \lambda_h)^{i-m}]/(\mu^i \times i!)), & i > m \end{cases} \quad (27)$$

Substituting the above equation in (26), we get

$$\pi_0 = \left(\sum_{i=0}^{m} ((\lambda_n+\lambda_h)^{i}/(\mu^{i} x\ i!)) + \sum_{i=m+1}^{C}(((\lambda_n+\lambda_h)^{m} x (P_{ac}(i)\ x\ \lambda_n+\lambda_h)^{i-m})/(\mu^{i} x\ i!))\right)^{-1} \quad (28)$$

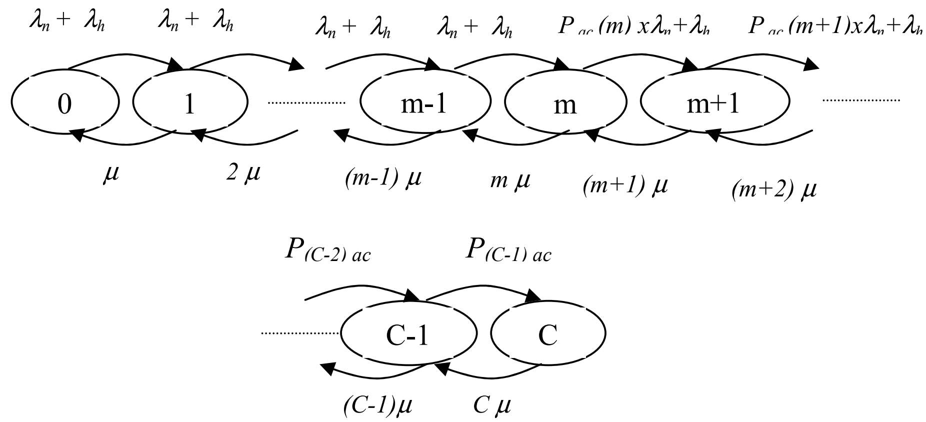


Figure 10. State transition of Markov Process for the DRCM

It should be noted that, even when the system state is above the threshold value, new calls still get access to available channels according to the accept probability, instead of being totally blocked out. Therefore, the new call blocking probability is derived as,

$$P_b = \sum_{i=m}^{C} \pi_i \text{ x } (1-P_{ac}(i)) \quad (29)$$

From Fig.10, for the handoff call dropping probability we have,

$$P_f = \pi_0 \text{ x } (((\lambda_n + \lambda_h)^{m}\ x\ (P_{(i)\,ac}\ x\ \lambda_n + \lambda_h)^{C-m}) / (\mu^{C}\ x\ C!)) \quad (30)$$

4.3 Software Simulations

The aim of the software simulations is to verify the calculated theoretical results about the QoS parameters P_f and P_b, and to provide predictions about direct bandwidth utilization. In the software simulation part, we have simulated the resource management algorithms of the four methods compared. The simulation programs, predict the P_b, P_f, and channel utilization of the four methods compared, under given scenario and environmental conditions. The simulation software parameters, like network traffic, subscriber mobility, and cell capacity include operational field to make the simulation runs as realistic as possible.

The operational filed data analyzed in Chapter III showed that network traffic and user mobility could vary over a wide range in actual network operations. Therefore, just like in the mathematical performance analysis case, we have performed the software simulation under conditions that included real operational field conditions as well. Moreover, we have performed several simulation runs with much wider range of network traffic and user mobility values also, to predict the performances under extreme cases as well. A series of simulation runs have been performed with a cell capacity of 44 user channels. This capacity is the same as a real operational cell from a highly populated downtown area in the capital city.

As the software simulation tool, we have used GPSS, the General Purpose Simulation Software. There are several reasons why we have chosen GPSS as our simulation environment. GPSS World™ has an intuitive object oriented interface, with many interactive views available, supporting even programmable simulation experiments with automatic data analysis. It includes over 50 GPSS Blocks, dozens of Interactive Commands, and has many System Numeric Attributes. In GPSS, simulations are not directly limited to the size of the physical random access memory. It uses the virtual memory, and can support simulations in the gigabyte range. The Multithreaded design of GPSS World™ makes it well suited for execution of experiments with multiple simulations running concurrently. Not only is screen update, user input, disk input/output, printing, and simulation done concurrently, but any number of simulations can be run at the same time, as well. The software exploits the 32-bit virtual address space, and it is optimized for Pentium compatible processors.

We have coded the resource management algorithms of the four methods compared into GPSS statements. The software source codes of the simulation programs developed for the four methods compared, make widely use of the key features of the GPSS tool. We present the software codes of the resource management algorithms of the NCR, FCR, DCR and DRCM methods, in Appendix-B.

The source codes are divided into initialization, simulation, scenario and traffic generation, and timing parts. The compiler skips the lines or characters after the semi column, therefore these are explanation parts. The scenario and traffic generation part is not fixed. It depends on the environmental conditions that are simulated. In Appendix-B, one sample scenario, for a typical 24-hour run, is presented.

When the simulation starts to run and the

```
INCLUDE       "seed50.txt"
```

part is reached, the program reads the content of the text file `"seed50.txt"`. In this file, the GPSS command "RMULT" is used to set the seed of random number generator. We change the seeds of the random variables in a controlled way, so that we can decide whether the results obtained are statistically significant or not. We use this input file also to do the replication runs, where we vary only the seeds of the random number.

The output file of the simulation, called GPSS Report file, contains by default many important information about the simulation. There are user defined and default fields in a report file. Some of the default information is information about how many times each transaction has been called, storage facility (radio channels in our case) usage frequency, mean and variance of the table entities defined. We present one report file in Appendix-C. From the output file, among much other information, we can read directly call statistics, like number of new call and handoff call arrivals, number of blocked new calls, number of dropped handoff calls, P_f, P_b and bandwidth utilization. These are bold font in the sample output file in Appendix-C.

We have performed several software simulation runs, to predict the P_f, P_b and bandwidth utilization performances of the compared methods. These software simulations were done both for 24-hour to simulate a whole day traffic, and for one hour to simulate the peak-hour traffic. The scenarios considered and the environments simulated include, but are not limited to, a network traffic range of

10%, 30%, 50%, 70%, and 90% of the total cell capacity, and a user mobility range of low user mobility (α=0.5), unity user mobility (α=1), and high user mobility (α=2). We have chosen these values of network traffic and user mobility, to match the scenarios and simulation environment to the cases considered in the mathematical analysis part. The simulation run results of all the scenarios and simulation environments considered are included in the CD provided. We present the results of some typical runs in section 5.2, in tabular form.

To have a better understanding about the peak hour behavior of the compared methods, we have performed separate simulation runs for the peak-hour analysis. Besides the P_f, P_b and bandwidth utilization results, in the peak-hour simulation results we have also recorded the handoff and new call count, and the handoff call drops and new call blockings, to have a better understanding about call statistics. In the peak-hour simulation runs, the mean values of the call arrivals are constant over the simulation period. We have categorized the scenarios and simulation environments in terms of network traffic and user mobility, according to the mean values of the call arrivals.

The aim of the software simulation runs was to prove the numerical performance analysis, and to predict direct bandwidth utilization analysis. Careful examination of the simulation results show that, the simulation runs predict indeed similar performance results compared to the mathematical analysis results obtained in section 5.1 about QoS parameters. We have presented the results of the software simulation runs in section 5.2, and have performed a detailed comparison of mathematical and simulation analysis results in section 5.3

In any software simulation, before reporting any results, we must prove that, the results obtained are not due to random noise and are statistically significant. Since the radio spectrum is a limited resource, the performance improvement of any solution will not be huge compared to existing solutions. Therefore, in our case, it is more important to prove that the performance improvement of the proposed DRCM method predicted by the simulations is significant. One efficient way to decide on the significance of the simulation results is to repeat the simulations for the same scenario, without changing the environmental conditions, until we can decide which results are real and which are random. Therefore, we need to perform a number of successive simulation runs to verify that the results obtained are not due to random noise and the predicted performance differences are statistically significant.

If simulation is to be used to solve any real problems, means how to tell which effects are random and which are real is needed. In the GPSS World, the “Analysis of Variance (ANOVA)” command provides a way for this purpose. The ANOVA command makes a first level of statistical analysis relatively easy. After fully testing a simulation under a variety of conditions, the simulation will tell the answer of some real problems. That is where experimentation comes in. In order to predict the effects of factors under our control, we will need to simulate each of the possibilities and determine if the result exceeds the random variation inherent in any simulation. The ANOVA command in GPSS provides an efficient way for this purpose.

Keeping in mind that few numbers of simulations for a specific scenario may not be enough to decide that the results are statistically significant; we have performed many runs or "replicas" for each of four methods compared, and for every scenario considered. Replicas are runs of identical conditions except that a different set of seeds is used to prime the pseudo-random number generators. This provides a baseline of variability due only to random effects. It will show us whether the results obtained are statistically significant, and are not due to random noise only.

When we use statistical methods to see if two alternatives are different in performance, we must not allow extraneous uncontrolled events to occur during the simulations. It would not be fair to load one run with additional activities at some unknown place in the simulation, and not to do precisely the same thing in all other runs. One problem about the multiple simulation runs is that, in any simulation, repeating simulation runs and changing nothing other than the random number seeds can cause what appear to be large differences in output. Therefore, we have used the same seed set that belongs to a specific scenario for all the methods compared. Since our results are in the form of an arithmetic average of many results, we are justified in using the ANOVA command to do a statistical analysis. Using the ANOVA block statement, we have derived the statistical mean and variance of the performance parameters Pb, Pf and bandwidth utilization, from the successive simulation runs, for each case under consideration.

For each scenario and environmental conditions considered, and for each of the four methods compared, we have performed successive simulation runs, and recorded the results from the ANOVA output file. Results of the replication runs are provided in section 5.2.

CHAPTER V

RESULTS OF PERFORMANCE ANALYSIS

In this section, the results of the performance analysis are presented. The analysis was carried out in two steps. First, equations based on models derived are solved and results were plotted for different operating conditions. They are presented section 5.1. The same operating conditions are used and software simulations of network operations were done using a simulation program. The results of these studies are presented in section 5.2. The final section of thesis chapter combines results of software simulations done under different conditions as a weighted average of handoff calls, dropped handoff calls, new calls admitted and new call rejected. Comparison of different approaches is given in this section. They clearly illustrate the way different approaches perform under varying traffic conditions. (Part of the results is presented in appendix due to lack of space in this section.)

5.1 Results of Numerical Analysis

In the numerical analysis part, we first focus on the performance of the resource reservation and new call admission processes, and on the ability of the user mobility definition in following actual subscriber behavior. Second, we will evaluate and compare the performances of the NCR, FCR, DCR and DRCM methods in terms of the two QoS parameters, namely the handoff call dropping probability and new call blocking probability. Finally, we will compare the spectral efficiency of the methods under consideration.

5.1.1. Resource Reservation

The threshold m was defined in detail in section II.2 as the limit between the normal channels and handoff channels (channels that are reserved for handoff calls). The threshold depends mainly on the long-term average of the user mobility, and is an important parameter that must be carefully decided on. Most suitable number of handoff channels that is to be reserved for handoff calls must be determined based on user mobility and network traffic patterns in the area.

Moreover, the resource reservation process must adjust *m* adaptively, depending on the changes in the subscriber behavior and network traffic variations.

The performance of the dynamic threshold adjustment process, in terms of how well it can follow changes, is examined under different case studies, each case representing different real operational environment conditions.

Figure 14 shows, for example, the threshold value with respect to changes in field user mobility. The actual field user mobility values are from a GSM service provider in the capital city. They are the operational traffic values taken form a cluster of cells in a crowded downtown area on a 24-hour basis. In Figure 11, the primary y-axis represents the threshold value, whereas the secondary y-axis represents the user mobility in logarithmic scale.

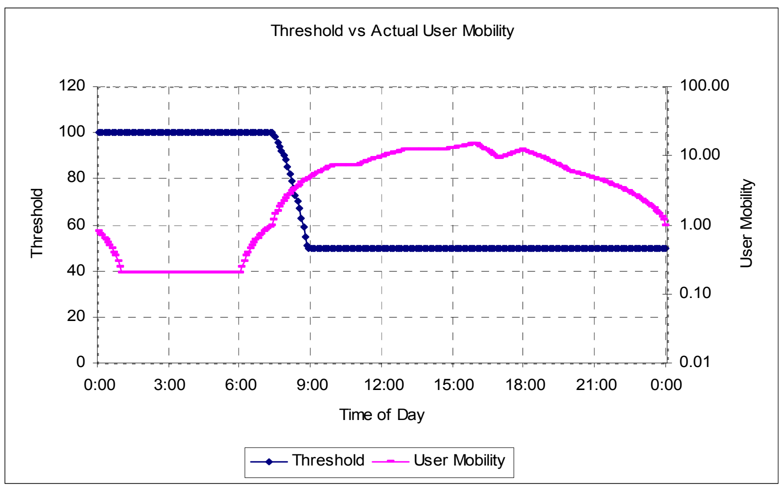


Figure 11. Threshold vs. actual user mobility

Data collected on 03/11/2003 shows low user mobility during night hours until around 07:00 in the morning. Therefore, the threshold adjusts itself to a high value to better accommodate the new call attempts. During the morning rush hours, mobility of the subscribers increases. Therefore, the threshold starts to decrease reserving more channels to handoff calls. Since the subscriber mobility is relatively high in this region from that time until the end of the day, the threshold reaches its minimum value and remains at this value until the end of the day. The resource management process recalculates and adjusts the threshold in each five-minute time interval using equation (7).

The actual field user mobility values presented in Figure 11 show that the subscriber mobility in that area is relatively high with low variations in it. Figure 12 considers a case where the filed user mobility has more fluctuations. Again, the primary y-axis represents the threshold value, whereas the secondary y-axis represents the user mobility in logarithmic scale.

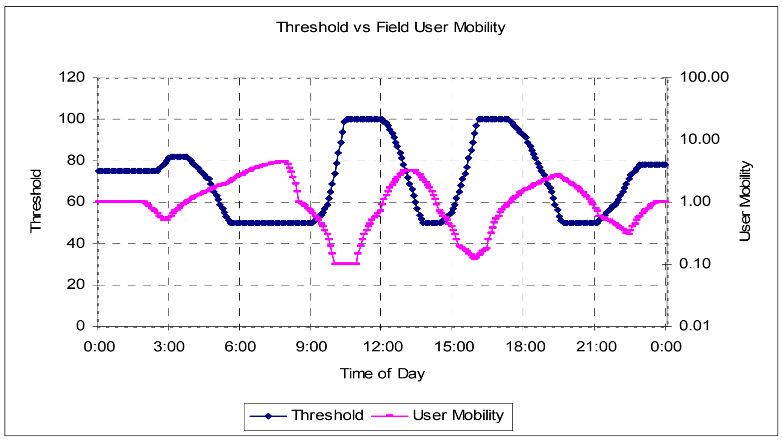


Figure 12. Threshold vs. field user mobility

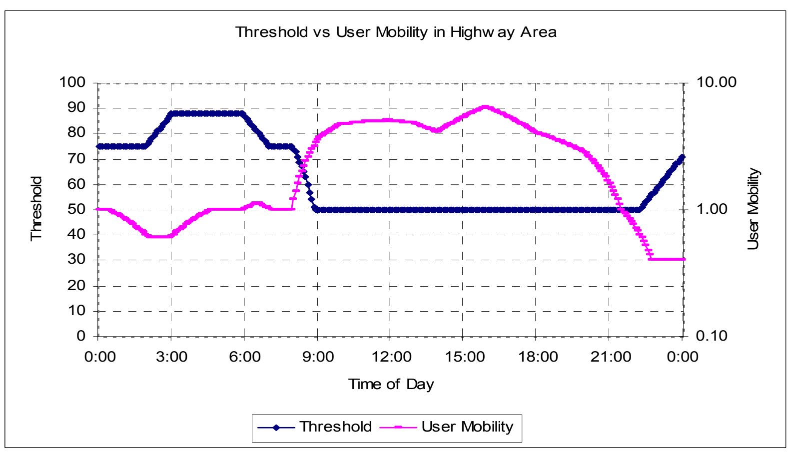


Figure 13. Threshold vs. user mobility in highway area

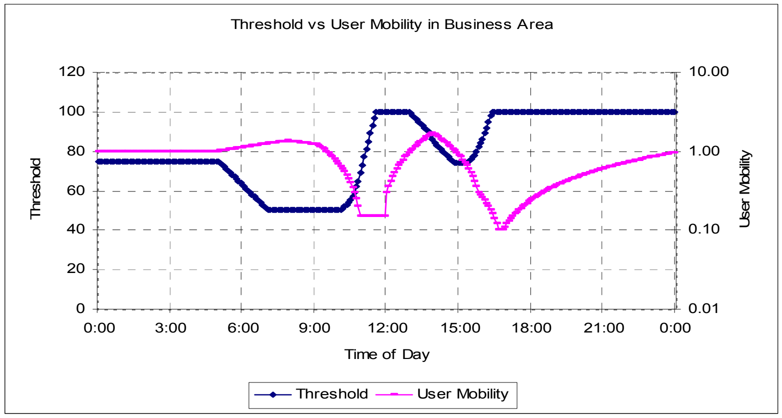


Figure 14. Threshold vs. user mobility in business area

The field user mobility in Figure 12 has peaks in the morning rush hours, noontime, and evening rush hours. The threshold adjusts quickly to its minimum value during these peak hours, reserving more channels for handoff calls. During the dips in user mobility, which are observed in the morning business hours and afternoon business hours, the threshold adjusts to its maximum value to enable more chance to the new calls that are expected to occur.

Figures 13-14 show the output of the threshold adjustment process, under user mobility values from two different regions with very different user mobility characteristics. These regions are highway area and business area. Besides those two regions, we have examined the performance of the threshold adjustment process, under other operational field data such as entertainment area and shopping area. The characteristics of those regions, in terms of subscriber distribution and mobility are from paper [11].

From Figures 11 through 14, it can be observed that irrespective of the subscriber mobility characteristics of region where the cell is located, the threshold adapts to the user mobility of the region and decides on the number of channels to be reserved for handoff calls accordingly.

As it was explained in section 2.2, the long-term average of user mobility given in equation (6) is used to adjust the threshold value. The long-term average is used, since the offered traffic is time-varying and a short interval may not support a sufficient estimation for determining a proper size for the reservation capacity. In this way, the threshold adjustment process is able to reflect the typical subscriber mobility characteristics of the region into the reserved capacity.

However, there might be cases where the network traffic and user mobility in a region show major deviations form their typical characteristics. These cases may be for example, some natural disasters, terror attacks or events involving many subscribers with common behavior like major social, cultural or sports activities. Important and instant step variations in network traffic load or subscriber mobility can be observed during such events.

Figures 15-16, consider scenarios with instant step variations in network traffic load, or subscriber mobility, on top of the typical patterns of the two cases considered in Figures 13-14.

From Figures 15 and 16, which consider scenarios with instant Step variation in network traffic load or subscriber mobility, it can be observed that, the threshold adjustment process, whose purpose is to adapt to long term variations, proves to be too slow for the instant changes. This can be observed from the Figures 15 and 16, where it can be seen that, although the threshold adjustment process starts to change the reserved capacity as soon as the change occurs, it takes some time before the desired threshold value that reflects the current mobility figures of the environment is reached. Therefore, during this initial time of the extreme case, the threshold fails to predict correctly the most suitable reserved capacity. This fact can cause inefficient resource utilization and poor QoS performance.

To overcome this difficulty, as part of the overall resource management algorithm, the new call admission process is used to instantly control new call admissions. The new call admission process, makes use of a probabilistic approach in accepting new calls, by making use of the *new call accept probability* implementation, as explained in section 2.3. The efficiency of this process is studied in the next section.

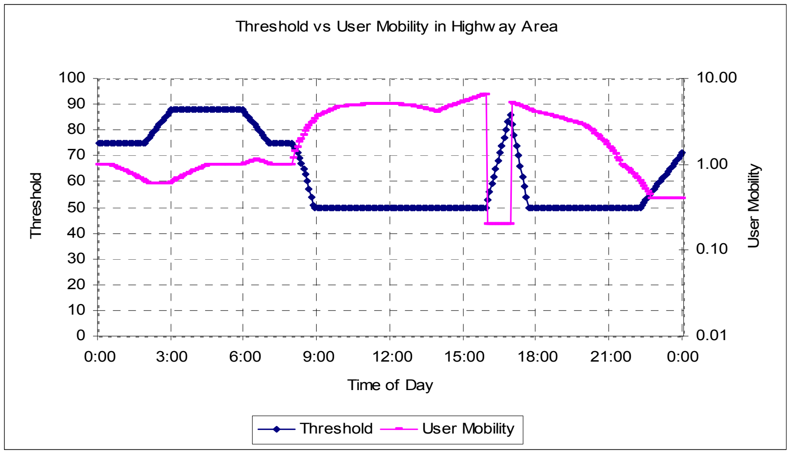


Figure 15. Step variation in subscriber mobility in highway area

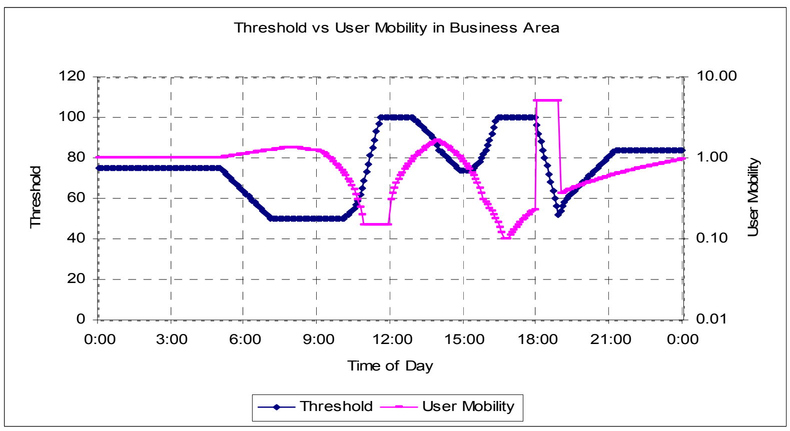


Figure 16. Step variation in subscriber mobility in business area

5.1.2 New Call Admission Process

The new call accept-probability was defined in detail, in section II.3. In each five-minute time interval, the value of the new call accept probability, P_{ac} is recalculated using equation (8). In equation (8) α is the instantaneous value of the user mobility, which includes the handoff reservation request arrival rates that are directly driven from individual mobile call statistics. Therefore, instantaneous variations in user mobility are reflected into P_{ac}.

Figures 17 through 20 show P_{ac} with respect to instantaneous variations in user mobility. The primary y-axis represents the instantaneous P_{ac} value, whereas the secondary y-axis represents the user mobility in logarithmic scale. The x-axis in those figures covers a one hour time duration.

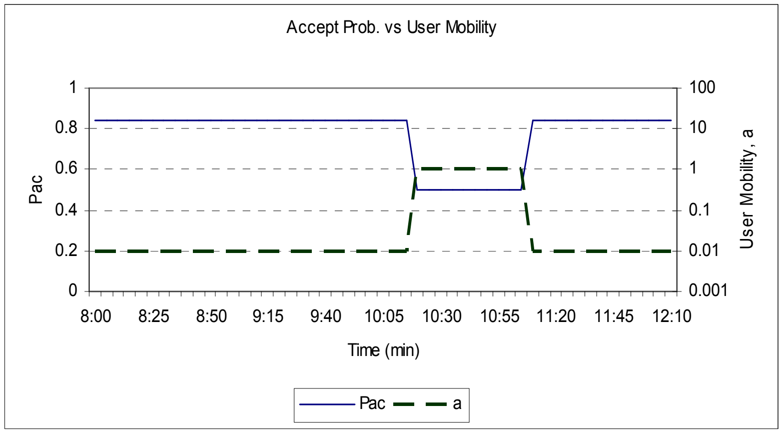


Figure 17. P_{ac} vs. instantaneous variations in user mobility (case-a)

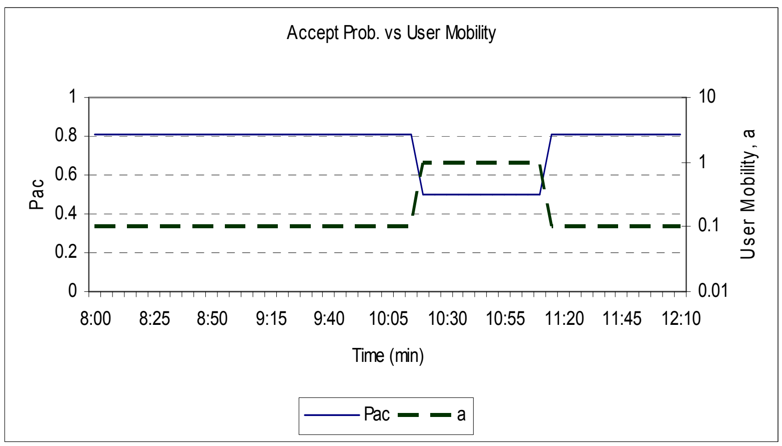


Figure 18. P_{ac} vs. instantaneous variations in user mobility (case-b)

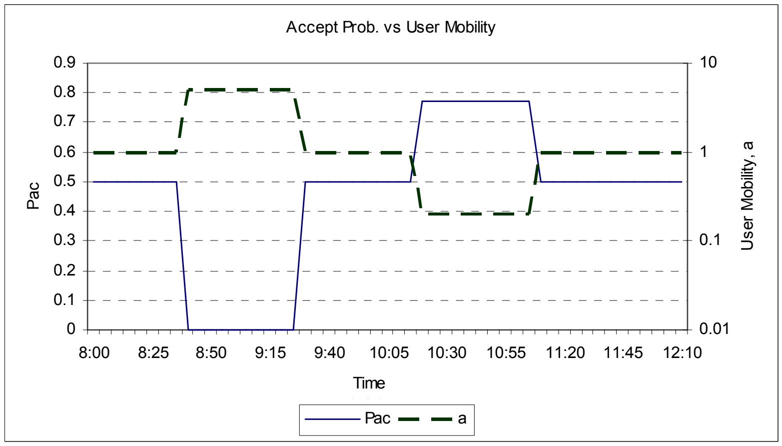


Figure 19. P_{ac} vs. instantaneous variations in user mobility (case-c)

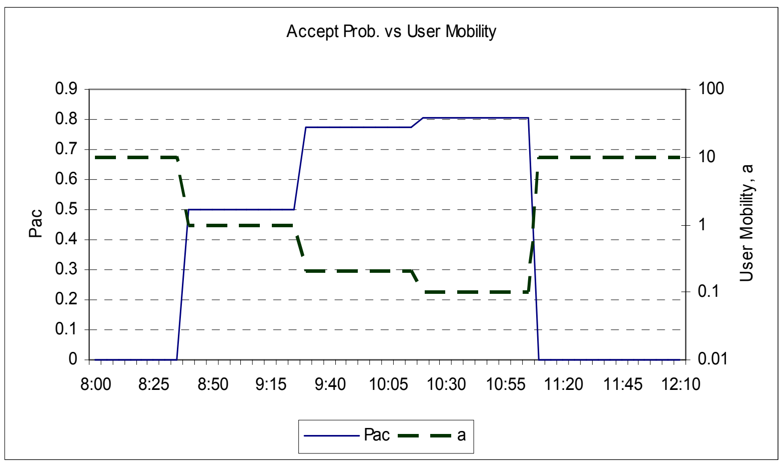


Figure 20. P_{ac} vs. instantaneous variations in user mobility (case-d)

Figures 17 through 20, consider different instantaneous jumps in user mobility. From those figures, we can observe that unlike the threshold, P_{ac} value can follow instantaneous variations in the user mobility. P_{ac} jumps into the new value instantly, as soon as there is a change in the system state, network traffic or user mobility values. This enables the overall resource management algorithm to compensate for the sudden changes in the need for handoff or normal channels. In this way, it will be possible to bring an improvement to the QoS parameters and bandwidth utilization.

The purpose of the P_{ac} is to bring a probabilistic approach to the new call admission process, with the aim of increasing bandwidth utilization by preventing unnecessary new call blockings. Dynamic channel reservation methods studied from literature that reserve some radio channels for handoff calls, block out all new call attempts once the regular channels are full, irrespective of the relative magnitudes of handoff call arrivals and new call arrivals. This can result in poor resource utilization and low P_b performance, especially in such cases where the system state is above the threshold, that is, normal channels are all occupied and the new call arrival rate is high compared to handoff call arrival rate. In those cases, the reserved channels will remain empty due to low handoff call arrivals, whereas new call attempts are refused due to lack of free normal channels. In the following figures of P_{ac} performance, without loss of generality, the cell capacity is assumed 100 radio channels, and the threshold is assumed to be 50 radio channels.

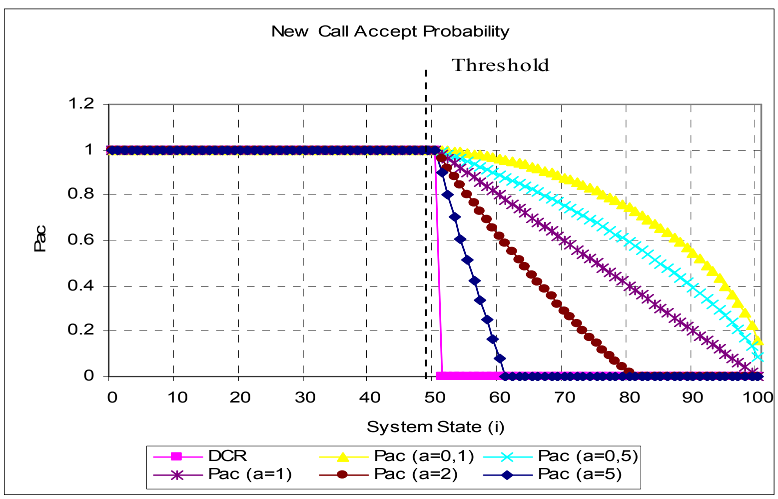


Figure 21. P_{ac} vs. system state in DCR and DCRM

Figure 21 shows the P_{ac} value with respect to system state for DCR and DRCM methods, under different user mobility conditions. The DCR methods considered are generic dynamic channel reservation methods studied from literature that reserve some radio channels for handoff calls, under five different user mobility values, starting from low mobility (a=0.1) till high mobility (a=5).

The x-axis is the value and the y-axis is the system state, that is, the number of occupied channels. As seen on this figure, in DCR, once the system state is above the threshold, independent of the user mobility and network traffic conditions, new call attempts are totally blocked out (P_{ac} = 0). This aims, of course, to increase handoff success. However, it will result in unnecessary new call blockings, which leads to very poor bandwidth utilization. Poor spectral efficiency will occur especially in such cases where the system state is above the threshold and the user mobility is very low.

In the proposed DRCM approach, once the system state is above the threshold, new call attempts are not totally blocked and get access to the reserved channels, as much as the new call accept probability allows. Unlike DCR, form Figure 22 we see that new call accept probability values are different with respect to the system state for five different user mobility cases, starting from low mobility (a=0.1) to high mobility (a=5). The accept probability drops with increasing system state. For high user mobility, meaning there are more handoff calls than new calls, P_{ac} drops faster with increasing system state, to give higher chance to handoff calls. On the contrary, for low user mobility, meaning there are more new call attempts than handoff call attempts, P_{ac} drops slower with increasing system state, to give higher chance to new calls. In this way, the resource management algorithm tries to prevent unnecessary new call blockings, which results in very poor bandwidth utilization.

In the case considered in Figure 22, the user mobility is low, meaning there are more new calls than handoff calls, the new call accept probability does not drop at a high rate, enabling more new call attempts to get access to reserved channels. That is, if there are more new calls compared to handoff calls, new calls are accepted with a higher probability. This will enable to utilize reserved radio channels that would be normally remain empty due to low handoff arrival rate, and prevent unnecessary blocking of new calls.

In the case considered in Figure 23, the user mobility is high, meaning there are more handoff calls compared to new calls, the new call accept probability falls down very fast, enabling the relatively higher handoff call arrivals to get access to reserved channels.

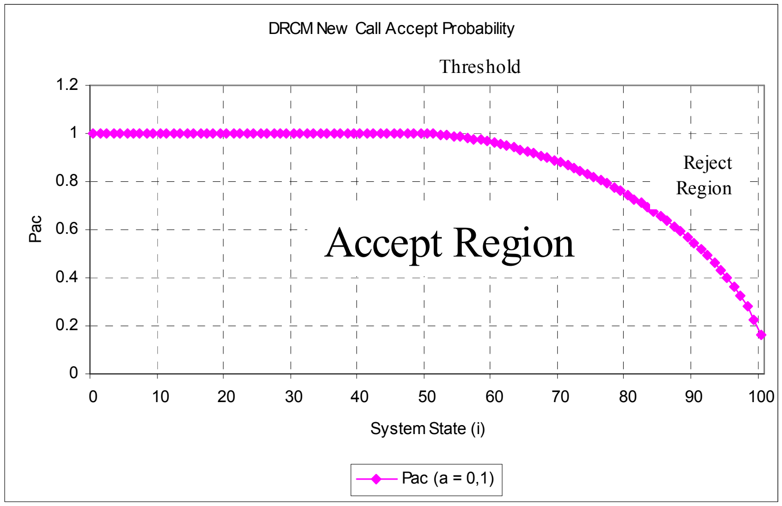


Figure 22. P_{ac} vs. system state in DRCM method under low user mobility

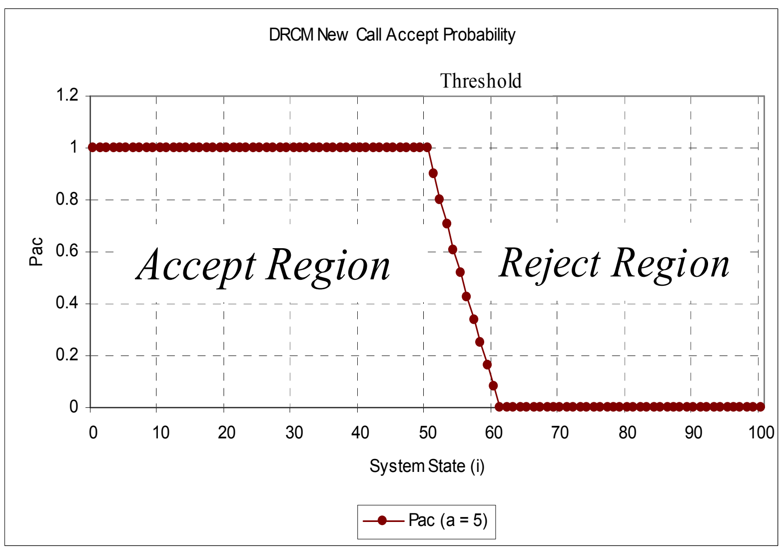


Figure 23. P_{ac} vs. system state in DRCM method under high user mobility

5.1.3. User Mobility

An efficient resource management algorithm must control the amount of reserved radio channels and the admission of new calls, depending on the relative magnitudes of λ_h and λ_n, that is depending on the subscriber mobility of the region. Therefore, user mobility is the most important parameter of both the threshold adjustment process and the new call admission process. These two processes, in turn, form the main part of the overall resource management algorithm. Therefore, the user mobility definition has a major effect on both the reserved number of channels and new call acceptance.

As detailed in section 3.1, the “subscriber profile prediction algorithm” makes use of call statistics of each individual mobile to derive the handoff reservation requests. With a high probability, handoff reservation requests will turn into real handoff calls in near future. This valuable information about the near future’s expected mobility figures is included in the user mobility definition of this study. We consider that it is important to include the handoff reservation request in the definition of user mobility. In this way, the channel reservation process and the new call admission process become ready for the near future changes in the network traffic and user mobility, instead of following the changes.

In this study, the user behavior α is defined as the ratio of the weighted sum of “handoff call arrival rate, λ_h” and “handoff reservation request arrival rate, λ_{hrq}” to the “new call arrival rate, λ_n”, as given in the equation (5) in section 3.2. The instantaneous value of α as defined in the equation (5) is used in the new call admission process. However, for the resource reservation process, we use the long-term average, as given in the equation (6).

The efficiency of both the resource reservation process and new call admission process depends very much on the efficiency of how close the user mobility definition can follow the actual subscriber mobility pattern of the area. The success of the user mobility definition itself depends on two parameter sets. The first set is the set of β parameters of equation (6), which are the weighting parameters of the moving average of “measured” mobility of subscribers from previous time intervals. The second set is the set of γ parameters of equation (5), which are the relative weights of λ_h and λ_{hrq}, where we propose to derive the λ_{hrq} from individual subscriber profile information.

We evaluate the performance of the user mobility definition in terms of how well it can follow the actual mobility pattern of the environment, under different operational field data, and compare the performance with the classical user mobility definition. To study the effect of β and γ parameters on user mobility performance, we have evaluated the performance of user mobility under:

i) Different distribution for the β parameters, like linear distribution, exponential distribution,

ii) Different number of previous values of α and N_{win} to be included in the moving average, like $N_{win}=5$, $N_{win}=10$. The number of previous values of α be included in the moving average are determined by N_{win} in equation (6).

iii) Different relative weights of γ parameters, starting from $\gamma_1=0.1$, $\gamma_2=0.9$, until $\gamma_1=0.9$, $\gamma_2=0.1$, with 0.1 steps,

iv) Different input data set of subscriber mobility, like field data collected from the downtown area in the capital city from one of the GSM service providers, field data from an area with higher mobility of subscribers, and field data from four different regions with typical mobility characteristics (business area, highway area, entertainment area, shopping area).

In those figures, the x-axis shows the time of the day. For better readability, we have divided the 24-hour period into six parts, each covering a 4-hour period with 5-minute time intervals. The vertical bars represent the observed field mobility of subscriber. These are the actual subscriber mobility pattern of the area. The triangular-line represent the classical user mobility found in the literature that we have examined so far, and the square-line represents the modified user mobility definition of this study that includes the handoff reservation requests coming from the individual mobile call statistics.

The set of figures in Figure 24-38, are the results of a case where the environment is a business area with the data set of subscriber mobility, accordingly. Each figure covers a 4-hour period. The β parameters are "exponentially distributed", with 10 β_i values in the moving average ($N_{win}=10$). The actual analysis considers each time a different relative value for the γ_1 and γ_2 are considered, starting from $\gamma_1=0.1$, $\gamma_2=0.9$, until $\gamma_1=0.9$, $\gamma_2=0.1$, with 0.1 steps. However, in the below figures a subset of the γ_1 and γ_2 are presented, which are

(γ_1=0.1, γ_2=0.9), (γ_1=0.5, γ_2=0.5), and (γ_1=0.9, γ_2=0.1). Since in the period 00:00-04:00 no major subscriber activities are observed, there is no major difference for different values of γ_1 and γ_2, therefore this time period is excluded from the figures.

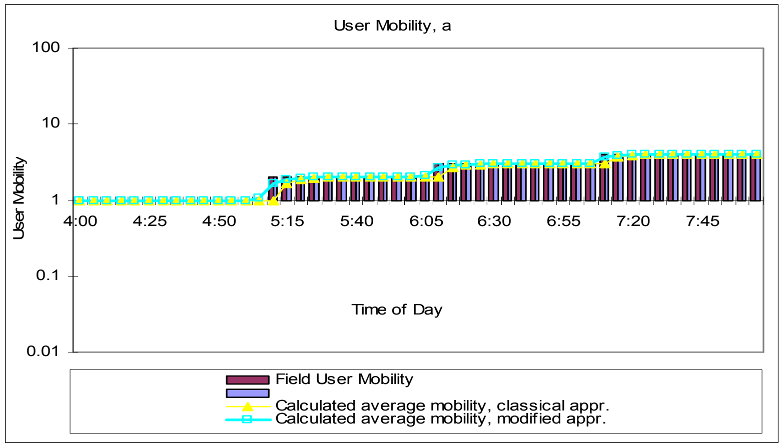


Figure 24. User Mobility in business area with exponential distribution of β parameters, and γ_1=0.1, γ_2=0.9

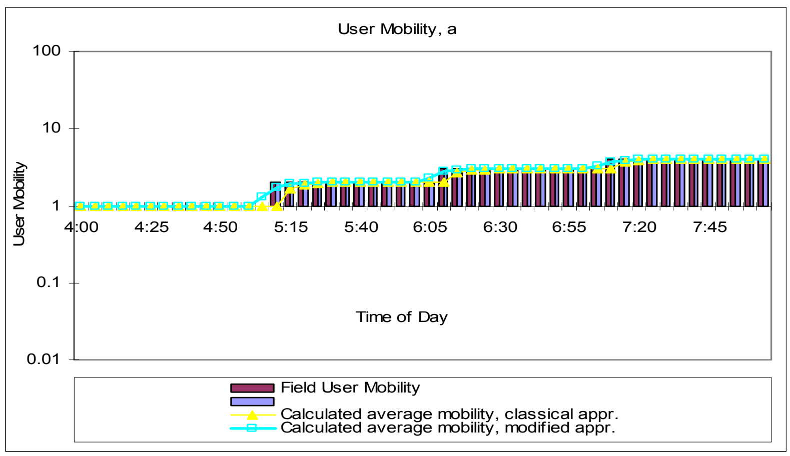


Figure 25. User Mobility in business area with exponential distribution of β parameters, and γ_1=0.5, γ_2=0.5

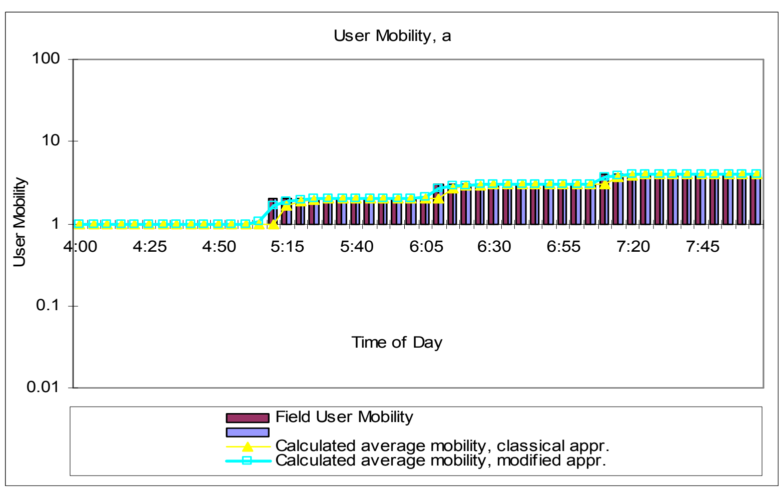


Figure 26. User Mobility in business area with exponential distribution of β parameters, and γ_1=0.9, γ_2=0.1

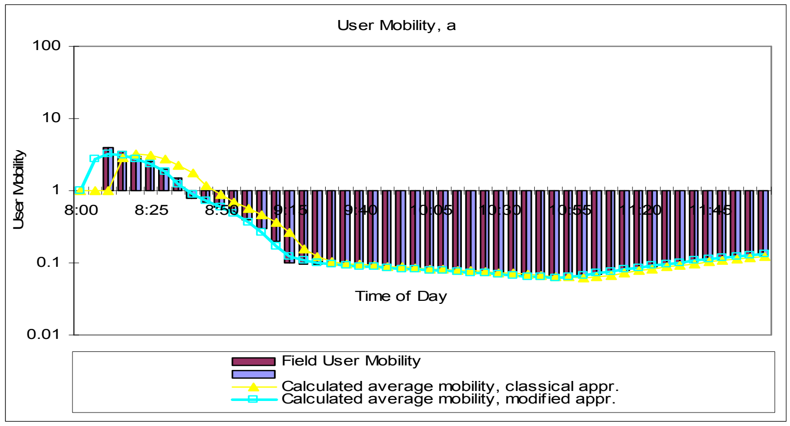


Figure 27. User Mobility in business area with exponential distribution of β parameters, and γ_1=0.1, γ_2=0.9

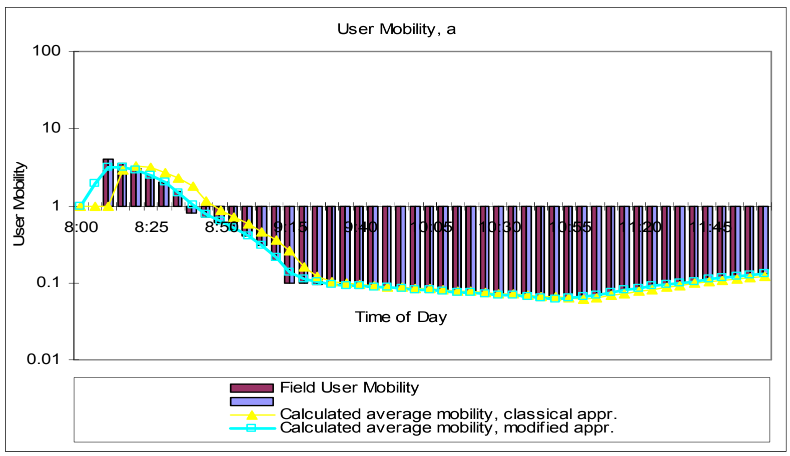


Figure 28. User Mobility in business area with exponential distribution of β parameters, and γ_1=0.5, γ_2=0.5

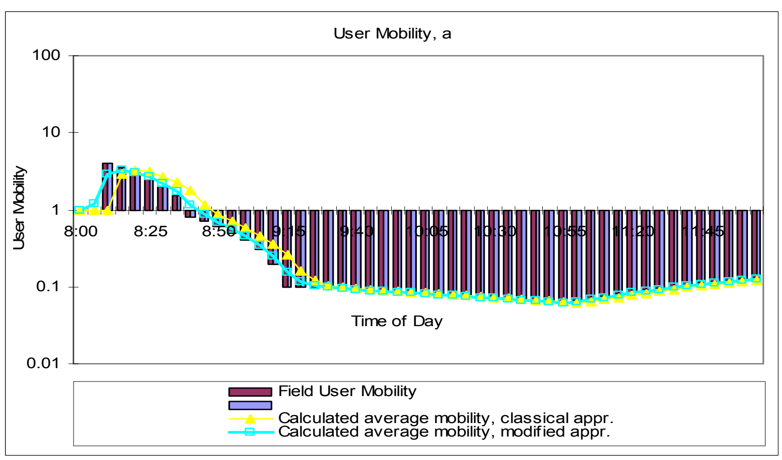


Figure 29. User Mobility in business area with exponential distribution of β parameters, and γ_1=0.9, γ_2=0.1

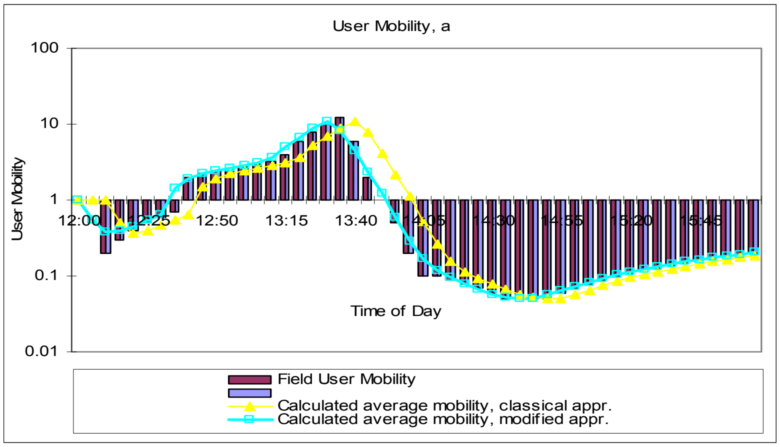


Figure 30. User Mobility in business area with exponential distribution of β parameters, and γ_1=0.1, γ_2=0.9

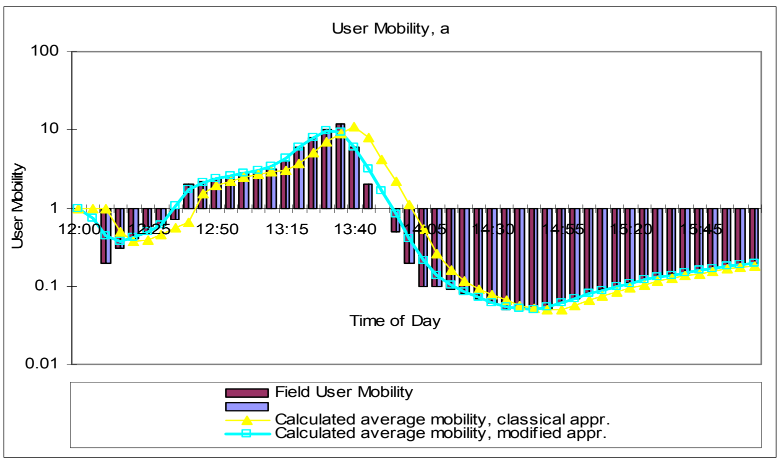


Figure 31. User Mobility in business area with exponential distribution of β parameters, and γ_1=0.5, γ_2=0.5

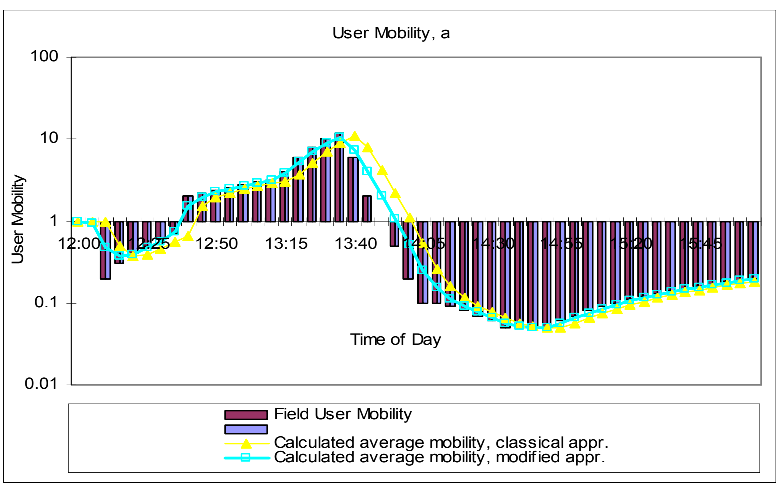


Figure 32. User Mobility in business area with exponential distribution of β parameters, and γ_1=0.9, γ_2=0.1

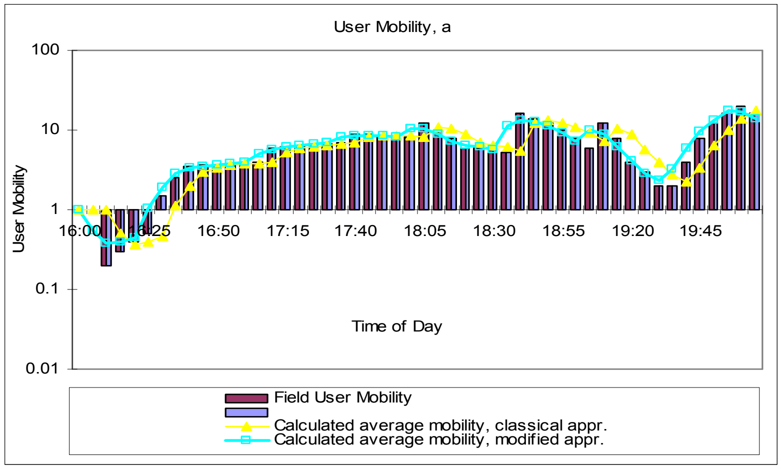


Figure 33. User Mobility in business area with exponential distribution of β parameters, and γ_1=0.1, γ_2=0.9

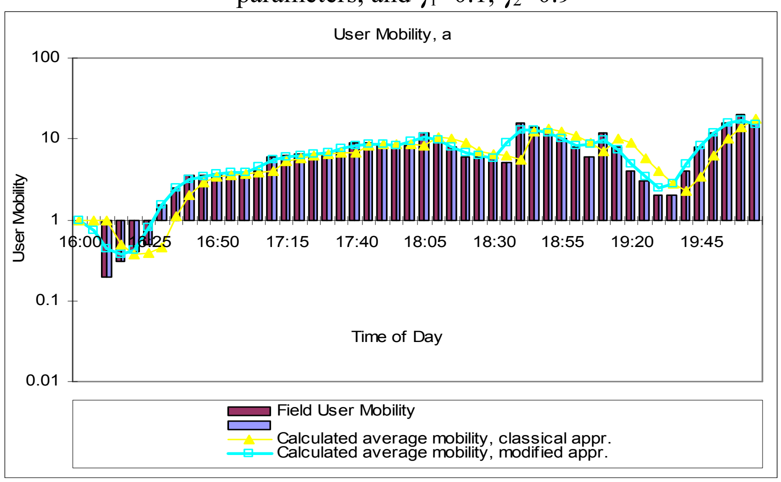


Figure 34. User Mobility in business area with exponential distribution of β parameters, and γ_1=0.5, γ_2=0.5

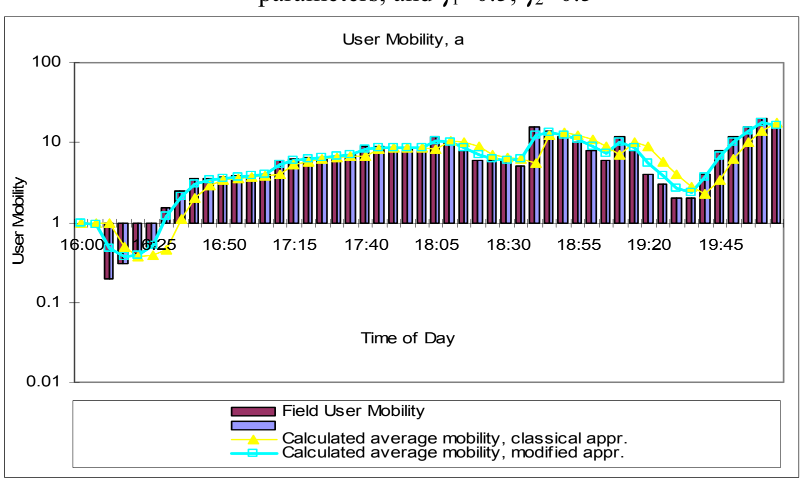


Figure 35. User Mobility in business area with exponential distribution of β parameters, and γ_1=0.9, γ_2=0.1

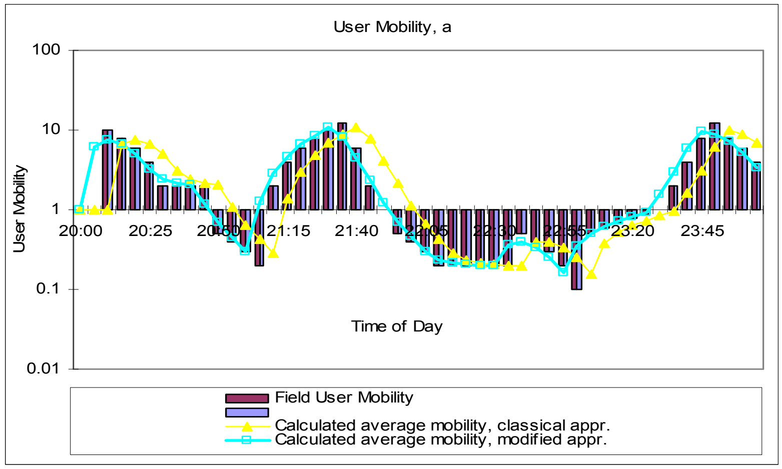


Figure 36. User Mobility in business area with exponential distribution of β parameters, and γ_1=0.1, γ_2=0.9

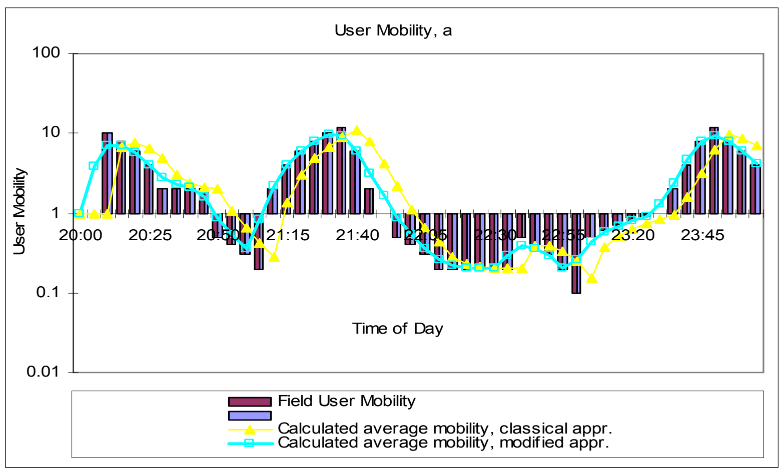


Figure 37. User Mobility in business area with exponential distribution of β parameters, and γ_1=0.5, γ_2=0.5

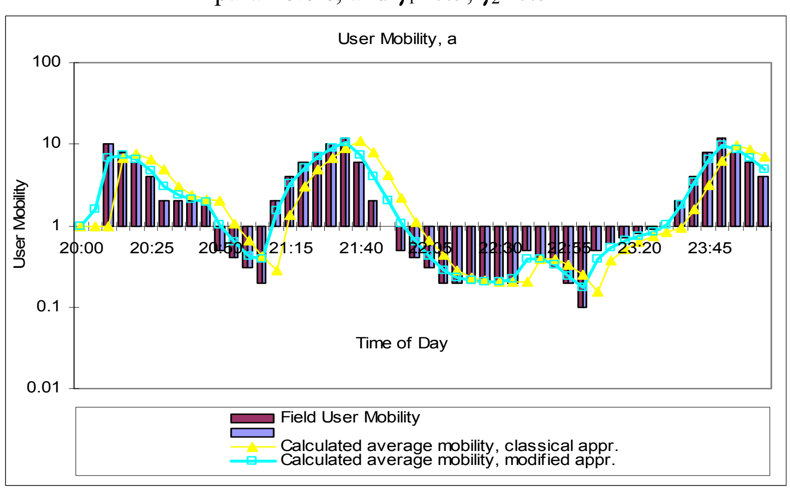


Figure 38. User Mobility in business area with exponential distribution of β parameters, and γ_1=0.9, γ_2=0.1

The set of figures presented in Figure 24-38, show that the modified user mobility definition can follow the actual mobility of subscribers, better that the classical approach. This is observed in all the periods, and for all the γ_1 and γ_2 values. The difference between the figures of same time period and different set of γ_1 and γ_2 values, although being not very large, show that with increasing γ_2 values, the effect of λ_{hrq} on user mobility definition with respect to λ_h is increasing. As the effect of λ_{hrq} increases, the system can adapt better to the subscriber mobility value of the next time interval. However, increasing γ_2 too much puts an overemphasis onto λ_{hrq}, and the user mobility starts to switch to the next time interval subscriber mobility value, prematurely. Study on different values of γ_1 and γ_2 parameters proved that γ_1=0.5 and γ_2=0.5, are suitable values. Therefore, for the γ_1 and γ_2 parameters, we propose to use γ_1=0.5 and γ_2=0.5. We believe that this is a fair and realistic definition for our purpose.

Table.1 User Mobility Parameters

Parameter	**Value**
Scenario (Network traffic and subscriber behavior)	Field data, business area, highway area, entertainment area, shopping area
Distribution of β parameters	Exponential, linear
Weights of γ_1 and γ_2 parameters	Starting from (γ_1=0.1, γ_2=0.9), until (γ_1=0.9, γ_2=0.1), with 0.1 steps
Window Size (N_{win})	Different values like, N_{win}=5, 10, 15

To analyze, in detail, the effects of different parameters on the performance of the modified user mobility definition, wide range of values for the parameters are considered during the performance analysis. The below table summarized all cases and parameters considered.

Not to repeat many figures, we have presented just some sample results in Figure 24-38. From the results of all the different cases considered, as well as from Figure 24-38, we can deduce some important results. These are as follows:

i) With exponential distributed β parameters, as compared to linear distribution, the modified user mobility definition can better follow the subscriber mobility of the environment.

ii) As of γ parameters, with increasing γ_2 values, the effect of λ_{hrq} on user mobility definition, compared to λ_h, is increasing. As the effect of λ_{hrq} increases, the system can adapt better to the subscriber mobility value of the next time interval. However, increasing γ_2 too much puts an overemphasis onto λ_{hrq}, and the user mobility value starts to reflect the next time interval subscriber mobility value, prematurely. We need to keep a balance between γ_1 and γ_2 values. Therefore, for the γ_1 and γ_2 parameters, we propose to use γ_1=0.5 and γ_2=0.5. We believe that this is a fair and realistic definition for our purpose.

iii) The modified user mobility definition could follow better the subscriber mobility of the area, compared to the classical approach, under all operational field input data sets.

iv) With N_{win}=10, as compared to N_{win}=5 case, the modified user mobility definition could closer follow the subscriber mobility of the environment. However, no noticeable difference has been observed for further increasing N_{win}.

From these observations, we can conclude that, for the user mobility using exponentially distributed β parameters, and with γ_1=0.5 and γ_2=0.5 values, we can reach a better user mobility definition, which is able to tack better the subscriber mobility of the area.

5.1.4. Handoff call dropping probability

From a subscriber's point of view, dropping a call, which is in progress, is considered far more annoying than blocking a new call establishment attempt [6, 7, 8, 18]. Therefore, handoff call dropping probability, that is, the handoff failure probability P_f is an important QoS parameter. An efficient resource management algorithm must keep P_f within acceptable limits. We have analyzed the performance of the NCR, FCR, DCR and DRCH approaches for the QoS parameter P_f, using the separate mathematical system performance models, which we derived for all those approaches in section 4.2.

We have used Microsoft Excel to formulate the mathematical system performance models, and to make the numerical analysis. Once the mathematical models are formulated, Microsoft Excel makes it very easy to consider many scenarios and perform many numerical analyses. This is done by just copying the originals model files and changing the network traffic and subscriber mobility values related to the desired scenario.

Figures 55-57 show the results of the P_f performance analysis under various user mobility conditions, and for a wide range of network traffic, starting from very low load to very high load conditions.

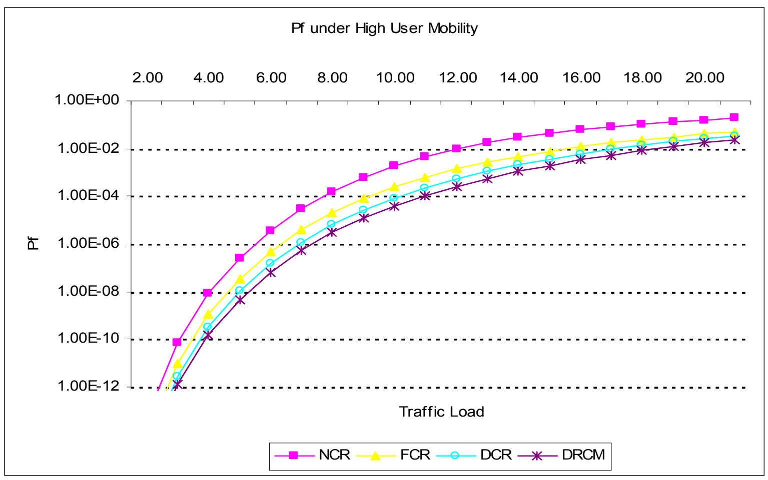


Figure 39. P_f performance results for the high user mobility (α=2) case

Figure 39 shows the P_f performance results for the high user mobility (α=2) case. From Figure 39, one can observe that channel reservation improves the P_f performance. All the channel reservation techniques have improved P_f performance, compared to the No Channel Reservation (NCR) case. For all network traffic values, the NCR, which does not reserve any channels for handoff calls and treats handoff call attempts and new call establishment attempts in the same way, shows the poorest P_f performance. Even the simplest channels reservation scheme FCR, which reserves a predefined fixed amount of radio channels for handoff calls, shows a considerable improvement compared to the

NCR case. However, since the case considered here assumes a relatively high user mobility condition, the DCR, which adjusts its reserved channels dynamically according to the local user mobility estimate within the cell of interest, reserves a higher number of radio channels compared to the FCR case. Therefore, it has an improved performance over the FCR case. The DRCM scheme shows improved P_f performance, even when compared with DCR. This is thanks to the highly adaptive threshold adjustment of DRCM. The DRCM scheme takes into account not only the current user mobility figures from the operational environment, but also the handoff reservation requests from the mobiles in the surrounding cells. In this way, it becomes ready for the near future expected changes in the user mobility conditions and reserves ideal number of channels for handoff calls.

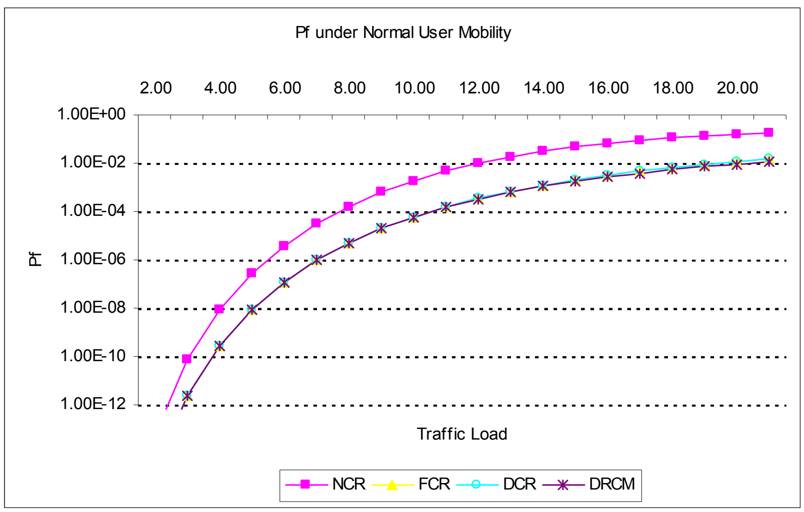


Figure 40. P_f performance results for the normal user mobility (α=1) case

Figure 40 shows the P_f performance results for the normal user mobility (α=1) case. In the normal user mobility case, the number of handoff call arrivals and new call arrivals are the same. In this case, the number of reserved channels for handoff calls is equal for all FCR, DCR and DRCM techniques. Therefore, P_f performance is equal for all of them and better than the NCR technique.

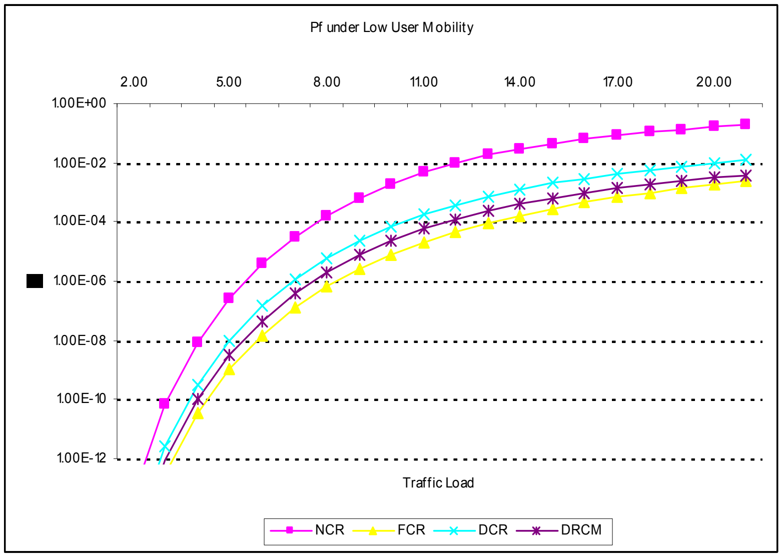


Figure 41. P_f performance results for the low user mobility (α=0,5) case

Figure 41 shows the P_f performance results for the low user mobility (α=0.5) case. From Figure 41, we can observe the effect of channel reservation on P_f performance. For all network traffic values, all of the channel reservation techniques perform far better than the NCR method. The FCR method performs superior under this user mobility condition. This is due to overemphasized number of reserved channels for handoff calls for this case. The drawback of this fact shows up, as the poorest P_b performance. The DRCM proves good P_f performance, without any drawback on P_b performance, as will be seen in the following section.

5.1.5 New Call Blocking Probability

Reserving radio channels for handoff calls improves handoff-dropping probability. This we have shown in section 5.1.4. Since we need to reserve radio channels to improve handoff-dropping probability, some new call blocking probability and BW utilization have to be sacrificed. However, reserving more than necessary radio channels can end up with unnecessary new call blockings. Unnecessary new call blockings results in poor radio channel utilization. From a service provider's point of view, however, the resource management algorithm must utilize the radio channels in an efficient way to maximize revenue (valuation is revenue per Kbps of spectrum).

In this section, we have analyzed the performance of the NCR, FCR, DCR and DRCH approaches for the QoS parameter P_b, using the separate mathematical system performance models, which we derived for all those approaches in section 4.2. Following figures summarize the results of the numerical analysis.

Figures 58-60 show the results of the P_b performance analysis under various user mobility conditions, and for a wide range of network traffic from very low load to very high load conditions.

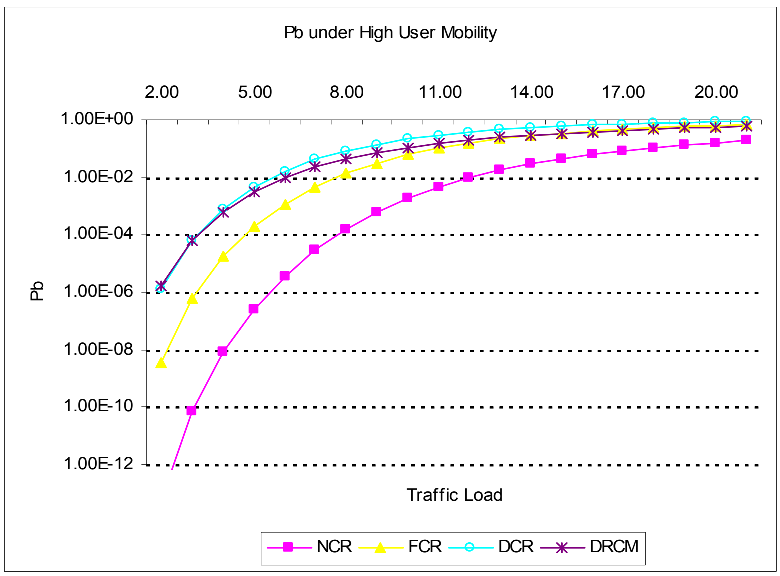


Figure 42. P_b performance results for the high user mobility (α=2) case

Figure 42 shows the P_b performance results for the high user mobility (α=2) case. Highest P_b performance is for the NCR scheme. This is, of course, something expected. Since the NCR does not reserve any channels for the handoff calls, least new call blocking will occur in the NCR case. Actually, for the NCR the P_b and P_f figures are the same. Because NCR treats both handoff call attempts and new call attempts equally, they have equal probability of being denied service. The more reservations are made for handoff calls, the more new call connections that are trying to access the resources will be denied. It is however interesting to note that, although the DRCM scheme that reserves highest number of channels for handoff calls in the high user mobility case, does not have poorest P_b performance. We can observe a certain amount of improvement, compared to the DCR case. We can observe that, although reserving higher number of channels for the handoff calls under high user mobility conditions to improve P_f performance, DRCM does not necessarily perform poorer than DCR in terms of P_b. This simultaneous improvement in both P_b performance and P_f performance is due to two facts. First, it is thanks to the simultaneous implementation of both the channels reservation process and the new call admission process in the resource management algorithm in DRCM, as explained in sections II.2 and II.3. Second, it is thanks to the situation awareness of the near future's expected subscriber mobility value, which is coming from the call statistics kept by the individual mobiles.

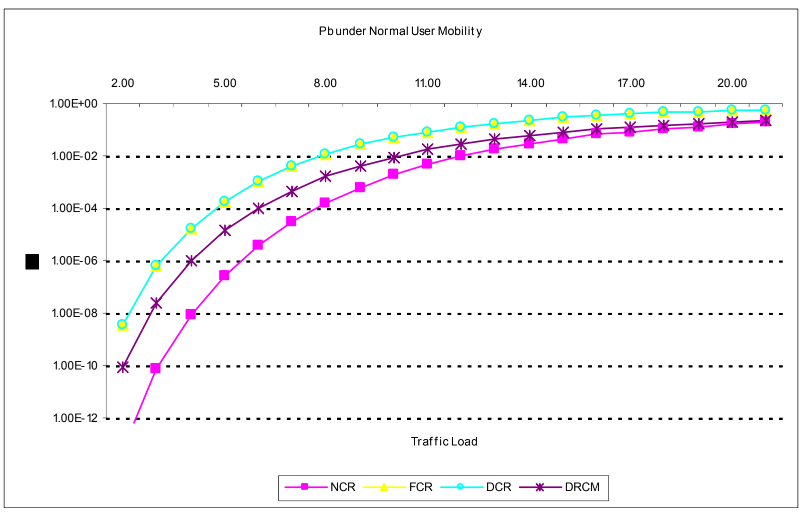


Figure 43. P_b performance results for the normal user mobility (α=1)

Figure 43 shows the P_b performance results for the unity user mobility (α=1) case. In the "unity" user mobility case, the number of handoff call arrivals and new call arrivals are the same. In this case, the number of reserved channels for handoff calls is equal for all FCR, DCR and DRCM techniques. Normally, one would expect same P_b performance for all of them, because the resource reservation process of the DRCM method predicts same amount of radio channels for handoff calls as compared to FCR and DCR. P_b performance is, indeed equal for FCR and DCR cases. However, the DRCM technique shows improved performance, in the normal user mobility case as well. This is because; the new call admission process prevents some unnecessary new call blockings.

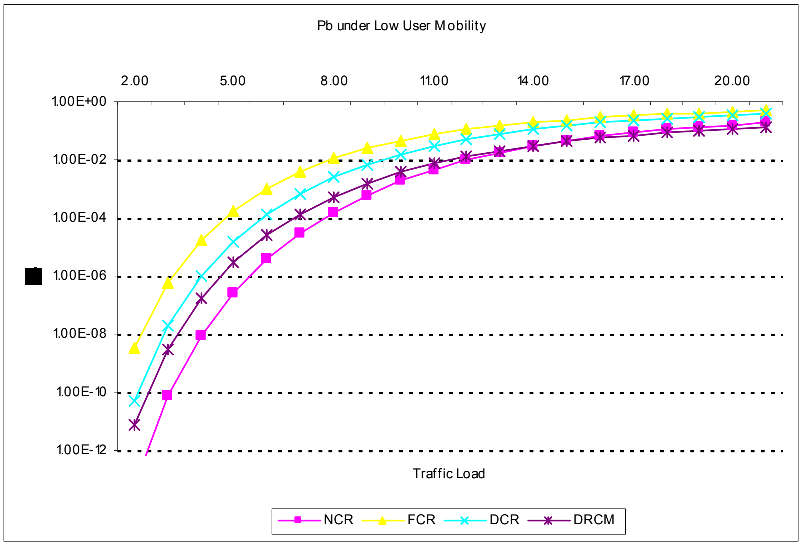


Figure 44. P_b performance results for the low user mobility (α=0.5) case

Figure 44 shows the P_b performance results for the low user mobility (α=0.5) case. From Figure 44 we can observe the poorest performance for the FCR case, which for this user mobility value reserves more than necessary radio channels for handoff calls. The DRCM technique, on the other hand, shows an important improvement over the DCR case, even under low user mobility value.

5.2 Results of Software Simulations

We have performed several software simulation runs, to predict the P_f, P_b and bandwidth utilization performances of the compared methods. These software simulations were done both for 24-hour to simulate a whole day traffic, and for one hour to simulate the peak-hour traffic. The scenarios considered and the environments simulated include, but are not limited to, a network traffic range of 10%, 30%, 50%, 70%, and 90% of the total cell capacity, and a user mobility range of low user mobility (α=0.5), unity user mobility (α=1), and high user mobility (α=2). We have chosen these values of network traffic and user mobility, to match the scenarios and simulation environment to the cases considered in the mathematical analysis part. The simulation run results of all the scenarios and simulation environments considered are included in the CD provided. We present the results of some typical runs here, in tabular form.

In the 24-hour simulation runs, both the user mobility and the network traffic are time-varying. These follow actual network traffic and subscriber mobility figures, as observed in collected field data. The user mobility values given in the below analysis are the average of the 24-hour. The network traffic values categorized as 10%, 30%, 50%, 70%, and 90% of the total cell capacity are the peaks experience during the 24-hour.

Table-1 shows the simulation results of 24-hour simulation runs. The scenarios considered have, on average, low network traffic (10% of the total cell capacity). For the subscriber mobility, three separate user mobility characteristics are considered. These are, low user mobility (α=0.5), unity user mobility (α=1), and high user mobility (α=2).

From Table-2 we can observe that there are no blocked new calls or dropped handoff calls, for all the user mobility values considered. This is something expected, of course, since the scenario considered has low network traffic (10% of the total cell capacity). For this low network traffic scenario, all the methods under comparison behave similarly. These values prove the expected results of the low user mobility case.

Table-3 shows other simulation results of 24-hour simulation run. In all the three cases, the scenarios considered have moderate network traffic (50% of the total cell capacity). For the subscriber mobility, again three separate user mobility characteristics are considered. These are, low user mobility (α=0.5), unity user mobility (α=1), and high user mobility (α=2).

Table-2 Results of the 24-hour simulation runs under low network traffic (10% of the total cell capacity) conditions

Simulation Results					
User Mobility		***NCR***	***FCR***	***DCR***	***DRCM***
α = 0.5	**Utilization**	0.090	0.090	0.090	0.090
	Pb	0.000	0.000	0.000	0.000
	Pf	0.000	0.000	0.000	0.000
α = 1	**Utilization**	0.100	0.100	0.100	0.100
	Pb	0.000	0.000	0.000	0.000
	Pf	0.000	0.000	0.000	0.000
α = 2	**Utilization**	0.088	0.088	0.088	0.088
	Pb	0.000	0.000	0.000	0.000
	Pf	0.000	0.000	0.000	0.000

Table-3 Results of the 24-hour simulation runs under moderate network traffic (50% of the total cell capacity) conditions

Simulation Results					
User Mobility		***NCR***	***FCR***	***DCR***	***DRCM***
α = 0.5	**Utilization**	0.425	0.376	0.408	0.418
	Pb	0.036	0.204	0.104	0.070
	Pf	0.039	0.000	0.003	0.016
α = 1	**Utilization**	0.397	0.376	0.368	0.384
	Pb	0.004	0.095	0.129	0.059
	Pf	0.003	0.000	0.000	0.001
α = 2	**Utilization**	0.393	0.379	0.360	0.376
	Pb	0.000	0.075	0.195	0.103
	Pf	0.001	0.000	0.000	0.000

From Table-3, we can observe that with that amount of traffic, there are already some blocked new calls or dropped handoff calls, at least for some of the methods compared and under some user mobility values considered. With this network traffic amount, we can observe the effect of different resource management algorithms implemented in the compared methods.

Table-4 shows, yet other 24-hour simulation run results. In all the three cases, the scenarios considered have high network traffic (90% of the total cell capacity). For the subscriber mobility, again three separate user mobility characteristics are considered. These are, low user mobility (α=0.5), unity user mobility (α=1), and high user mobility (α=2).

Table-4 Results of the 24-hour simulation runs under high network traffic (90% of the total cell capacity) conditions

Simulation Results					
User Mobility		***NCR***	***FCR***	***DCR***	***DRCM***
α = 0.5	**Utilization**	0.662	0.554	0.632	0.652
	Pb	0.210	0.488	0.307	0.258
	Pf	0.244	0.001	0.098	0.156
α = 1	**Utilization**	0.600	0.496	0.522	0.569
	Pb	0.167	0.509	0.440	0.329
	Pf	0.173	0.001	0.004	0.031
α = 2	**Utilization**	0.600	0.517	0.488	0.531
	Pb	0.164	0.600	0.700	0.551
	Pf	0.157	0.019	0.016	0.021

Table-4 shows the simulation results for 24-hour simulation run, for an area with high network traffic characteristics. Since the network traffic is very high, we notice some important performance differences. The NCR method satisfies the desired P_f performance ($P_{f,target}$=0.1) in non of the user mobility cases considered. All the channels reservation methods bring improvement to the P_f performance. However, since the network traffic considered is very high, the improvement in P_f performance has a deep impact on P_b performance. In the FCR and DCR cases, the adverse effect on P_b performance is very high, especially in the high mobility case, as expected. This is the main reason of the drop in channel utilization, for the FCR and DCR cases. Just like in the mathematical analysis part, the software simulation under the given scenario predict that, the DRCM has improved channel utilization and P_b performance compared to the FCR and DCR cases. The effect of the two-way implementation in the resource management algorithm, which are the resource reservation and new call admission processes, shows itself as improved P_b performances and higher spectral efficiency in the DRCM case compared to the FCR and DCR cases.

The scenario simulated in this case has high network traffic. Therefore, in Table-4 we can observe relatively high blocked new calls or dropped handoff calls. Although the case considered here is a high network traffic scenario, the bandwidth utilization figures are, somehow low compared to what someone would expect under that much network traffic. This is because, the simulation run covers a 24-hour period, during which the peak network traffic reaches 90% of the total cell capacity. The handoff call droppings and new call blockings are mainly from such network traffic peaks. This leads us to the peak-hour simulations.

To have a better understanding about the peak hour behavior of the compared methods, we have performed separate simulation runs for the peak-hour analysis. Besides the P_f, P_b and bandwidth utilization results, in the peak-hour simulation results we have also recorded the handoff and new call count, and the handoff call drops and new call blockings, to have a better understanding about call statistics. We have presented these in the below tables related to peak-hour performance results.

In the peak-hour simulation runs, the mean values of the call arrivals are constant over the simulation period. We have categorized the scenarios and simulation environments in terms of network traffic and user mobility, according to the mean values of the call arrivals.

The performance results of all network traffic and user mobility cases evaluated are included in the attached CD. Since there are no major performance differences for the low network traffic conditions, as it was in the 24-hour simulation case, we provide here the performance results of high network traffic scenarios with a number of different user mobility cases.

Table-5 Peak-Hour simulation results under high network traffic and low user mobility (α=0.3) conditions

Peak Hour Simulation Results				
	NCR	***FCR***	***DCR***	***DRCM***
Channel Utilization	0,904	0,765	0,792	0,857
P_b	0,138	0,290	0,287	0,176
P_f	0,129	0,000	0,000	0,024
New Call Count (Blocked/Total)	330/2391	687/2367	688/2394	399/2271
Handoff Call Count (Dropped/Total)	76 / 589	0 / 574	0 / 580	15 / 613

Table-5 shows the peak-hour simulation run results for high network traffic (90% of the total cell capacity) and low user mobility (α=0.3) conditions. As in all peak-hour simulation run results, in Table-10 we can see that the channel utilizations are relatively high for all the methods under investigation, as compared to the 24-hour simulation run results. This is because during the peak-hour simulation runs, the radio network is heavily utilized continuously.

From Table-5, we can derive some important conclusion. Here again, the NCR method, although having highest channel utilization, can not satisfies the desired P_f performance ($P_{f,target}$=0.1). Since channel reservation methods need to reserve some radio channels for handoff calls to improve handoff-dropping probability, they have to sacrifice some new call blocking probability and BW utilization. That is exactly what we observe in the FCR, DCR and DRCM methods. All channel reservation methods bring improvement to the P_f performance. However, this improvement is at a cost of increase in P_b performance and decrease in channel utilization. Since the case considered in Table-5 is a low user mobility case, meaning higher number of new calls compared to handoff calls, reserving radio channels generously, combined with high traffic figures, can bring considerable amount of adverse effect on P_b performance. This is exactly what happens in the FCR and DCR cases. To prevent 76 handoff call droppings observed in the NCR case during one hour, both methods cause over 350 additional new call blockings. The DRCM method, on the other hand, prevents 65 handoff call droppings out of the 76, by just sacrificing 69 additional new call attempts. This is, of course, a reasonable trade-off, and the high spectral efficiency of the DRCM case verifies this trade-off.

Going through Tables 6-8, we can make similar observations and similar conclusions. For example, in the equal handoff and new call arrival case, whose results we present in Table-6, 321 handoff call drops occurred in the NCR case. Both the FCR and DCR methods reduce this amount of handoff call drops to eight handoff call drops, at a cost of more that 600 additional new call blockings. For the DRCM method, this cost is 400 new calls only.

From Table-8, we can see that with the increasing user mobility, the FCR and DCR methods are justified in their approach, to some extend. That is why the bandwidth utilization of both methods is increasing with increasing user mobility.

With increasing mobility, the number of unnecessary new call blockings, that can be detected and prevented by the DRCM method, becomes smaller and smaller.

Table-6 Peak-Hour simulation results under high network traffic and low user mobility (α=0.5) conditions

Peak Hour Simulation Results				
	NCR	***FCR***	***DCR***	***DRCM***
Channel Utilization	0.881	0.756	0.756	0.834
P_b	0.110	0.299	0.299	0.221
P_f	0.110	0.000	0.000	0.013
New Call Count (Blocked/Total)	198 / 1793	526 / 1759	526 / 1759	397 / 1800
Handoff Call Count (Dropped/Total)	133 / 1212	0 / 1202	0 / 1202	16 / 1220

Table-7 Peak-Hour simulation results under high network traffic and unity user mobility (α=1) conditions

Peak Hour Simulation Results				
	NCR	***FCR***	***DCR***	***DRCM***
Channel Utilization	0.915	0.799	0.798	0.862
P_b	0.177	0.509	0.507	0.395
P_f	0.178	0.005	0.004	0.037
New Call Count (Blocked/Total)	313 / 1765	933 / 1834	932 / 1836	713 / 1808
Handoff Call Count (Dropped/Total)	321 / 1801	8 / 1774	8 / 1776	68 / 1843

Table-8 Peak-Hour simulation results under high network traffic and high user mobility (α=2) conditions

Peak Hour Simulation Results				
	NCR	***FCR***	***DCR***	***DRCM***
Channel Utilization	0.908	0.805	0.796	0.819
P_b	0.162	0.526	0.609	0.482
P_f	0.176	0.011	0.002	0.021
New Call Count (Blocked/Total)	192 / 1185	677 / 1288	771 / 1266	578 / 1198
Handoff Call Count (Dropped/Total)	431 / 2454	26 / 2290	5 / 2370	49 / 2362

The aim of the software simulation runs was to prove the numerical performance analysis, and to predict direct bandwidth utilization analysis. Careful examination of the simulation results show that, the simulation runs predict indeed similar performance results compared to the mathematical analysis results obtained in section 5.1 about QoS parameters. We have performed a detailed comparison of mathematical and simulation analysis results in section 5.3

In any software simulation, before reporting any results, we must prove that, the results obtained are not due to random noise and are statistically significant. Since the radio spectrum is a limited resource, the performance improvement of any solution will not be huge compared to existing solutions. Therefore, in our case, it is more important to prove that the performance improvement of the proposed DRCM method predicted by the simulations is significant. One efficient way to decide on the significance of the simulation results is to repeat the simulations for the same scenario, without changing the environmental conditions, until we can decide which results are real and which are random.

The simulation results presented in Table2 through Table8 consider a wide range of network traffic and subscriber mobility. The simulation results proved to be consistent with the mathematical results. However, these results were the average obtained from three simulation runs for each case. Three simulations may not be sufficient to decide on the stability and quality of the results. Therefore, we need to perform a number of successive simulation runs to verify that the results obtained are not due to random noise and the predicted performance differences are statistically significant.

In any simulation, repeating simulation runs and changing nothing other than the random number seeds can cause what appear to be large differences in output. If we are to use simulation in real problems, we need a means how to tell which effects are random and which are real. In the GPSS World, the “Analysis of Variance (ANOVA)” command provides a way for this purpose. The ANOVA command makes a first level of statistical analysis relatively easy. After one has fully tested a simulation under a variety of conditions, one will probably want the answers to some questions from the simulation. That is where experimentation comes in. In order to predict the effects of factors under our control, we will need to simulate each of the possibilities and determine if the result exceeds that due only to random variation. The ANOVA command in GPSS provides an efficient way for this purpose.

Keeping in mind that little number of runs for a specific scenario may not be enough to decide that the results are statistically significant; we have performed many runs or "replicas" for each of four methods compared, and for every scenario considered. Replicas are runs of identical conditions except that a different set of seeds is used to prime the pseudo-random number generators. This provides a baseline of variability due only to random effects. It will show us whether the results obtained are statistically significant, and are not due to random noise only.

When we use statistical methods to see if two alternatives are different in performance, we must not allow extraneous uncontrolled events to occur during the simulations. It would not be fair to load one run with additional activities at some unknown place in the simulation, and not to do precisely the same thing in all other runs. Therefore, we have used the same seed set that belongs to a specific scenario for all the methods compared. Since our results are in the form of an arithmetic average of many results, we are justified in using the ANOVA command to do a statistical analysis. Using the ANOVA block statement, we have derived the statistical mean and variance of the performance parameters Pb, Pf and bandwidth utilization, from the successive simulation runs, for each case under consideration.

For each scenario and environmental conditions considered, and for each of the four methods compared, we have performed successive simulation runs, and recorded the results from the ANOVA output file. Figure 45 illustrates a sample ANOVA output file. From this file, we can read the mean and variance of the QoS parameter under investigation. As a starting point, we started with 10 replications for each scenario and environmental conditions considered, and repeated these 10 replications for all the four methods compared.

Anova (Pbresults, 2, 2)

ANOVA

Source of Variance	Sum of Squares	Degrees of Freedom	Mean Square	F	Critical Value of F (p=.05)
A	0.000	0			
Error	0.087	44	0.002		
Total	0.087	44			

Treatment Level A	Count	**Mean**	Min	Max	95% C.I. (SE)
1	45	**0.198**	0.167	0.335	(0.185, 0.211)

Variance 0.0443941

Anova (Pfresults, 2, 2)

ANOVA

Source of Variance	Sum of Squares	Degrees of Freedom	Mean Square	F	Critical Value of F (p=.05)
A	0.000	0			
Error	0.066	44	0.002		
Total	0.066	44			

Treatment Level A	Count	**Mean**	Min	Max	95% C.I. (SE)
1	45	**0.096**	0.009	0.132	(0.084, 0.108)

Variance 0.0387694

Anova (Unresults, 2, 2)

ANOVA

Source of Variance	Sum of Squares	Degrees of Freedom	Mean Square	F	Critical Value of F (p=.05)
A	0.000	0			
Error	0.030	44	0.001		
Total	0.030	44			

Treatment Level A	Count	**Mean**	Min	Max	95% C.I. (SE)
1	45	**0.895**	0.799	0.923	(0.887, 0.902)

Variance 0.0261210

Figure 45. Sample Analysis of Variance (ANOVA) output file

To see the effect of the replications on the performance, we have repeated the replications, each time with increased number of simulation runs in each replication. The increments were additional five repetitions at each stage. As we can see from Figures 46-51, repeating replications beyond 50 simulation runs turned to be useless, since we could observe no noticeable difference in performance after 40-50 simulation runs.

Figure 46 through Figure 51 show the results of a scenario where the network traffic is relatively high (90% of total cell capacity), and the user mobility is low (α=0.5). In those figures, we present the mean and variance of P_b, P_f and bandwidth utilization, as the output of successive runs. The x-axis shows the number of successive simulation runs, which we have performed each time with a different seed set. The purpose of running many successive simulations is to verify that the results are not due to random noise and the performance differences observed are statistically significant. To have a fair comparison, we use the same seed sets for all the four methods compared. We started with 10 successive simulation runs for each case, and continued until there is no more performance difference among the replications.

Figure 46-51 show the mean and variance of P_b, of the compared four methods. The scenario considered is high network traffic (90% of total cell capacity) and low user mobility (α=0.5) scenario. The replications start with a replication of 10 simulation runs and extend to a replication with 60 simulation runs. From the results presented in Figure 46-47, we can observe that there is a clear and steady separation between the P_b performance figures of the four methods compared. Besides, there is no much difference between the 10 simulation run results and the 60 simulation run results. Moreover, the variance analysis results, presented in Figure 47, show small variance values. Therefore, we can conclude from Figure 46-47, that the P_b performance results obtained are statistically significant, and the performance difference among the compared methods is well above random noise.

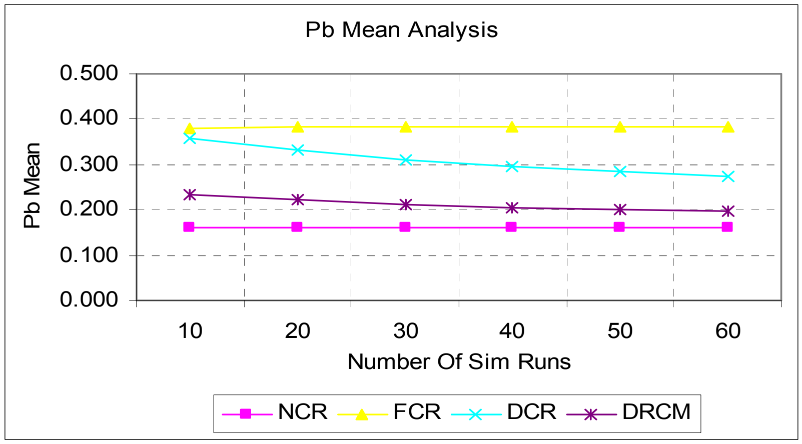


Figure 46. P_b Mean Analysis under high network traffic (90% of total cell capacity) and low user mobility (α=0.5).

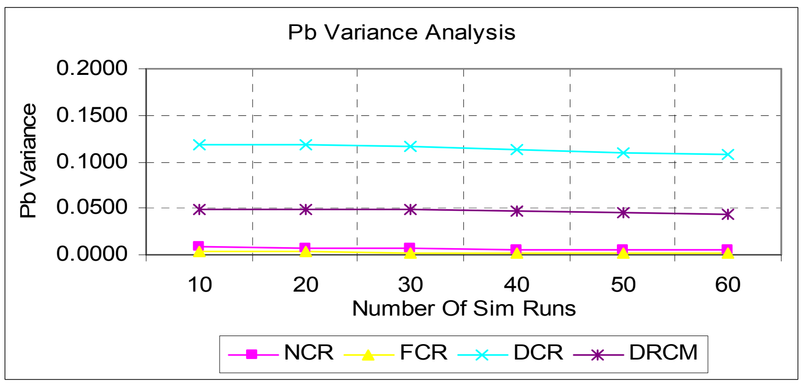


Figure 47. P_b Variance Analysis under high network traffic (90% of total cell capacity) and low user mobility (α=0.5).

Figure 48-49 show the mean and variance of P_f, of the compared four methods. The scenario considered is high network traffic (90% of total cell capacity) and low user mobility (α=0.5) scenario. Again, the replications start with a replication of 10 simulation runs and extend to a replication with 60 simulation runs. From the results presented in Figure 48-49, we can observe that there is no much difference between the 10 simulation run results and the 60 simulation run results, and the results prove to be consistent. Moreover, the variance analysis results, presented in Figure 49, show very small variance values, compared to the respective mean values. Therefore, we can conclude from Figure 48-49, that the P_f performance results obtained are statistically significant, and the performance difference among the compared methods is well above random noise.

Figure 50-51 show mean and variance analysis results of the bandwidth utilization. From the results presented in Figure 50, we can observe that the low channel utilization for the FCR method, under this scenario with high network traffic and low user mobility values, is persistent. Besides, the performances of the dynamic reservation methods are stable and approach to that of the baseline method (the NCR method). The very low variance figures presented in Figure 51, compared to the high mean values, clears any doubts about the performance differences in bandwidth utilization results being well above random noise, and therefore being statistically significant.

The P_b, P_f, and utilization mean and variance analysis results presented in Figure 50-51 proves a clear performance difference among the compared methods. The results obtained using many replications prove that the performance difference observed are not due to random noise. We conclude that the performance improvement of the DRCM is statistically significant, at least for the low user mobility case.

In Figure 46-51, we have presented the mean and variance analysis results, derived from the replication simulation runs for a scenario of high network traffic (90% of total cell capacity) and low user mobility (α=0.5). In order to have a throughout study, and include all scenarios considered in the 24-hour and peak hour simulation runs, as well as all cases considered in the mathematical analysis part, we have repeated the replication runs to do the mean and variance analysis, for the unity user mobility (α=1) and high user mobility (α=2) cases as well. Results of the mean and variance analysis of high network traffic (90% of total cell capacity) and unity user mobility (α=1) are presented in Figure 52-57, and the results of the mean and variance analysis of high network traffic (90% of total cell capacity) and high user mobility (α=2) are presented in Figure 58-63.

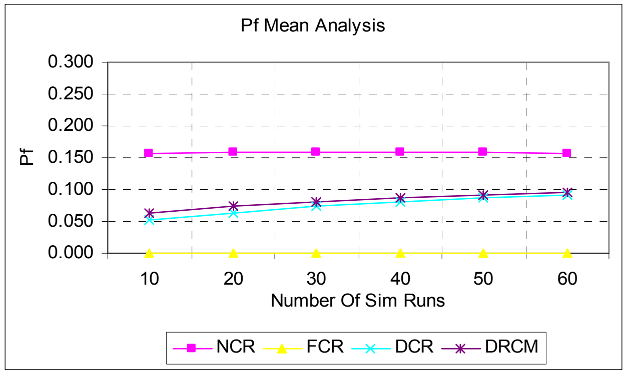


Figure 48. P_f Mean Analysis under high network traffic (90% of total cell capacity) and low user mobility (α=0.5).

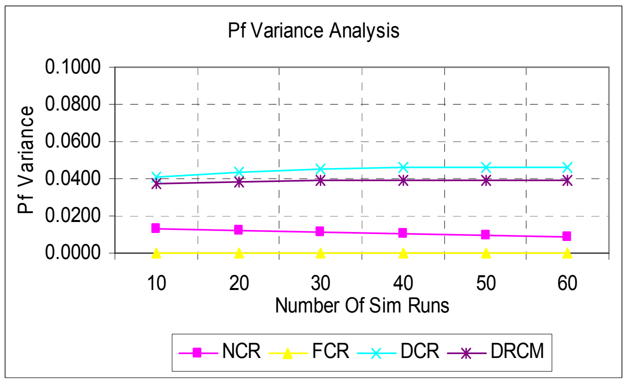


Figure 49. P_f Variance Analysis under high network traffic (90% of total cell capacity) and low user mobility (α=0.5).

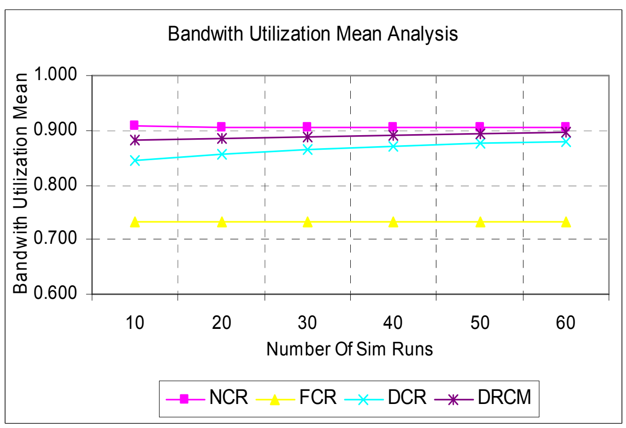


Figure 50. Bandwidth Utilization Mean Analysis under high network traffic (90% of total cell capacity) and low user mobility (α=0.5).

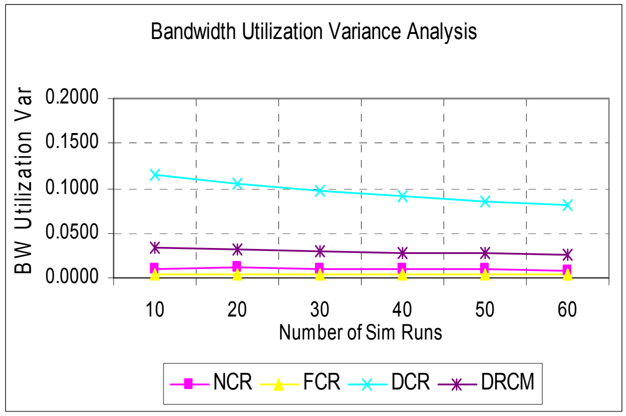


Figure 51. Bandwidth Utilization Variance Analysis under high network traffic (90% of total cell capacity) and low user mobility (α=0.5).

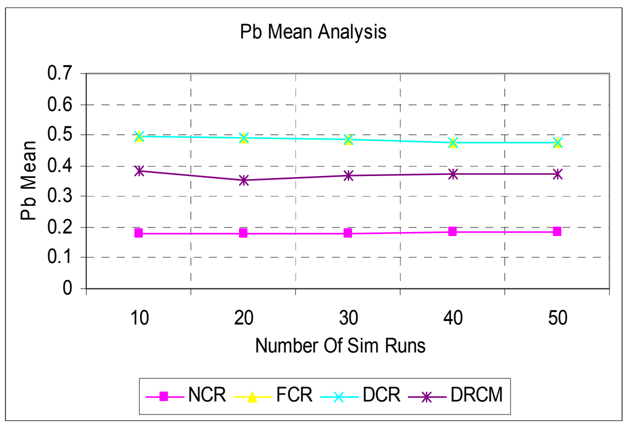


Figure 52. P_b Mean Analysis under high network traffic (90% of total cell capacity) and unity user mobility (α=1).

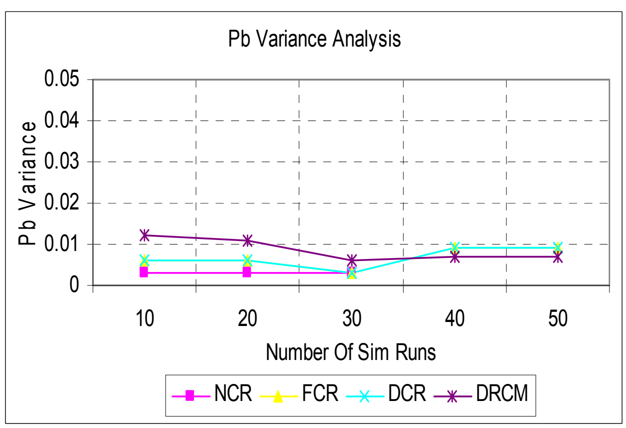


Figure 53. P_b Variance Analysis under high network traffic (90% of total cell capacity) and unity user mobility (α=1).

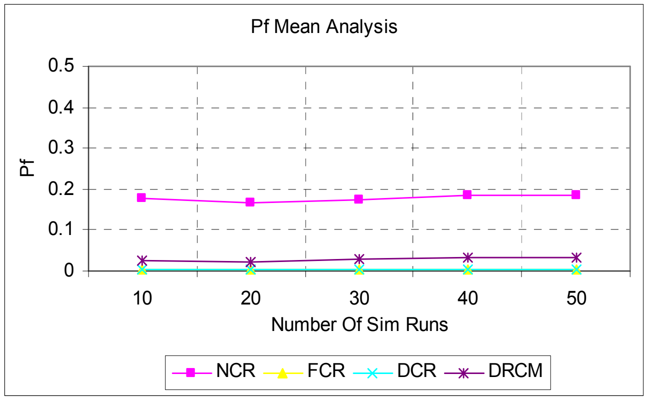


Figure 54. P_f Mean Analysis under high network traffic (90% of total cell capacity) and unity user mobility (α=1).

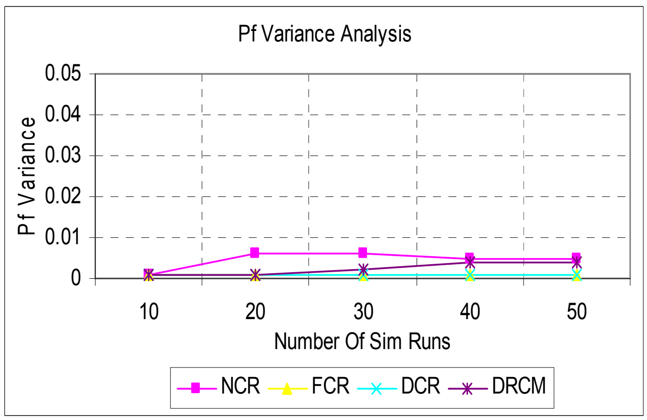


Figure 55. P_f Variance Analysis under high network traffic (90% of total cell capacity) and unity user mobility (α=1).

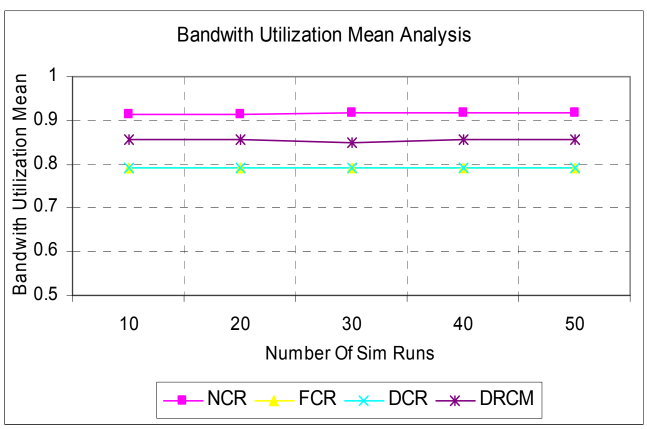


Figure 56. Bandwidth Utilization Mean Analysis under high network traffic (90% of total cell capacity) and low user mobility (α=1).

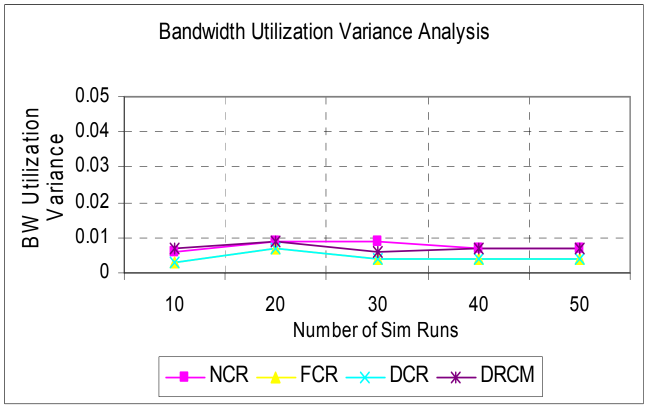


Figure 57. Bandwidth Utilization Variance Analysis under high network traffic (90% of total cell capacity) and low user mobility (α=1).

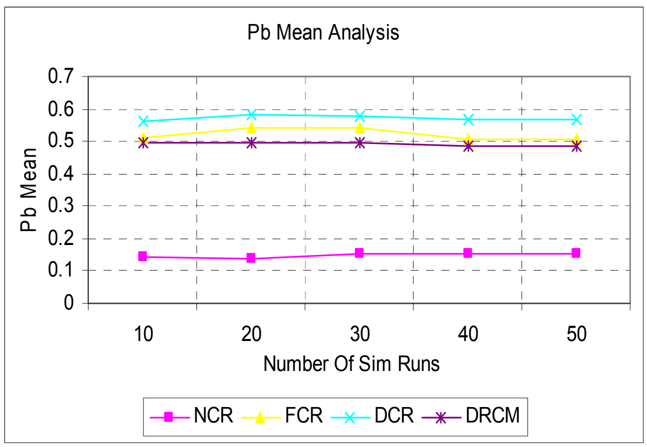


Figure 58. P_b Mean Analysis under high network traffic (90% of total cell capacity) and high user mobility (α=2).

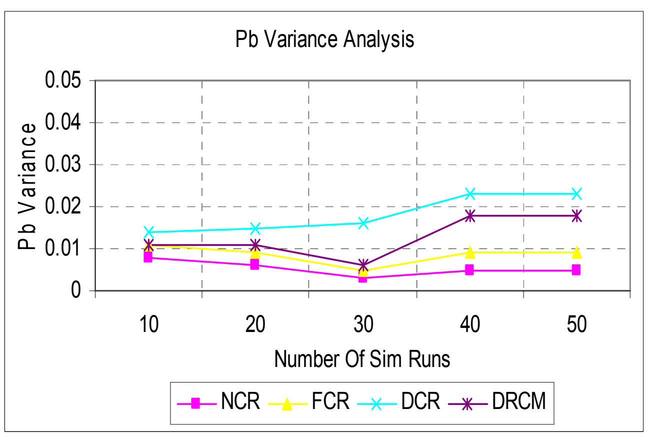


Figure 59. P_b Variance Analysis under high network traffic (90% of total cell capacity) and high user mobility (α=2).

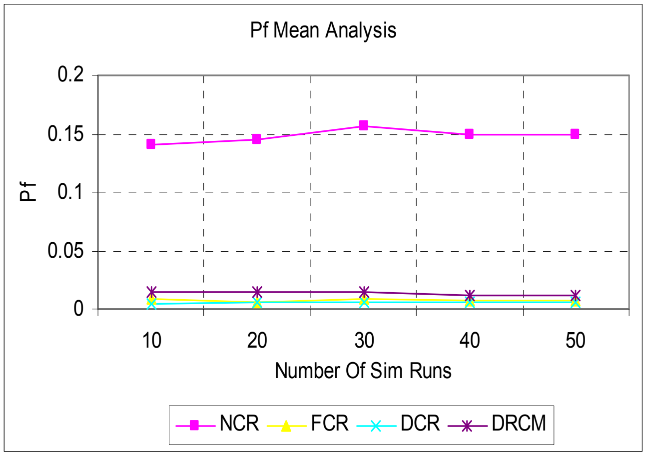


Figure 60. P_f Mean Analysis under high network traffic (90% of total cell capacity) and high user mobility (α=2).

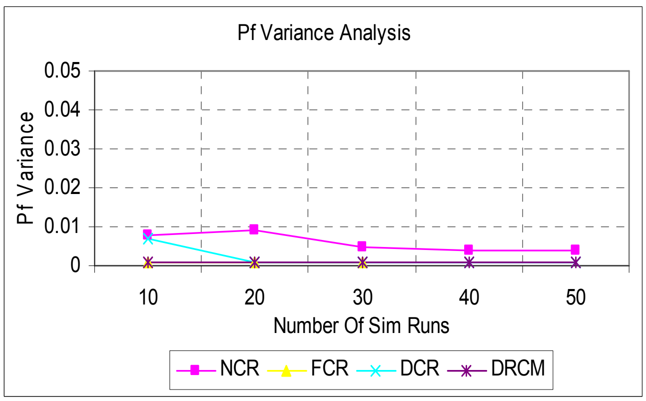


Figure 61. P_f Variance Analysis under high network traffic (90% of total cell capacity) and high user mobility (α=2).

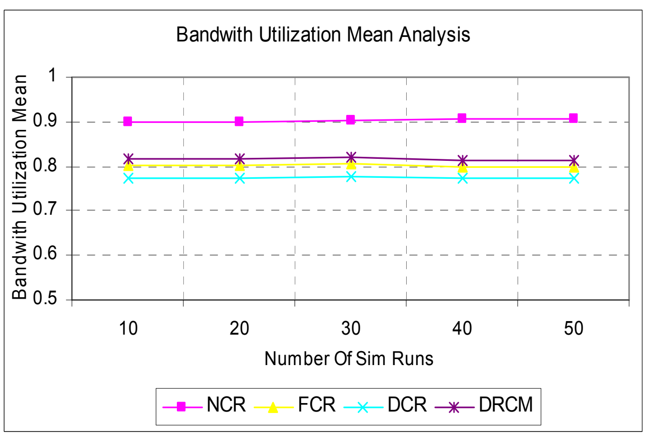


Figure 62. Bandwidth Utilization Mean Analysis under high network traffic (90% of total cell capacity) and high user mobility (α=2).

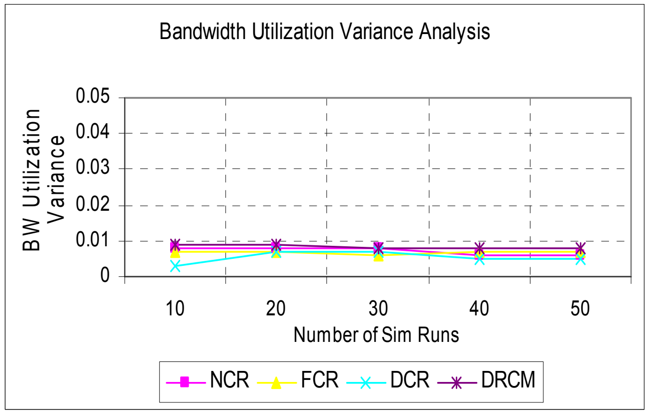


Figure 63. Bandwidth Utilization Variance Analysis under high network traffic (90% of total cell capacity) and high user mobility (α=2).

Going through Figure 46 to Figure 63, we can derive some important conclusions. The purpose of the replication runs was to prove that the performance results predicted by the software simulation runs are statistically significant. Our aim was to repeat each simulation run, for a specific method under consideration and under a specific scenario, without changing any environmental parameter, as many times as it is necessary, until we could be sure about the stability and quality of the results that we have obtained. We could observe that there was no much difference between the results of the replication run consisting of 10 repeated simulations and the results of the replication run consisting of 50 repeated simulations. Besides, the performance difference among the methods under evaluation was stable. Moreover, the variance analysis proved very small variance compared to the corresponding mean values of P_b, P_f, and bandwidth utilization. Therefore, we could conclude that the simulation results for the P_b, P_f, and spectral efficiency analysis were statistically significant.

The mean and variance analysis derived from the replication simulation runs, not only proved the quality and stability of the software simulations results, but also verified the mathematical analysis results derived in the previous section. Section 5.4 provides a comparison of the mathematical analysis results and the software simulation results.

5.3 Software Simulations under fixed P_f

The results of software simulations presented in Section 5.2 were somehow difficult to compare because there were difficulties in finding a satisfactory basis for comparisons. Such a common basis could be to fix one of the parameters, such as P_f. In making simulations, the approach adopted was to fix P_f and determine performance of the four different approaches for this fixed P_f value. This has been done by an iterative procedure where input traffic was adjusted in a step by step manner until the targeted P_f value is obtained. It was a time consuming procedure where five different user mobility cases and five target P_f values were considered, resulting in a total of 25 different scenarios. This procedure was repeated for each of the four different approaches. Input of the simulation program, i.e. *input traffic* was changed in a trial and error manner until P_f value was within an acceptable range.

During simulations, values of carried traffic (successfully completed handoff and new calls), lost traffic (dropped handoff calls and blocked new calls), successful handoff calls, admitted new calls, dropped handoff calls and blocked new calls were evaluated. The obtained results are presented in the following.

Figure 64 shows the carried traffic for all of the user mobility values. The carried traffic is defined as the sum of successfully completed handoff calls and the new calls admitted during one hour simulation period. They show the carried traffic for the four compared methods under five different user mobility conditions ($\alpha = 4$, $\alpha = 2$, $\alpha = 1$, $\alpha = 0.5$, and $\alpha = 0.25$), and for five different handoff failure probability values of $P_f = 0.05$, $P_f = 0.10$, $P_f = 0.15$, $P_f = 0.20$, and $P_f = 0.25$. From the results, we have observed that the supported traffic per hour increases with increasing handoff failure probability for all the methods compared. This can be observed in Figure 64, from the increasing number of supported traffic with respect to increasing P_f value for a specific mobility value. The DRCM approach shows a clear improvement in terms of total supported number of calls for most of the cases considered. The only case where the FCR has shown better performance was the low user mobility cases.

One of the significant ways of comparing performance is look at the offered traffic values. It gives a good indication of efficiency of channel reservation process. Figure 65 gives simulation results as the ratio of carried traffic over the offered traffic. By definition, offered traffic is the sum of handoff call arrivals and new call arrivals, and carried traffic is the sum of successfully completed handoff calls and new calls admitted. Results of a total of 25 simulation runs were presented. The simulation runs cover the five mobility values ($\alpha = 4$, $\alpha = 2$, $\alpha = 1$, $\alpha = 0.5$, $\alpha = 0.25$), and for each of them five different P_f values ($P_f = 0.05$, $P_f = 0.10$, $P_f = 0.15$, $P_f = 0.20$, $P_f = 0.25$). From Figure 65, one can observe that, under high carried traffic for a wide range of user mobility and network traffic conditions, the DRCM method results in a fairly stable carried traffic over offered traffic ratio. This is an indication that the DRCM method can maintain a desired P_f value without causing unnecessarily high new call blockings. From Figure 65, one can also observe that, for user mobility equal to one, i.e. equal handoff and new call arrivals, the performance of the FCR approaches that of the DCR. This is something expected since for unity user mobility the DCR predicts the same amount of reserved capacity as FCR.

Figure 65 also shows ratio of carried traffic over offered traffic for all the mobility conditions. It can be observed that DRCM was able to show fairly stable performance in terms of carried traffic over offered traffic compared to the other channels reservation methods. Furthermore, one conclude that FCR which shows higher number of supported calls under low user mobility conditions can actually provide this at the cost of very high input traffic. This is because of the fact that FCR overemphasizes the importance of the handoff calls, rejecting a very large number of new calls.

Another comparison that is performed is based on the lost traffic. Figure 66 illustrates the lost traffic during the peak hour simulation for all the methods compared. Each figure shows the performance of the methods under a different user mobility value. The lost traffic is due to the dropped handoff calls and blocked new calls. Figure 66 proves the fact that the FCR supports higher number of calls for low user mobility values, however, this at a cost of high lost traffic.

The set of figures presented in Figure 67 show the performance comparison of the methods under evaluation in terms of a new concept. The two measures, P_f and P_b reflect two quantities which are not closely linked. Any comparison which takes into account only one of these two parameters could be misleading. In order to avoid this, weighted sum of successful handoff calls, successful new calls, dropped handoff calls and blocked new calls was studied. The weighted sum was calculated as:

$$W = a_1 \times NC_{success} + a_2 \times HC_{success} - b_1 \times NC_{fail} - b_2 \times HC_{fail}$$

where weights were real numbers. We can interpret such a weighted sum as a measure of net revenue earned by an operator. Plus sign means earning and minus sign means lost revenue. Then, an operator can choose these weights to maximize its earnings. This is equivalent to using a_1, a_2, b_1, and b_2 as guidelines for the policies to be followed during selection of channel reservation and new call rejection policies.

During this study, the effect of various values of a_1, a_2, b_1, and b_2 parameters have been analyzed. It could be observed that increasing the weights for the handoff performance parameters was increasing the performance gap between the NCR case and the channel reservation methods. On the other hand, increasing the weights for the new call admission performance was increasing the performance gap between FCR and the two dynamic channels reservation methods DCR and DRCM.

Results of five different set a_1, a_2, b_1 and b_2 values are provided in the attached CD. Due to lack of space, the results of one set are provided here. As a typical example, Figure 67 shows the performance comparison of the four methods under a_1=1, a_2=2, b_1=0.1 and b_2=0.2. From graphs it can be seen that the proposed DRCM method shows a superior performance compared to the other methods in all of the scenarios considered.

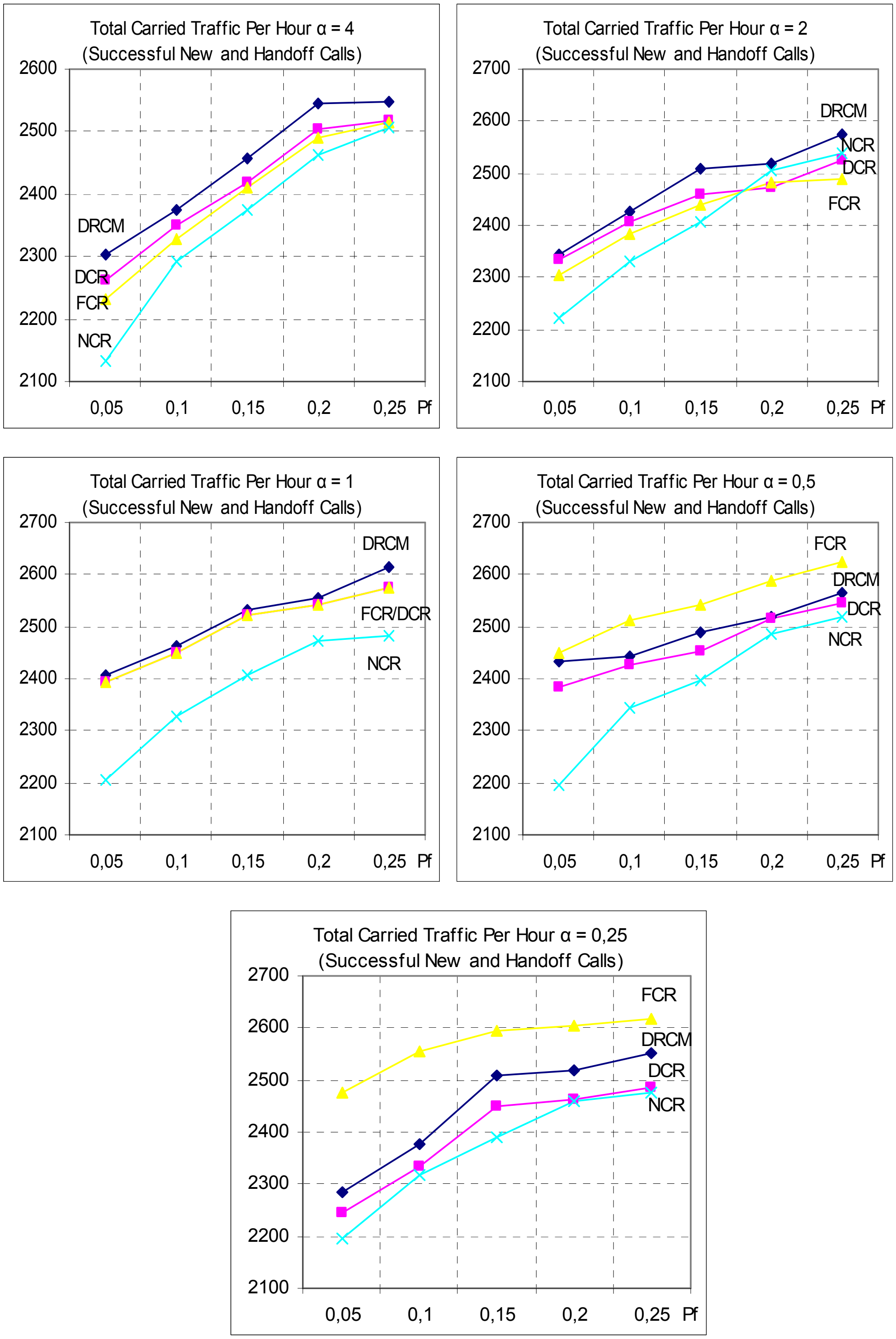


Figure 64. Total Carried Traffic with respect to increasing Pf

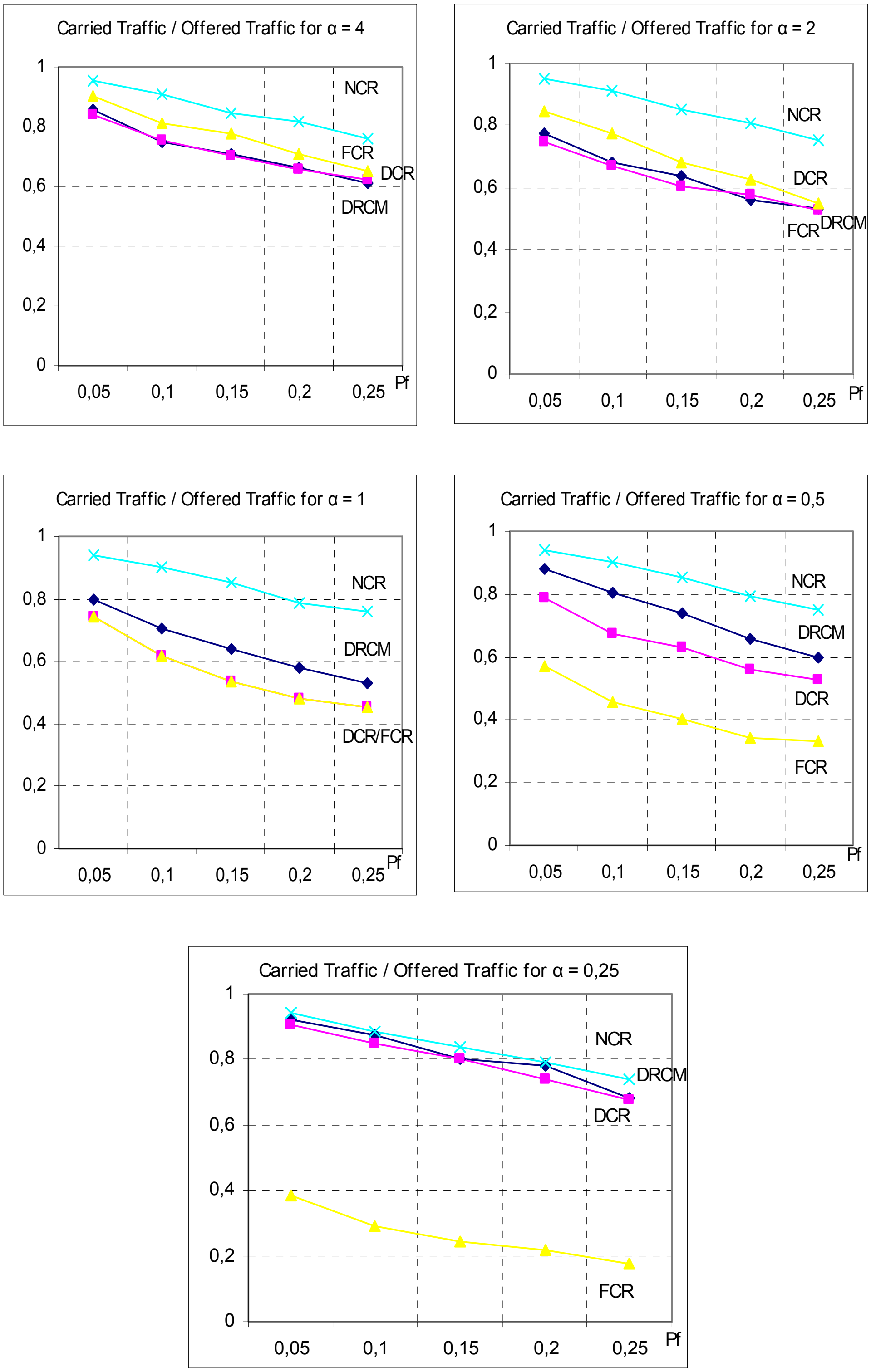


Figure 65. Ratio of Carried Traffic over Offered Traffic

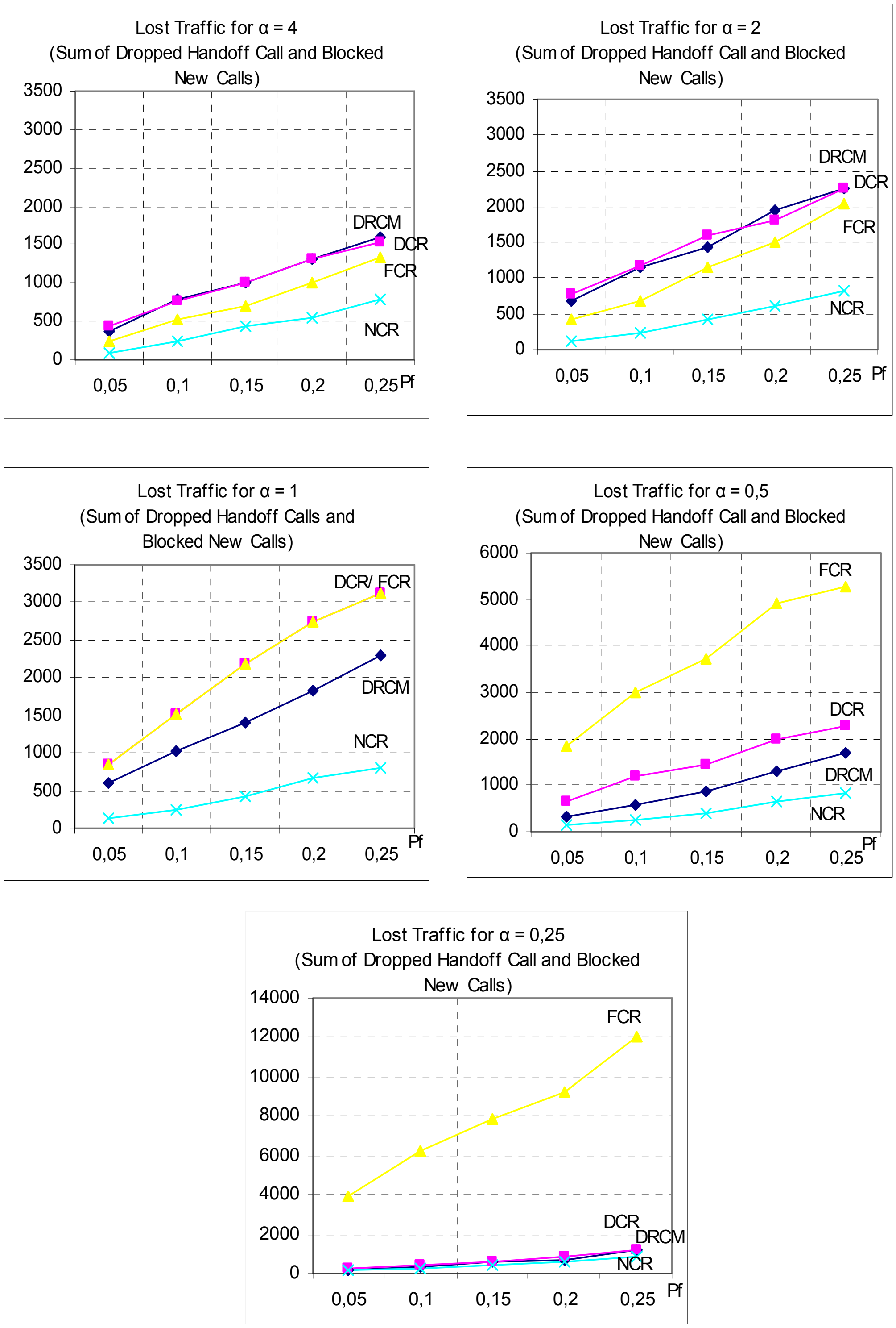


Figure 66. Lost Traffic

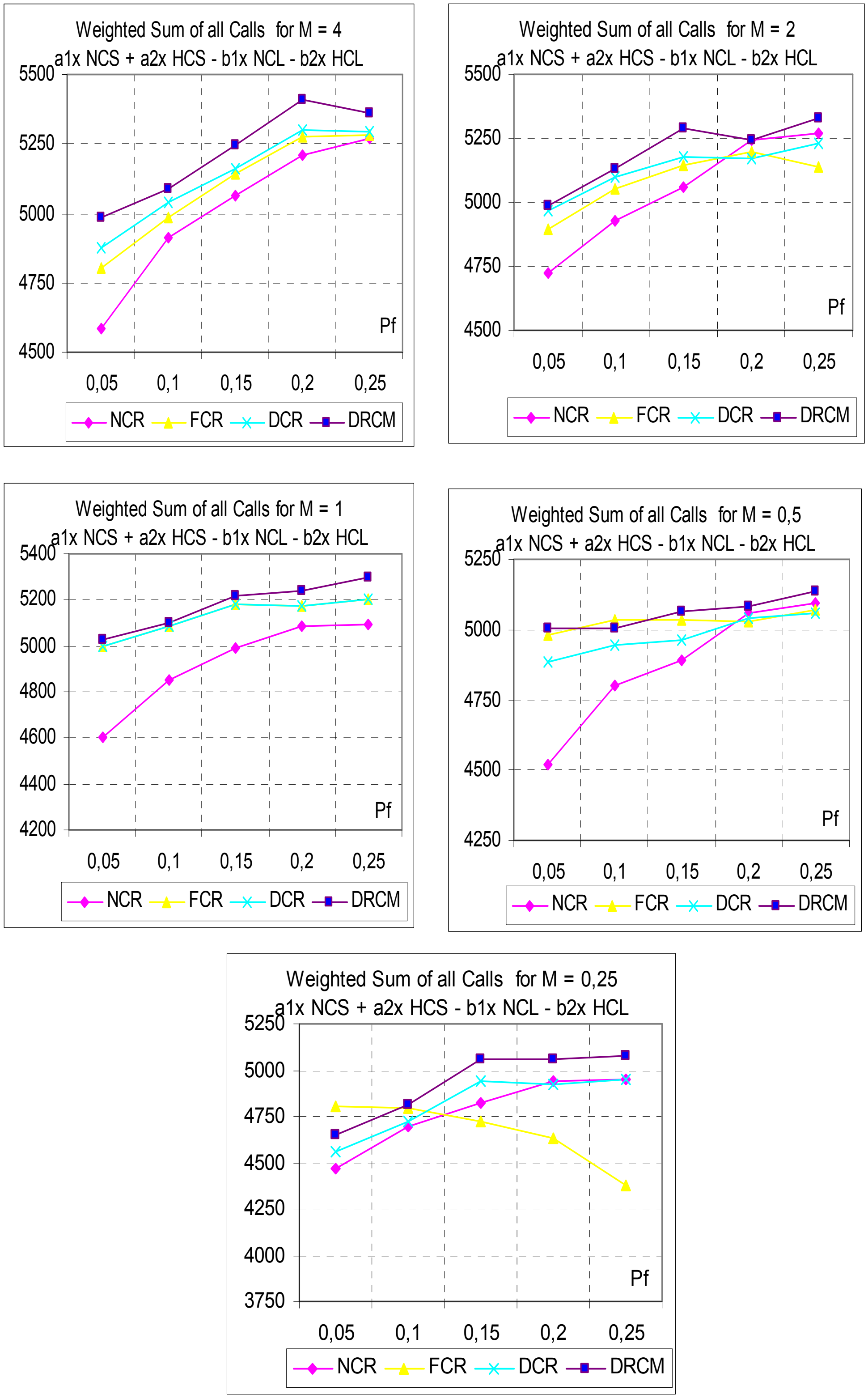


Figure 67. Weighted Sum of All Calls

5.4 Comparison of Results of Mathematical Analysis and Software Simulations

In section 5.1, we have presented the results of the mathematical analysis for the two QoS parameters, namely P_b and P_f. These were the numerically calculated P_b and P_f values for the four methods compared, based on the system performance models, which we have derived in section 4.2. In the mathematical analysis part, for given user mobility values, we have derived P_b and P_f as a function of network traffic, covering a full range of network traffic.

The aim of the software simulations, whose results we presented in section 5.2, was to verify the calculated theoretical results about the QoS parameters P_f and P_b, and to provide direct spectral efficiency predictions. In the software simulation part, we have simulated the resource management algorithms of the four methods compared. The simulation programs, predict the P_b, P_f, and channel utilization of the four methods compared, under given scenario and environmental conditions. Software scenarios cover the network traffic and subscriber mobility patters, environmental conditions cover parameters like the cell capacity.

To be able to perform fair and realistic comparisons about the numerical results and simulation results, we need to base the comparisons on common criteria in terms of network traffic and subscriber mobility. Under given subscriber mobility figures, the numerical analysis presented in section 5.1 cover a full range of network traffic, and the software simulation run on scenarios describing network traffic and subscriber mobility.

The performance comparison figures below consist of two set of figures. The first set consists of mathematical analysis results. These are the figures from the section 5.1, redrawn however to detail the results of the high network traffic load part. The second set of figures display the results of the software simulation runs belonging to the high network load scenarios.

Going through figures 68-79, we can see that the performance parameters predicted by the software simulations support to a large extend the values foreseen by the theoretical calculations.

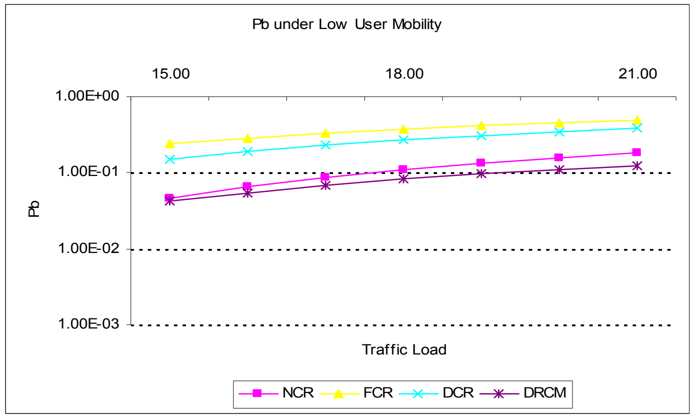


Figure 68. P_b results of mathematical analysis for low user mobility

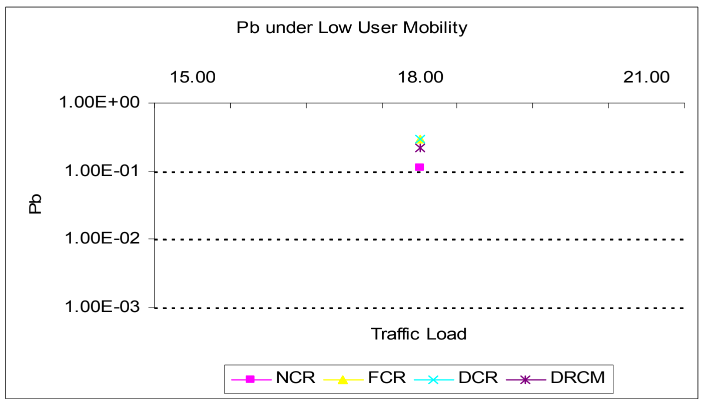


Figure 69. P_b results of software analysis for low user mobility

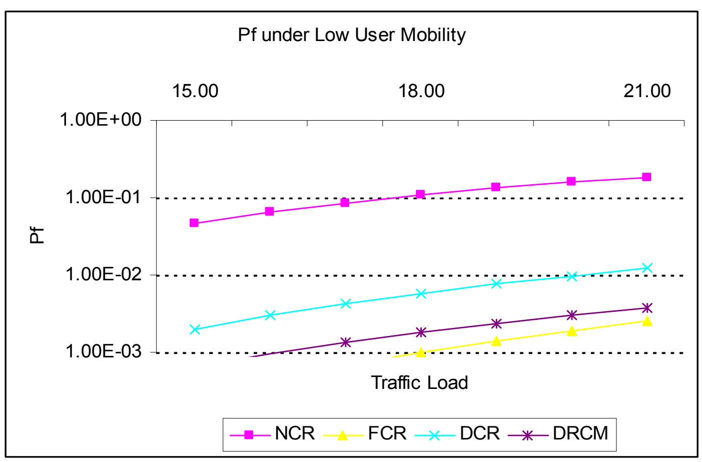


Figure 70. P_f results of mathematical analysis for low user mobility

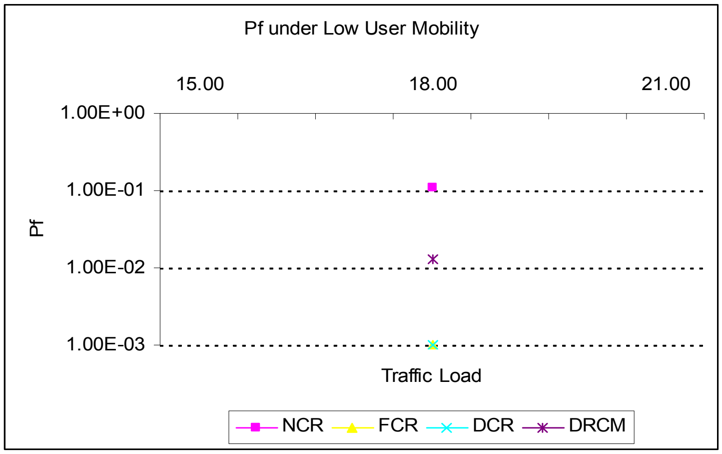


Figure 71. P_f results of software simulation for low user mobility

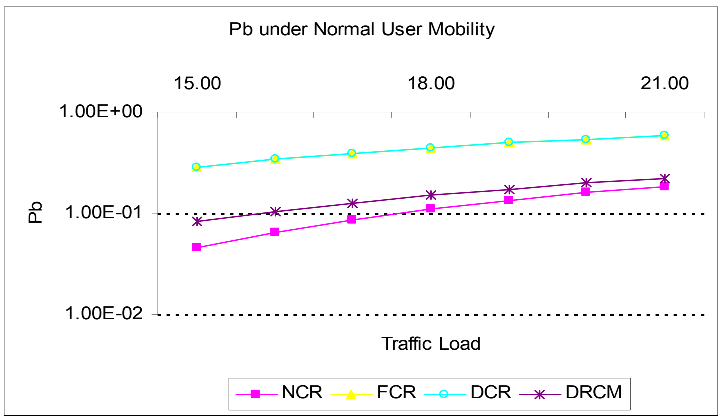


Figure 72. P_b results of mathematical analysis for unity user mobility

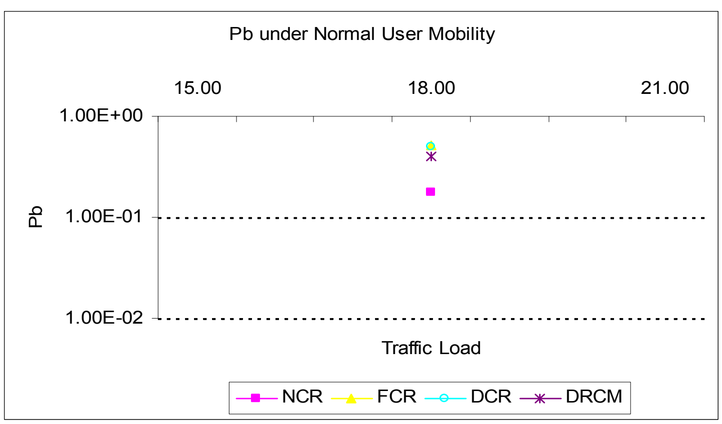


Figure 73. P_b results of software simulation for unity user mobility

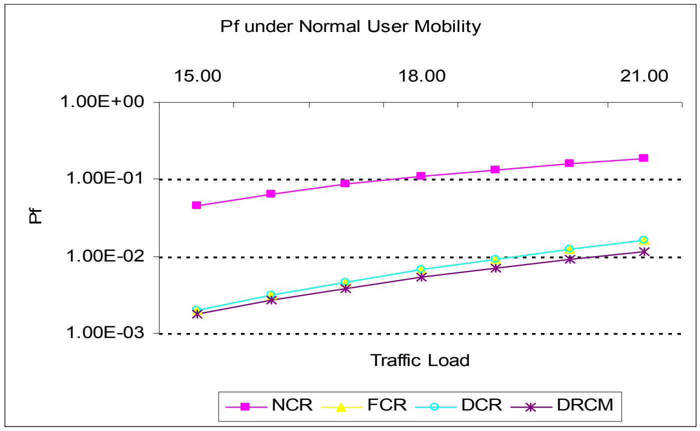


Figure 74. P_f results of mathematical analysis for unity user mobility

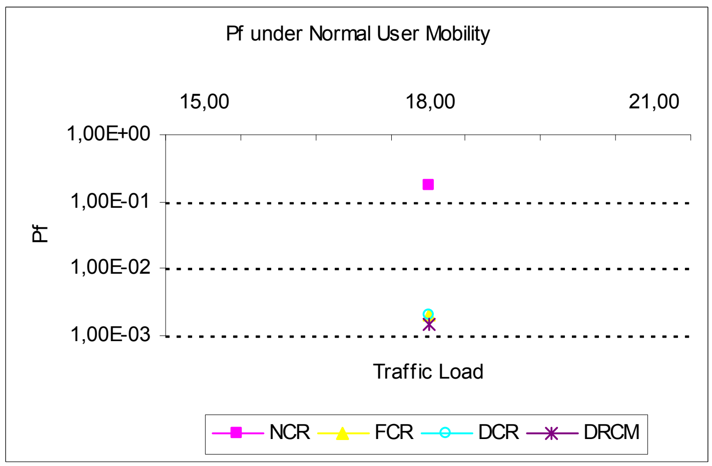


Figure 75. P_f results of software simulation for unity user mobility

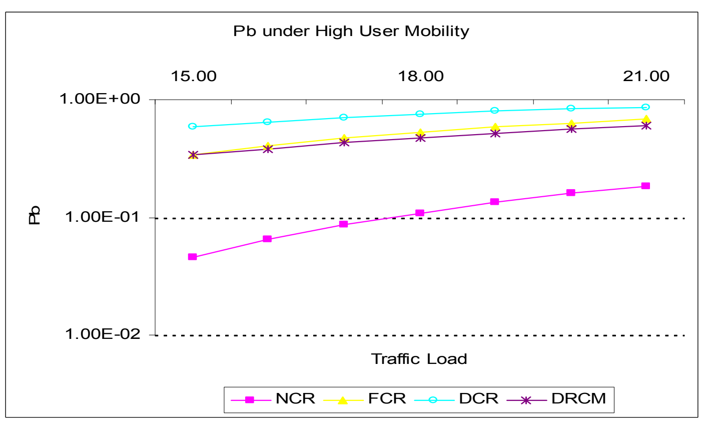


Figure 76. P_b results of mathematical analysis for high user mobility

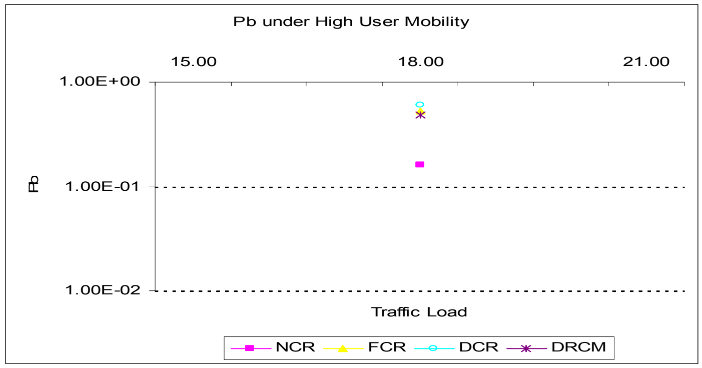


Figure 77. P_b results of software simulation for high user mobility

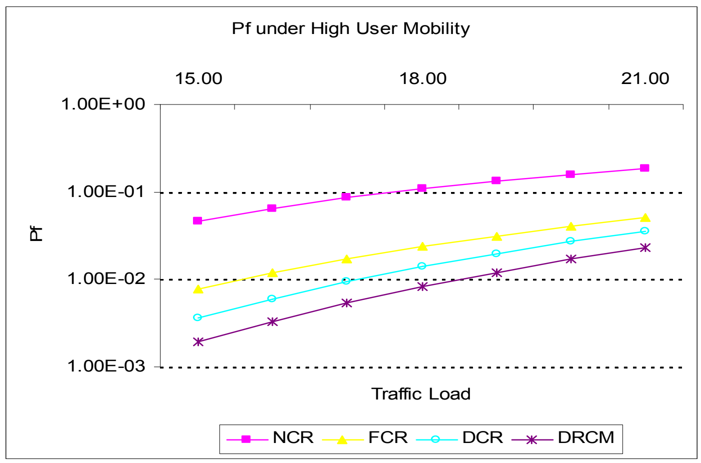


Figure 78. P_f results of mathematical analysis for high user mobility

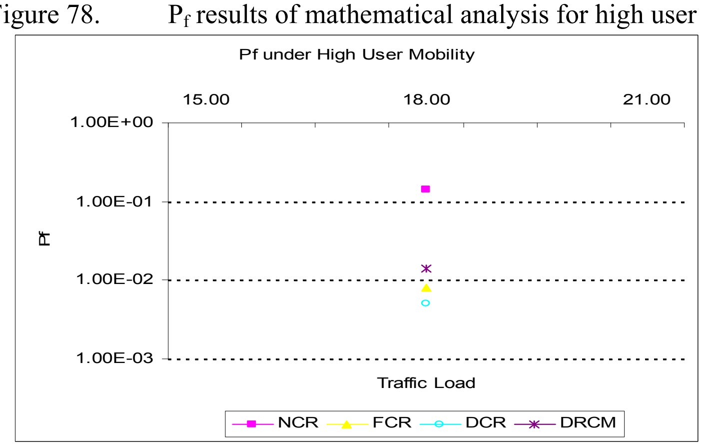


Figure 79. P_f results of software simulation for high user mobility

5.5 Cost Analysis

The motivation of this study was the simultaneous satisfaction of three main goals. These are;

i. Minimization of handoff calls droppings.

ii. Minimization of new call blockings.

iii. Maximization of radio channels utilization.

From the subscriber's point of view, it is important to minimize handoff call droppings, and to minimize new call blockings. From the service provider's point of view, on the other hand, it is important to maintain a guaranteed level of QoS for customer satisfaction, while at the same time to maximize the resource utilization in order to maximize revenue.

Careful examination of the results obtained from the mathematical analysis, as well as the software simulations, show that there is actually a trade-off between dropping probabilities and blocking probabilities, and between dropping probabilities and bandwidth utilization. Since we need to reserve some radio channels to improve P_f, we have to sacrifice some new call blockings and bandwidth utilization. It will be important to balance the trade-off between the performance parameter. Therefore, a cost function has been defined to balance the trade-off and to have a better understanding about the performances of the compared methods. The cost function definition includes the three critical parameters, BW, P_f, P_b and it is normalized with the baseline method, namely the NCR case. Following a similar approach as in [1], the definition of the cost function is as follows:

$$C = \alpha\,(P_{f,i} / P_{f,o}) + \beta\,(U_o / U_i) + \gamma\,(P_{b,i} / P_{b,o})$$

In this cost function definition, U_o, $P_{f,o}$, and $P_{b,o}$ are the values of bandwidth utilization, handoff call dropping probability, and new call dropping probability of the baseline (NCR) case, respectively. The U_i, $P_{f,i}$, and $P_{b,i}$ are the values of bandwidth utilization, handoff call dropping probability, and new call dropping probability of the method under comparison (one of FCR, DCR or DRCM) case, respectively. α, β, and γ are the weights of handoff call dropping probability, bandwidth utilization, and new call dropping probability, respectively.

The weights of the three parameters α, β, and γ are adjusted so that the cost of the baseline case is C =1. Since an efficient resource management algorithm must result in minimum cost for a wide range of relative weights of the three parameters, we have compared the cost of the methods under consideration for wide range feasible weights of U, P_f, and P_b.

The figures related to the cost analyses results are presented in Appendix-D. As seen from all these figures, the cost function of the baseline case (NCR) is equal to "one", for all the relative weights of α, β, and γ. In each of these figures, one of α, β, and γ weights are fixed, and the cost function variation is shown with respect to variation in the other two parameters. Since the sum of the α, β, and γ are equal to "one", increase in one of the parameters means, of course, decrease in the other. The figure in Appendix-D.1, shows the cost functions of the under fixed BW weight (β=0,3), and increasing P_f weight (decreasing P_b weight). Here we can observe two important facts;

i. All the channel reservation methods improve P_f performance. This can be observed from the decreasing cost value with increasing P_f weight, for all the compared methods.

ii. The proposed DRCM method can maintain a cost below the baseline case for a wide range of feasible P_f weights.

The figure in Appendix-D.2 shows the cost functions under fixed P_b weight (γ=0,3) and increasing BW weight (decreasing P_f weight). Here we can see that the improvement in P_f performance for all the dynamic channel reservation methods observed is actually at a cost of poorer BW utilization. This can be observed from the increasing cost with increasing BW weight. The cost paid for improving the P_f performance is especially high for the FCR and DCR methods. For BW weights above 0,3 the FCR and DCR methods results in higher cost compared to the baseline case, which is an indication of poor BW utilization. The proposed DRCM method, on the other hand, can maintain a cost below the baseline case for a wide range of feasible BW weights. This is due to the fact that, DRCM brings a considerable improvement to handoff performance by better utilizing the radio channels. From the fixed P_f weight (α=0,3) figure (increasing BW weight, decreasing P_b weight) in Appendix-D.3, it can be observed that, the proposed method can maintain lowest cost among the compared methods for the same desired P_f performance.

CHAPTER VI

CONCLUSION

In today's highly competitive markets, service providers try to achieve simultaneous satisfaction of a high level of QoS and a high level of resource utilization in order to maximize their revenues. Therefore, the objective of this study has been to develop an efficient resource management algorithm to improve handoff call dropping probability in a cellular system without degrading the QoS, which has been a challenging task. It was considered to be useful to obtain and analyze traffic data collected by one of the national 1800 MHz GSM service providers. Two sets of data has been obtained and analyzed. The first set consists of data collected from cells all over Turkey on a 24-hour basis. The second set consists of one-week data from a cluster of cells in business area in Ankara. Careful analysis of the data showed that the time and location dependent network traffic load and subscriber mobility figures behave as expected. However, handoff failure rates were higher than our expectations. Handoff failure rates were especially critical during some heavy traffic periods. It has been the conclusion that as cell sizes reduce in future generation mobile networks, resource management algorithms will face problems that are difficult to solve if handoff failure rates have to be limited to low levels for high QoS.

In order to evaluate the performances of the methods discussed, mathematical models for NCR, FCR, DCR and DRCM were developed. The results obtained using these models showed that reserving some radio channels for handoff calls explicitly, improves P_f performance. This could be easily observed from the performance difference between the NCR method and the channel reservation methods, FCR, DCR and DRCM.

Both the network traffic load and the mobility of subscribers are time varying. The field data analyzed in this study showed wide range of network traffic and instantaneous variations in subscriber mobility. Therefore, the amount of radio channels to be reserved for handoff calls at any moment can not be fixed and must change adaptively. That is why; the FCR method could not guarantee the desired P_f performance for all network traffic and subscriber mobility values. From the results of section 5.1, we could see that, depending on the network traffic and subscriber mobility values, the FCR can cause poor P_f and P_b performance. The FCR method showed poor P_f performance for subscriber mobility values that demand more radio channels and poor P_b performance for low subscriber mobility values that need less radio channels than the FCR assumes.

Unlike FCR, the DCR method tries to adjust adaptively the radio channels reserved for handoff calls. It decides on the number of radio channels to be reserved for the handoff calls depending on the mobility figures in the cell area. The obtained results indicate that, in general, DCR performs better in terms of P_f and P_b compared to the FCR. However, depending on the network traffic and subscriber mobility values, the FCR may to be superior compared to the DCR, in one or the other QoS parameter. This is because with its fixed amount of reserved channels, FCR may be improving one or the other parameter. The result is either poor QoS or poor bandwidth utilization.

If the network operator can get apriori information on subscriber behavior and its mobility beforehand, it can apply an appropriate resource management policy based on this information. In this way, the resource management algorithm can realistically make changes in advance, in the way the traffic is handled, rather than adapting to conditions with a delay. The DRCM method proposes a way to provide this information, based on call statistics kept by each mobile using its own resources. The DRCM method makes use of apriori information about mobility statistics to decide on the most suitable number of radio channels to be reserved, and in the new call admission process.

The results of analysis in section 5.1 showed that the DRCM technique brings improvement to the P_b performance. It performs better than the DCR, especially for low user mobility conditions. The DRCM, in general, showed improved P_f performance as well compared to DCR, though not as high as the improvement in P_b performance. It is important to note that this improvement in

P_f is not at the cost of decreased P_b performance. It is due to efficient utilization of the radio channels. In other words, simultaneous improvement in the QoS and radio channel utilization. It was also concluded that DRCM could adapt better to instantaneous changes in network traffic and subscriber mobility, resulting in better P_b and P_f performances.

Software simulations were done to verify the numerical results obtained during the studies. Simulation studies were carried out in two steps. First, the simulations were performed over a 24-hour period, i.e. over a full day. Second, daily one-hour simulations were performed to simulate peak-hour times, i.e. under heavy traffic conditions. From the results of the software simulation runs presented in section 5.1, it was observed that simulation results conform to the results of analysis. Moreover, the bandwidth utilization figures obtained from simulation runs showed that the bandwidth efficiencies were consistent with the predicted performances of QoS parameters. This fact can be observed from the figures in section 5.3.

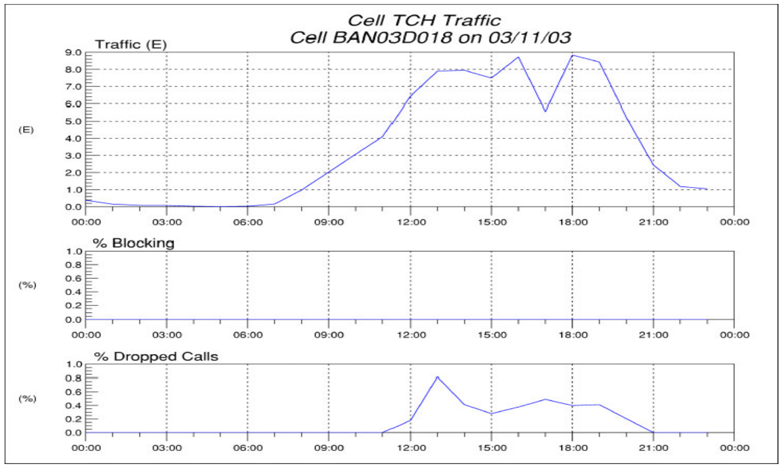
In this study, an efficient and feasible approach for subscriber profile prediction has been proposed where individual mobiles drive statistical information from their daily activities. Then, cell transition probabilities could be obtained and decisions of whether to make a handoff reservation or not could be based for each mobile separately, which could lead to very realistic scenarios. Unfortunately, such a detailed modeling and simulation was beyond the means of this study. Instead, average values which were in agreement with field data were used. This detailed study could be the subject of further studies in the simulation of cellular networks.

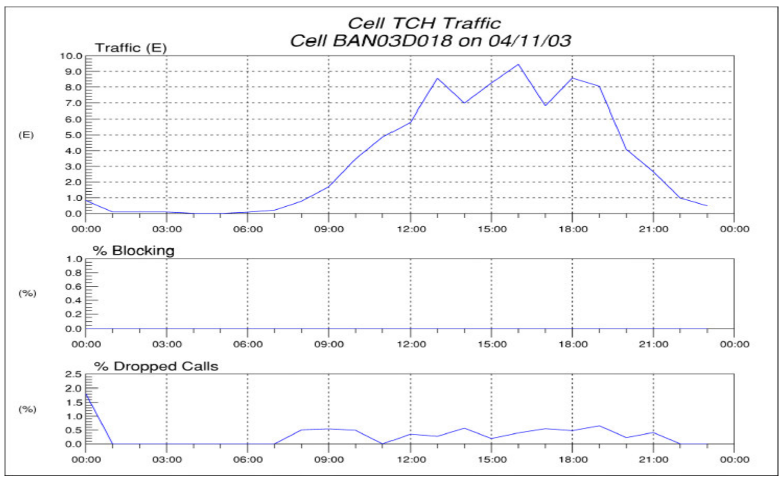
In summary, Channel reservation improves handoff success performance but at a cost of an increase in the new call blocking probability. In parallel to this, a substantial decrease in the channel utilization can be observed. Poor channel utilization will occur if too many channels are reserved for handoff and stayed empty. It has been demonstrated that dynamic radio channel reservation helps to overcome these disadvantages to some extend by adaptively changing the number of reserved radio channels according to changes user mobility and network traffic conditions. Similar performance increases has been obtained in the DCR and DRCM approaches. However, it is the conclusion that DRCM approach has the potential of leading to considerable improvement in the handoff failure performance by using the apriori information about hand off reservations and using a probabilistic approach to the new call admissions. The performances observed in simulations as well as in calculations were better when compared with published DCR approaches. This improvement in handoff failure probability is the result of better utilization of the radio channels.

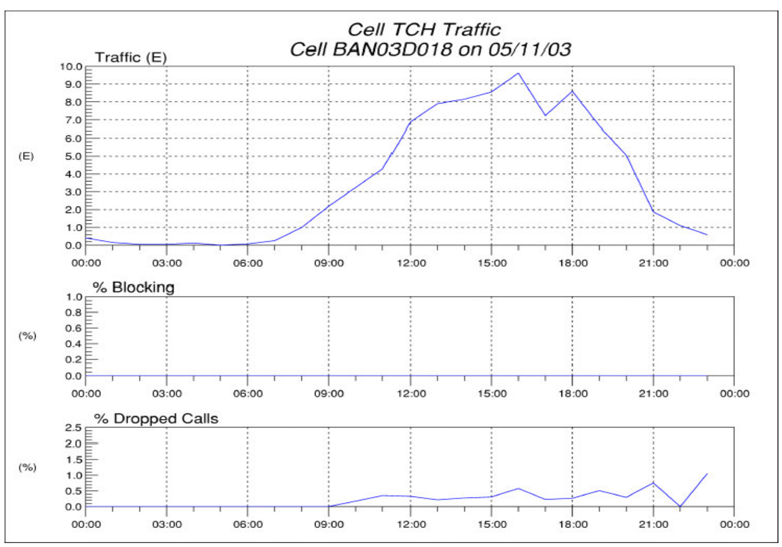
As a final step in studies, simulation results were repeated for fixed P_f conditions to make better comparisons between performances of different approaches. Furthermore, to create a suitable measure for comparing performances of different methods as far as P_f and P_b are concerned, a weighted sum of four important parameters were plotted versus traffic conditions. These four parameters were number of successful handoff calls, dropped handoff calls, new calls admitted and finally new calls rejected. This weighted average was a good measure of net revenues earned by the operator since ongoing calls represent earned revenue and rejected or dropped calls represent revenue lost under fixed P_f conditions. The results have shown that, weighted average performance of the proposed approach is satisfactory for most cases and it could be said that improvement over investigated approaches were very clear.

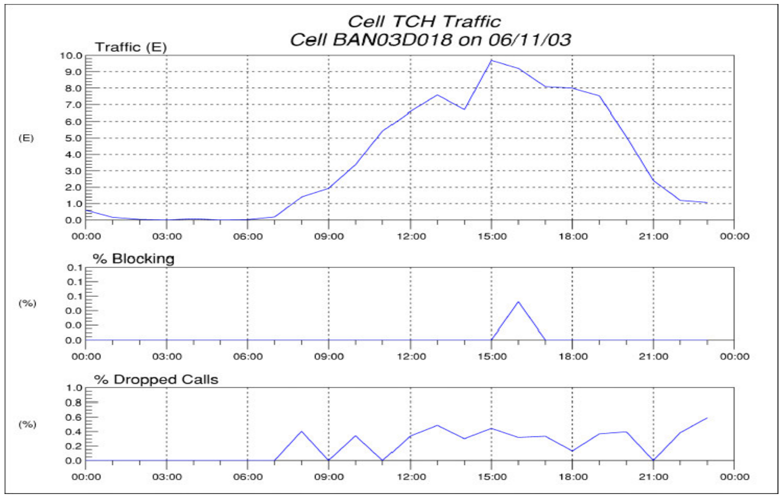
APPENDIX A

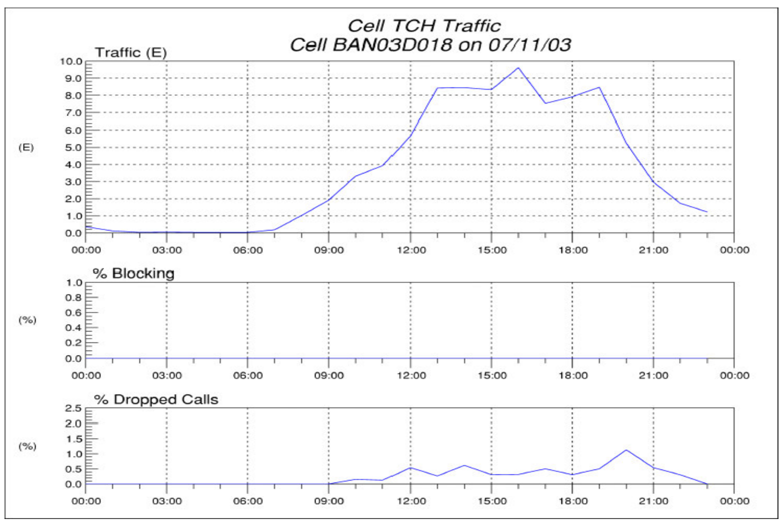
Appendix-A.1 Operational Field Network Traffic Data

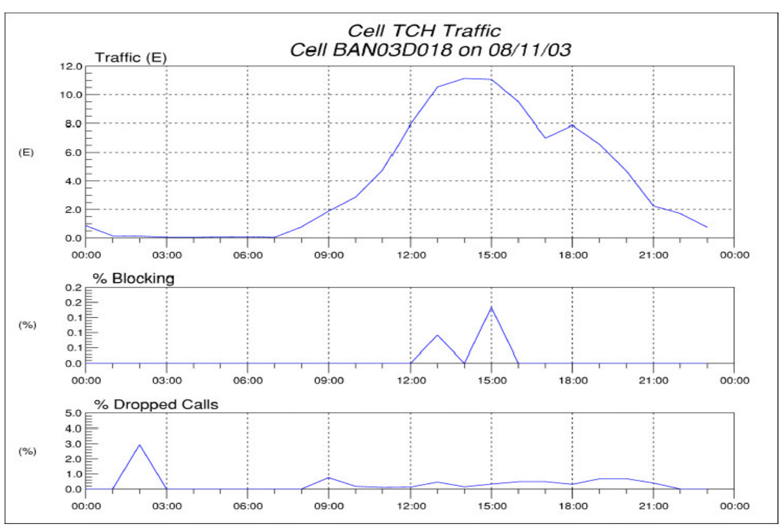


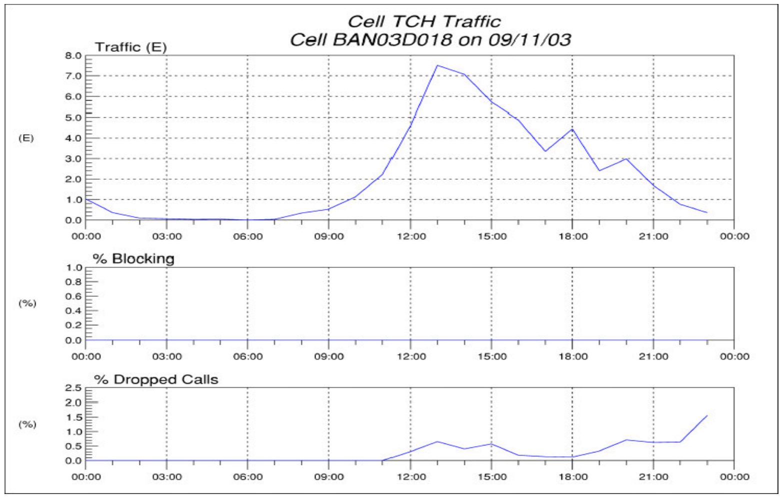


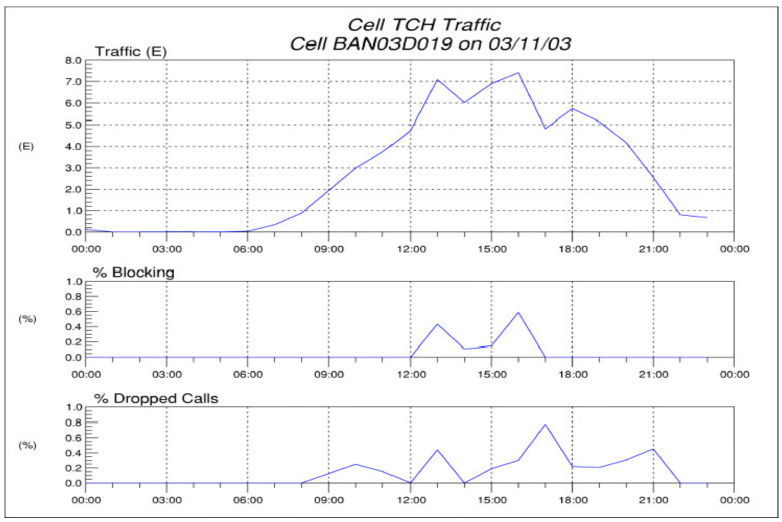


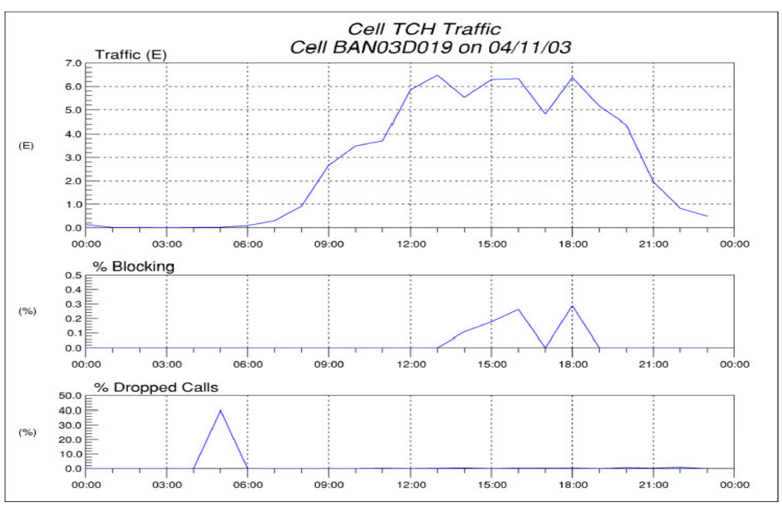

Cell TCH Traffic
Cell BAN03D018 on 06/11/03
Traffic (E)
(E)
% Blocking
(%)
% Dropped Calls
(%)
00:00 03:00 06:00 09:00 12:00 15:00 18:00 21:00 00:00

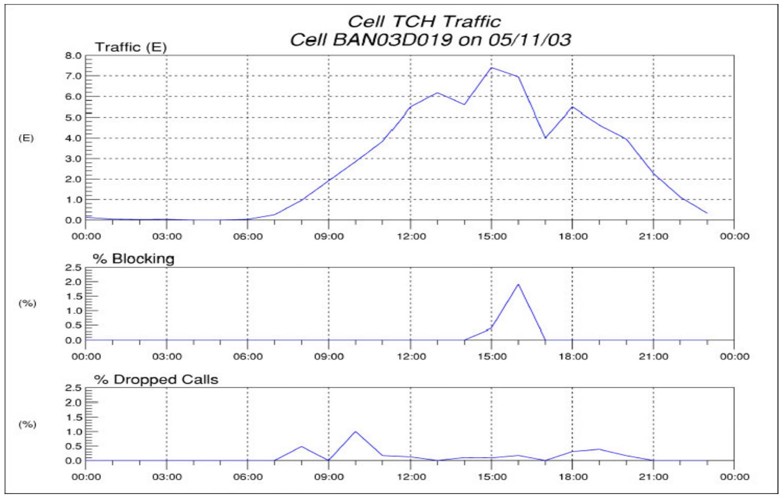

Cell TCH Traffic
Cell BAN03D018 on 07/11/03
Traffic (E)
(E)
% Blocking
(%)
% Dropped Calls
(%)
00:00 03:00 06:00 09:00 12:00 15:00 18:00 21:00 00:00


Cell TCH Traffic
Cell BAN03D018 on 08/11/03
Traffic (E)
(E)
% Blocking
(%)
% Dropped Calls
(%)
00:00 03:00 06:00 09:00 12:00 15:00 18:00 21:00 00:00

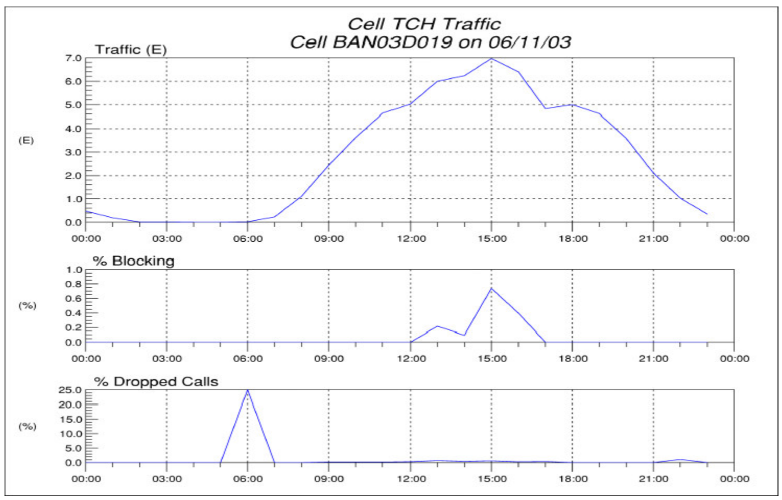

Cell TCH Traffic
Cell BAN03D018 on 09/11/03
Traffic (E)
% Blocking
% Dropped Calls


Cell TCH Traffic
Cell BAN03D019 on 03/11/03
Traffic (E)
% Blocking
% Dropped Calls

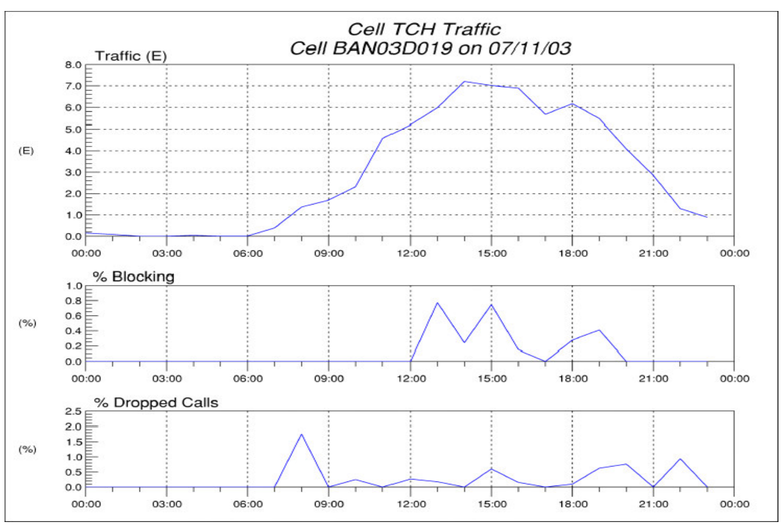

Cell TCH Traffic
Cell BAN03D019 on 04/11/03
Traffic (E)
% Blocking
% Dropped Calls



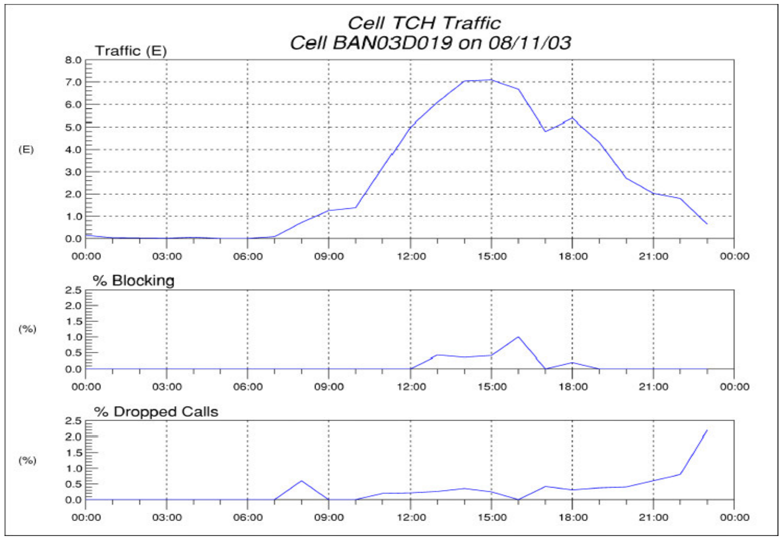
Cell TCH Traffic
Cell BAN03D019 on 05/11/03
Traffic (E)
(E)
% Blocking
(%)
% Dropped Calls
(%)

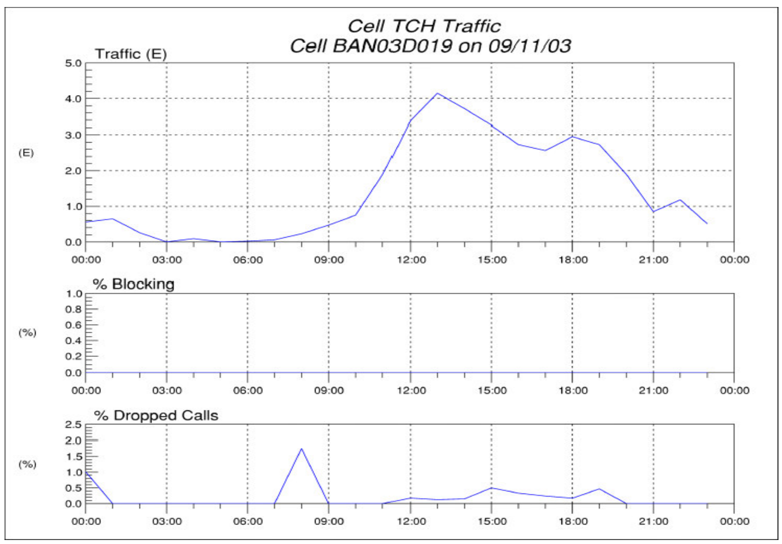


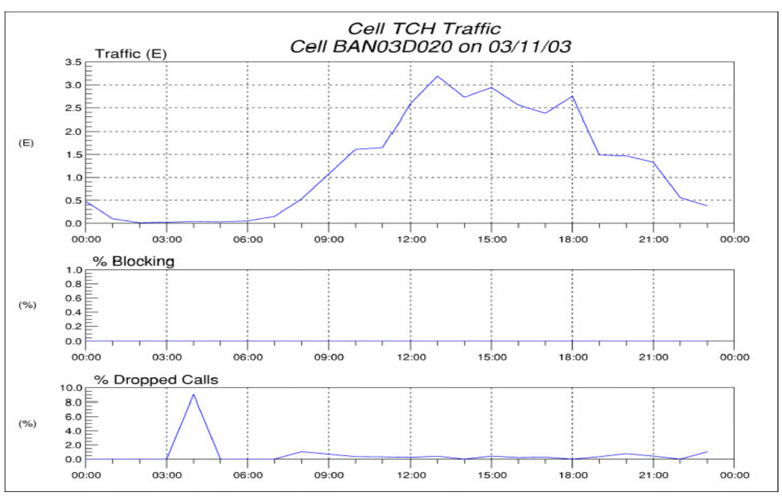
Cell TCH Traffic
Cell BAN03D019 on 06/11/03
Traffic (E)
(E)
% Blocking
(%)
% Dropped Calls
(%)

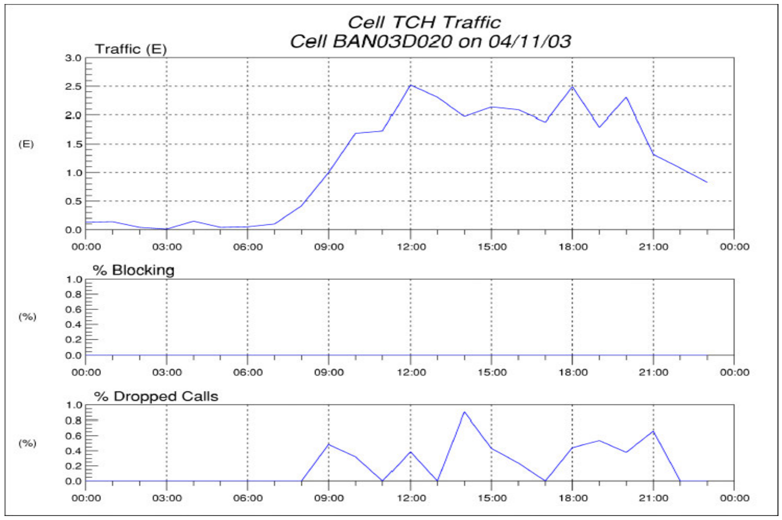


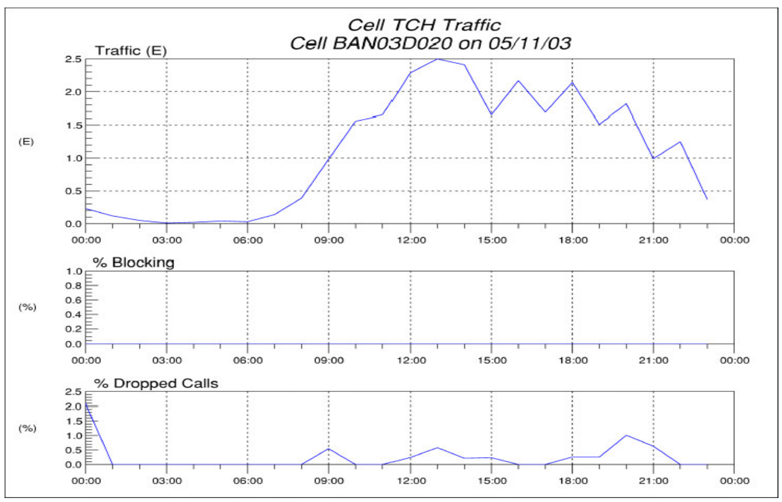
Cell TCH Traffic
Cell BAN03D019 on 07/11/03
Traffic (E)
(E)
% Blocking
(%)
% Dropped Calls
(%)

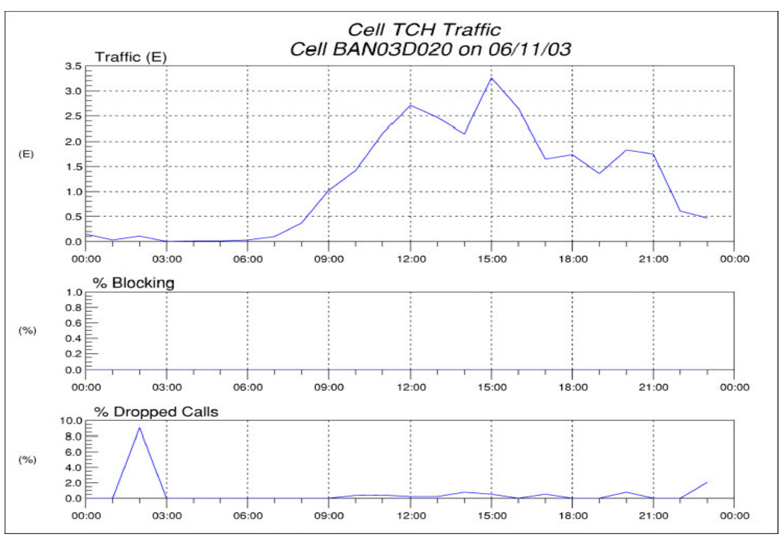

Cell TCH Traffic
Cell BAN03D019 on 08/11/03
Traffic (E)
% Blocking
% Dropped Calls

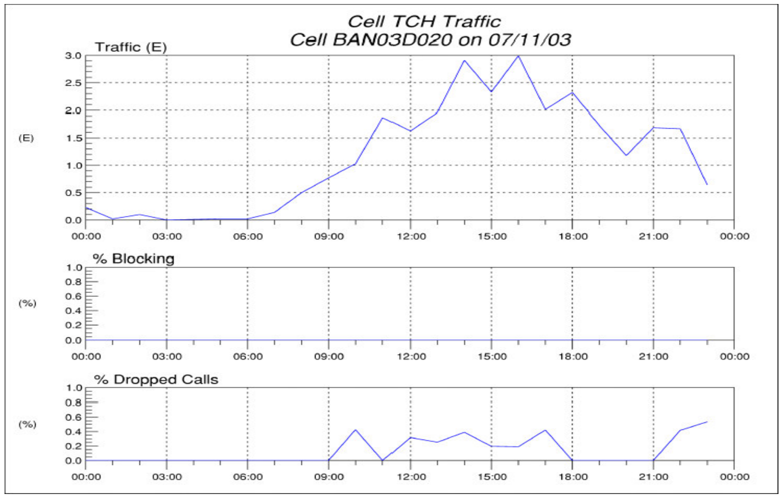

Cell TCH Traffic
Cell BAN03D019 on 09/11/03
Traffic (E)
% Blocking
% Dropped Calls

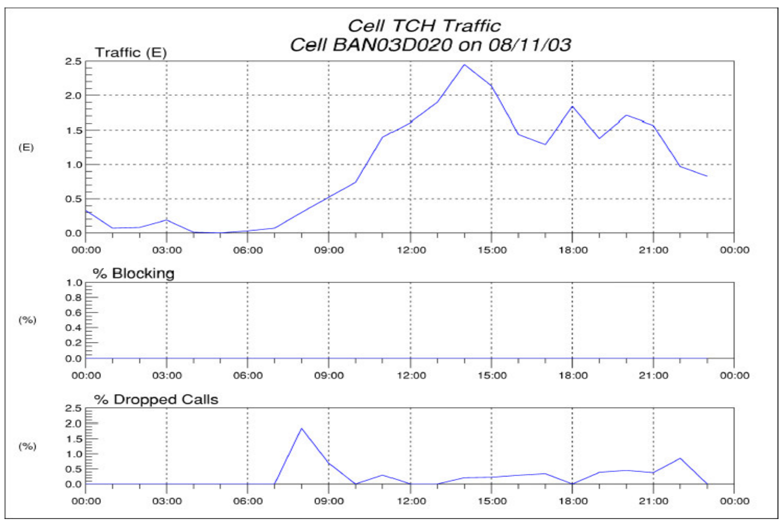

Cell TCH Traffic
Cell BAN03D020 on 03/11/03
Traffic (E)
% Blocking
% Dropped Calls

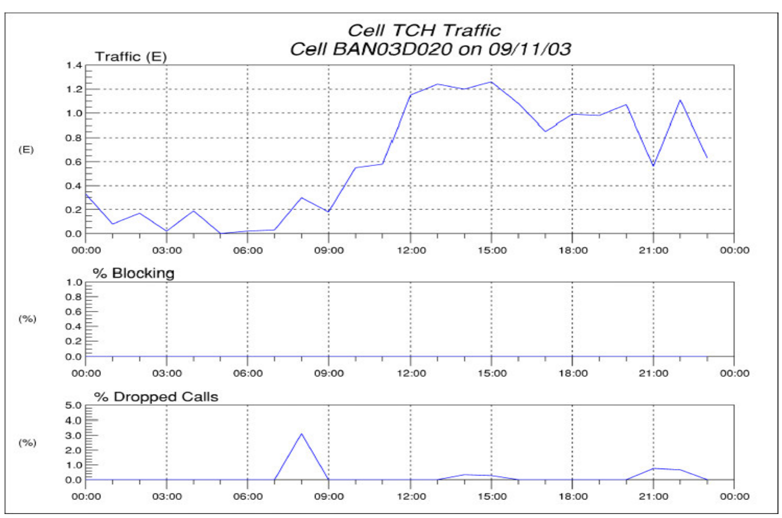

Cell TCH Traffic
Cell BAN03D020 on 04/11/03
Traffic (E)
(E)
% Blocking
(%)
% Dropped Calls
(%)
00:00 03:00 06:00 09:00 12:00 15:00 18:00 21:00 00:00


Cell TCH Traffic
Cell BAN03D020 on 05/11/03
Traffic (E)
(E)
% Blocking
(%)
% Dropped Calls
(%)
00:00 03:00 06:00 09:00 12:00 15:00 18:00 21:00 00:00


Cell TCH Traffic
Cell BAN03D020 on 06/11/03
Traffic (E)
(E)
% Blocking
(%)
% Dropped Calls
(%)
00:00 03:00 06:00 09:00 12:00 15:00 18:00 21:00 00:00

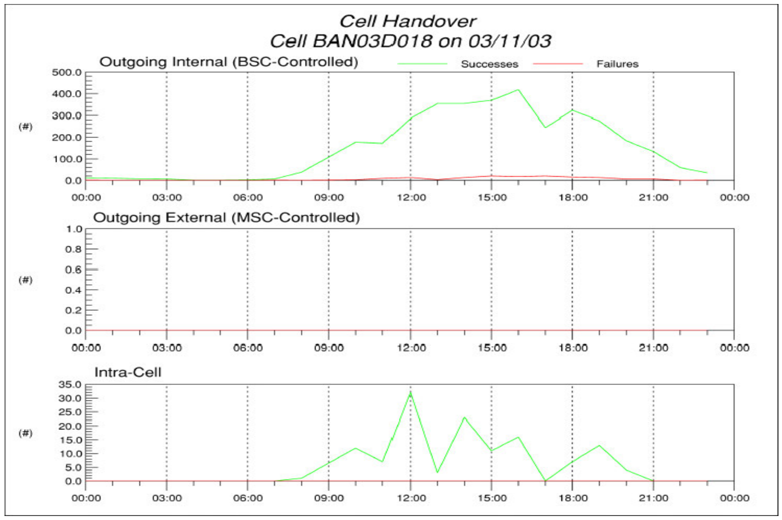

Cell TCH Traffic
Cell BAN03D020 on 07/11/03
Traffic (E)
% Blocking
% Dropped Calls

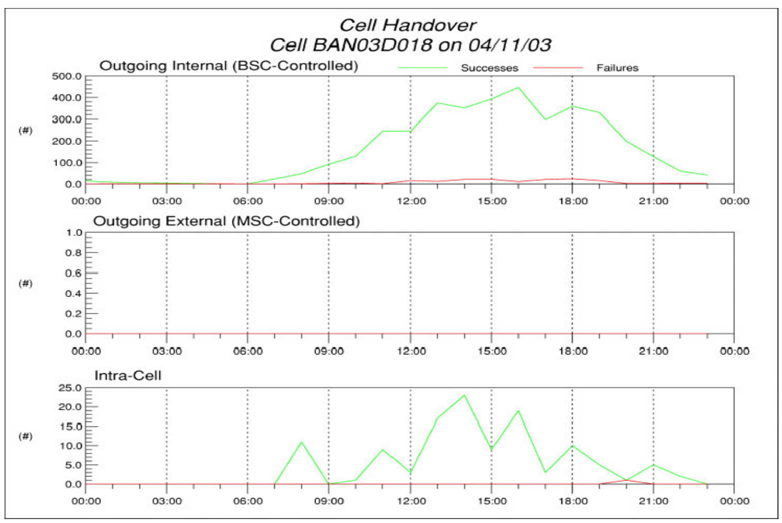

Cell TCH Traffic
Cell BAN03D020 on 08/11/03
Traffic (E)
% Blocking
% Dropped Calls

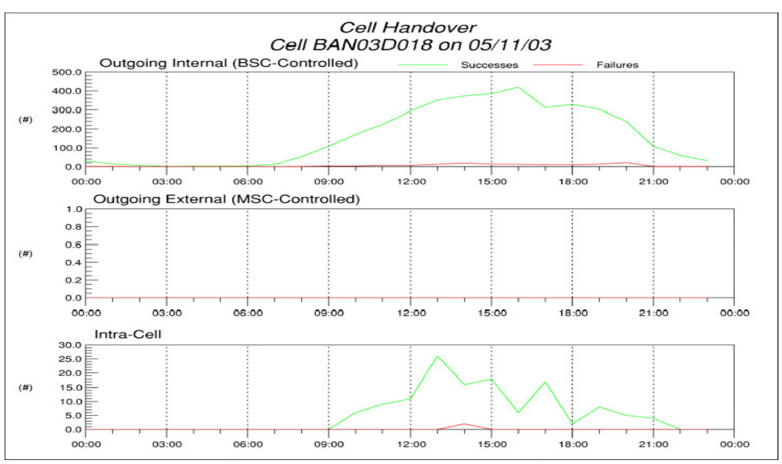

Cell TCH Traffic
Cell BAN03D020 on 09/11/03
Traffic (E)
% Blocking
% Dropped Calls

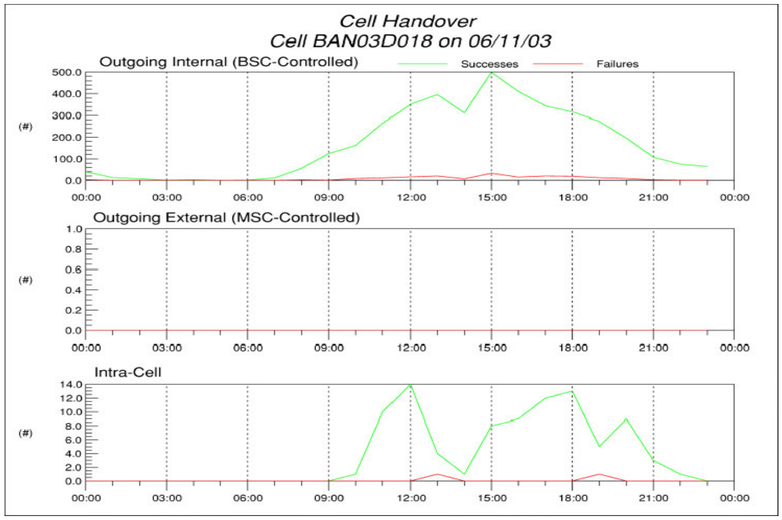
APPENDIX A

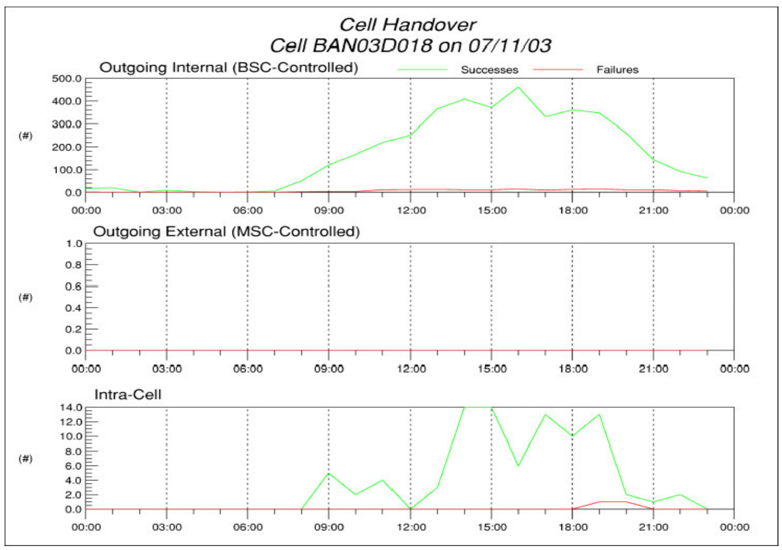
Appendix-A 2 Operational Field Handoff Traffic Data

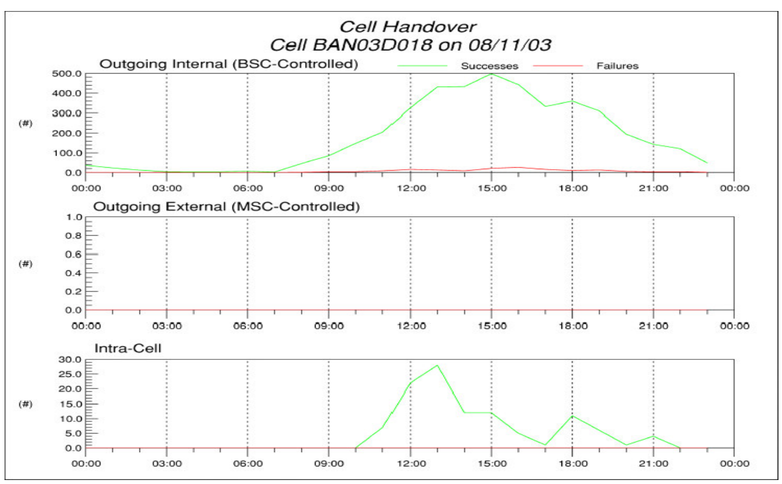


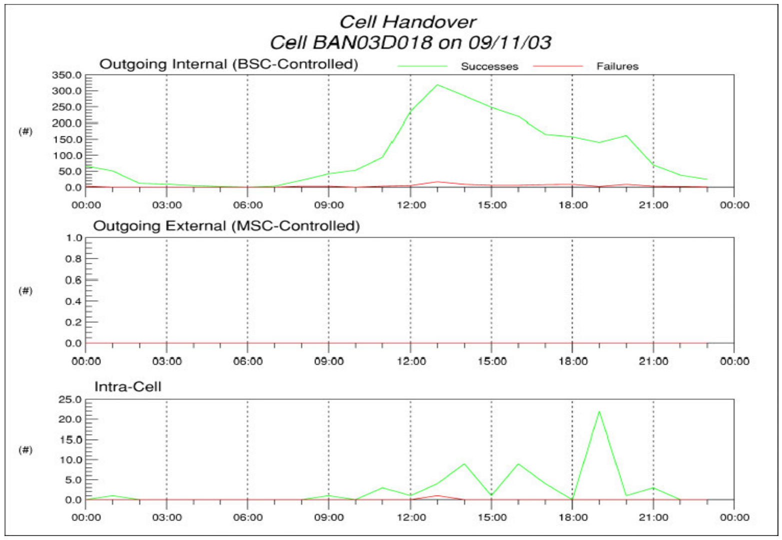


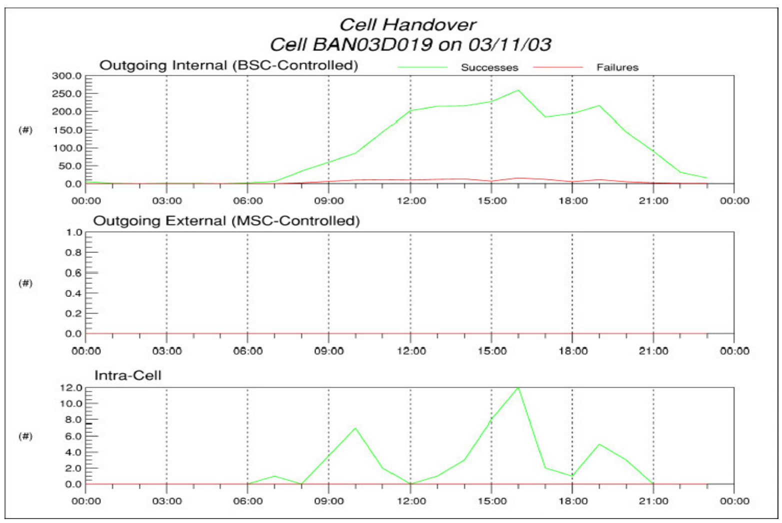


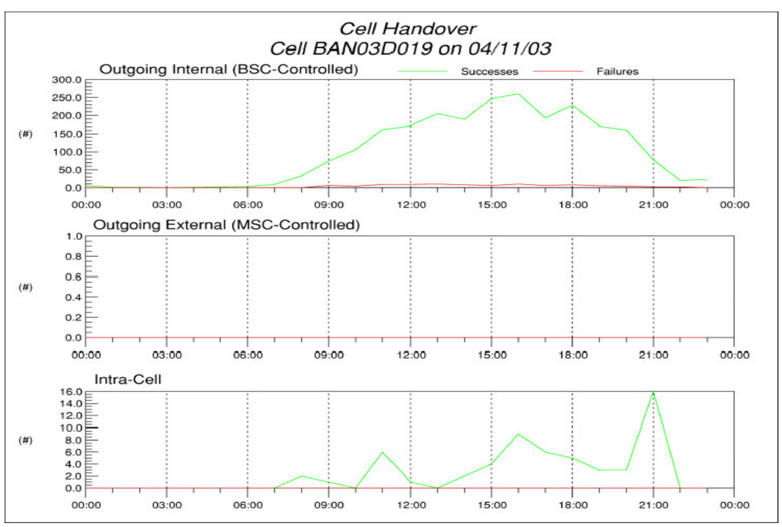

Cell Handover
Cell BAN03D018 on 06/11/03
Outgoing Internal (BSC-Controlled)
Successes
Failures
Outgoing External (MSC-Controlled)
Intra-Cell

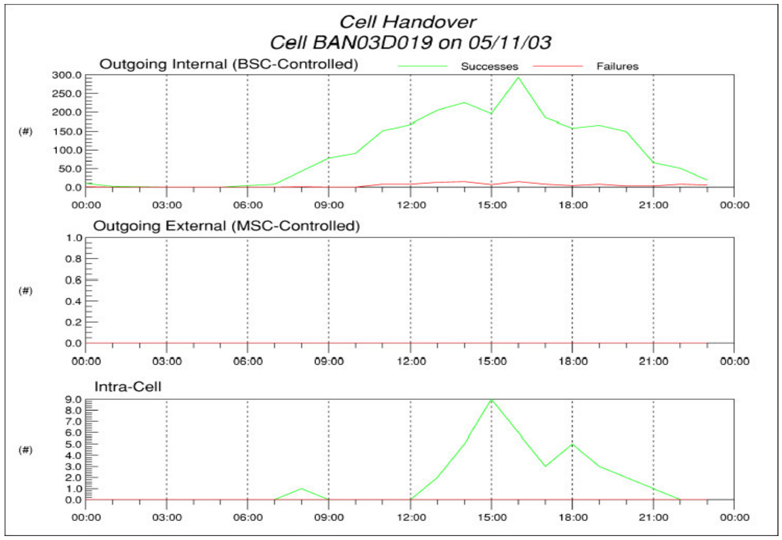

Cell Handover
Cell BAN03D018 on 07/11/03
Outgoing Internal (BSC-Controlled)
Successes
Failures
Outgoing External (MSC-Controlled)
Intra-Cell

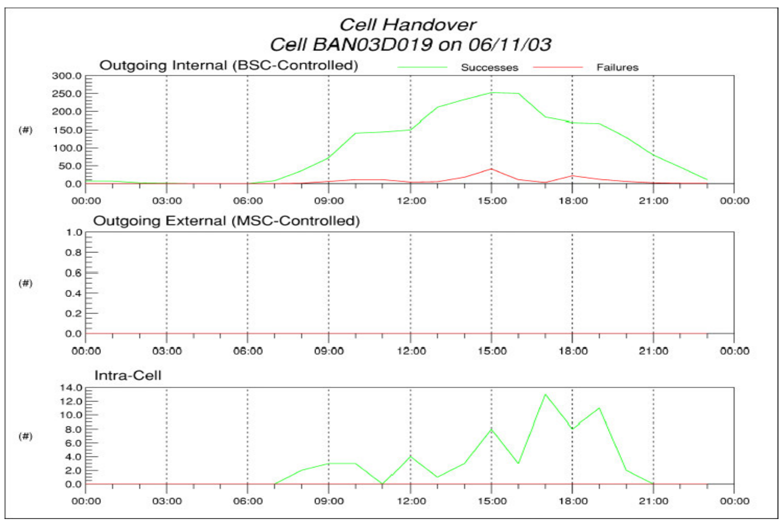

Cell Handover
Cell BAN03D018 on 08/11/03
Outgoing Internal (BSC-Controlled)
Successes
Failures
Outgoing External (MSC-Controlled)
Intra-Cell

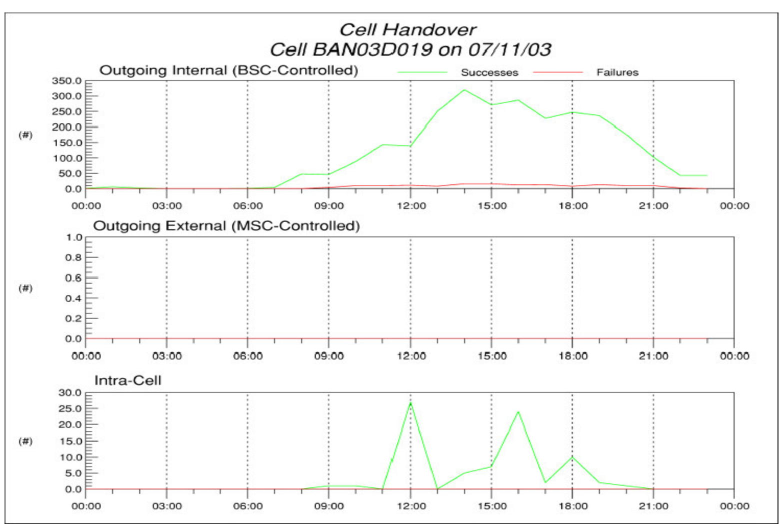

Cell Handover
Cell BAN03D018 on 09/11/03
Outgoing Internal (BSC-Controlled)
Successes
Failures
Outgoing External (MSC-Controlled)
Intra-Cell
(#)

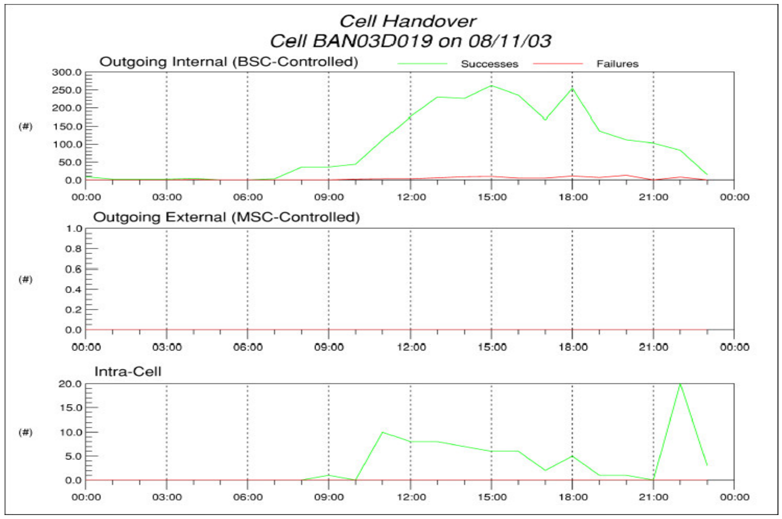

Cell Handover
Cell BAN03D019 on 03/11/03
Outgoing Internal (BSC-Controlled)
Successes
Failures
Outgoing External (MSC-Controlled)
Intra-Cell
(#)

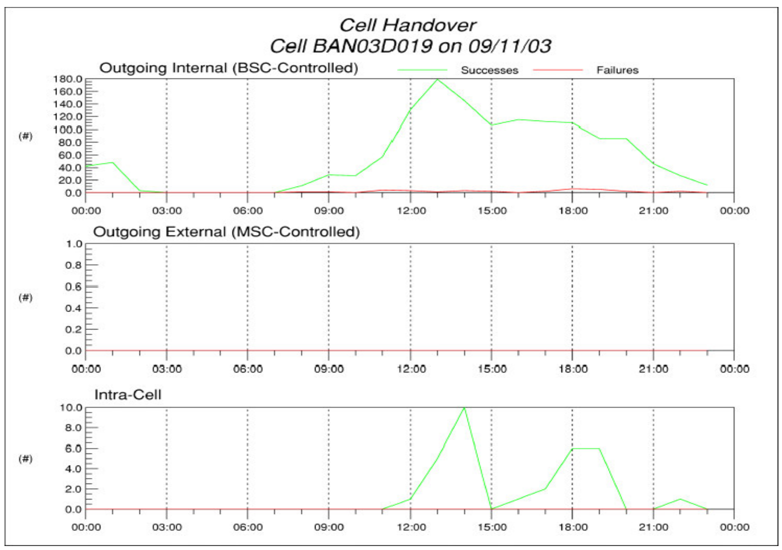

Cell Handover
Cell BAN03D019 on 04/11/03
Outgoing Internal (BSC-Controlled)
Successes
Failures
Outgoing External (MSC-Controlled)
Intra-Cell
(#)

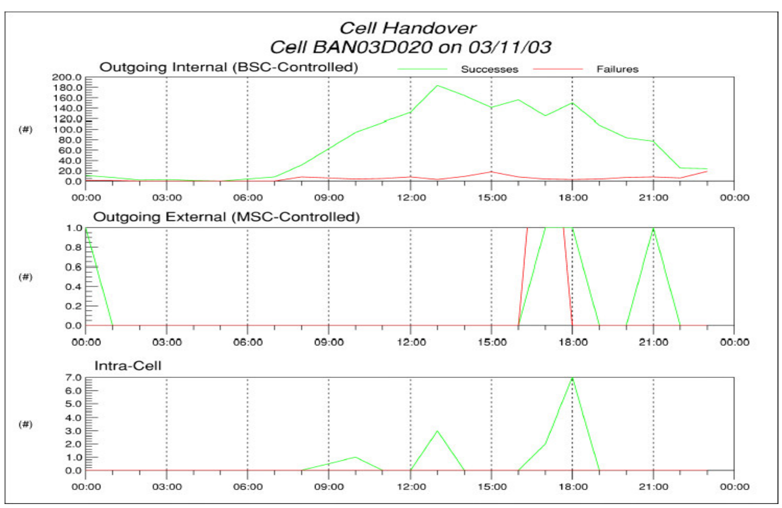

Cell Handover
Cell BAN03D019 on 05/11/03
Outgoing Internal (BSC-Controlled)
Successes
Failures
Outgoing External (MSC-Controlled)
Intra-Cell

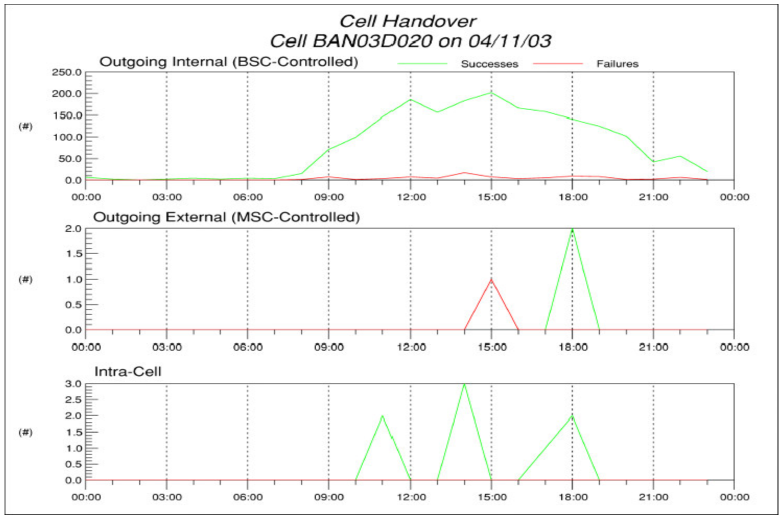

Cell Handover
Cell BAN03D019 on 06/11/03
Outgoing Internal (BSC-Controlled)
Successes
Failures
Outgoing External (MSC-Controlled)
Intra-Cell

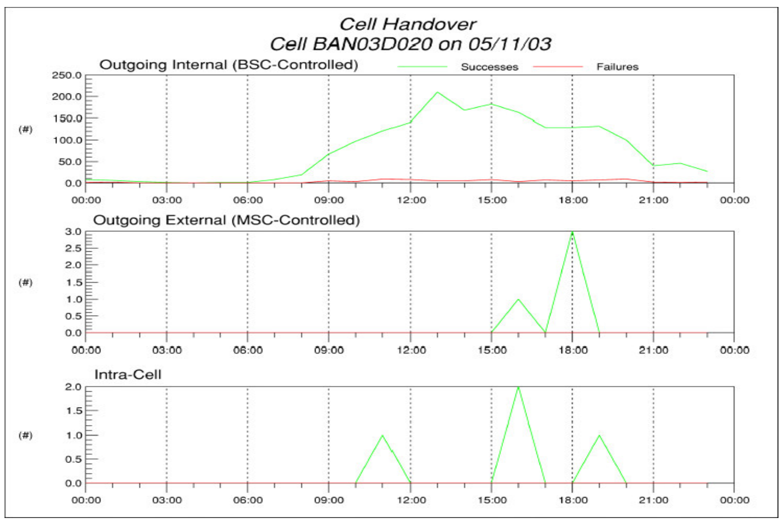

Cell Handover
Cell BAN03D019 on 07/11/03
Outgoing Internal (BSC-Controlled)
Successes
Failures
Outgoing External (MSC-Controlled)
Intra-Cell

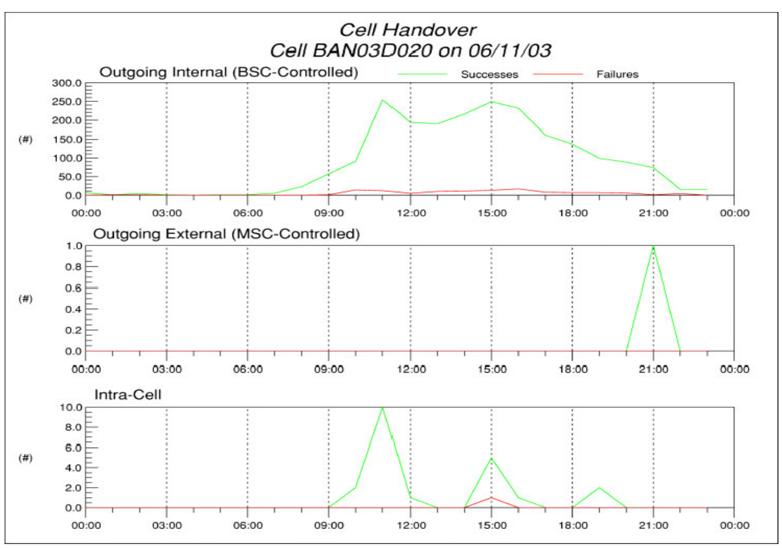

Cell Handover
Cell BAN03D019 on 08/11/03
Outgoing Internal (BSC-Controlled)
Successes
Failures
Outgoing External (MSC-Controlled)
Intra-Cell
(#)

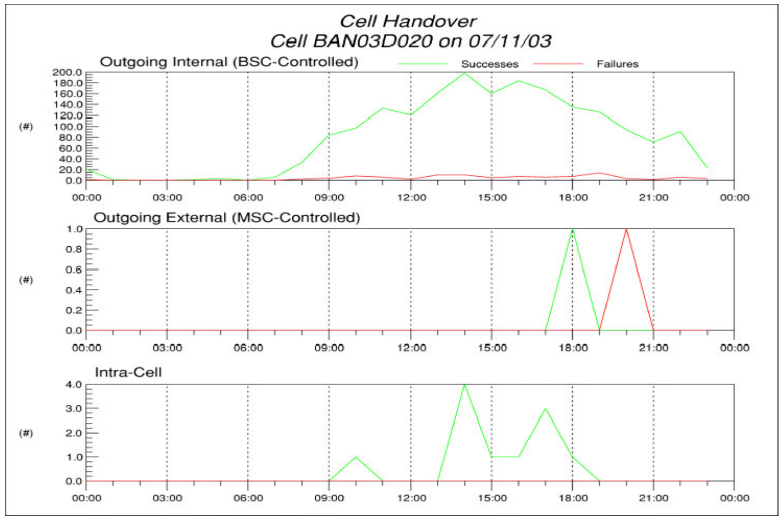

Cell Handover
Cell BAN03D019 on 09/11/03
Outgoing Internal (BSC-Controlled)
Successes
Failures
Outgoing External (MSC-Controlled)
Intra-Cell
(#)

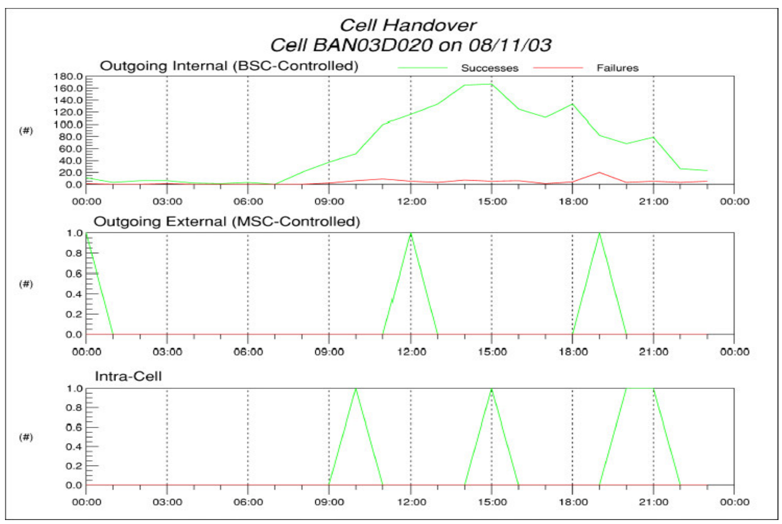

Cell Handover
Cell BAN03D020 on 03/11/03
Outgoing Internal (BSC-Controlled)
Successes
Failures
Outgoing External (MSC-Controlled)
Intra-Cell
(#)

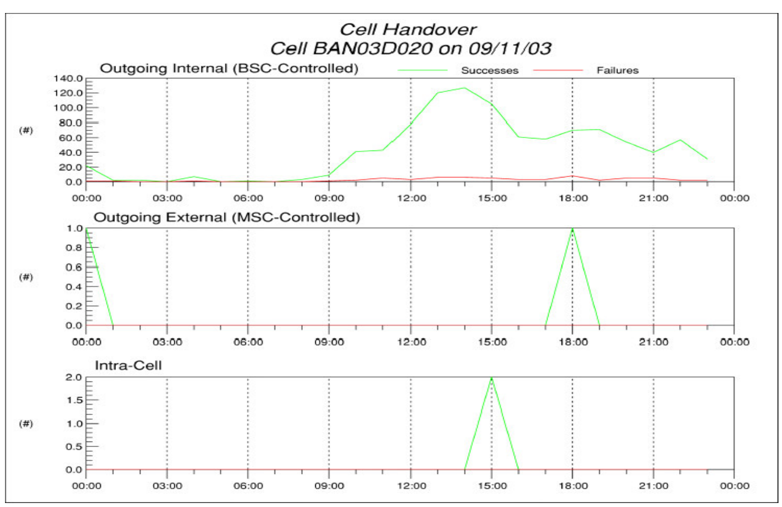

Cell Handover
Cell BAN03D020 on 04/11/03
Outgoing Internal (BSC-Controlled)
Successes
Failures
Outgoing External (MSC-Controlled)
Intra-Cell


Cell Handover
Cell BAN03D020 on 05/11/03
Outgoing Internal (BSC-Controlled)
Successes
Failures
Outgoing External (MSC-Controlled)
Intra-Cell


Cell Handover
Cell BAN03D020 on 06/11/03
Outgoing Internal (BSC-Controlled)
Successes
Failures
Outgoing External (MSC-Controlled)
Intra-Cell


Cell Handover
Cell BAN03D020 on 07/11/03
Outgoing Internal (BSC-Controlled)
Successes
Failures
Outgoing External (MSC-Controlled)
Intra-Cell
(#)


Cell Handover
Cell BAN03D020 on 08/11/03
Outgoing Internal (BSC-Controlled)
Successes
Failures
Outgoing External (MSC-Controlled)
Intra-Cell
(#)


Cell Handover
Cell BAN03D020 on 09/11/03
Outgoing Internal (BSC-Controlled)
Successes
Failures
Outgoing External (MSC-Controlled)
Intra-Cell
(#)

APPENDIX A

Appendix-A.3 Cell-to-Cell Handoff Report

Target	Source	Attempts	Failures	% Fail	% Data
x	y	14	2	14.29	79
x	y	60	2	3.33	79
x	y	202	13	6.44	79
x	y	29	2	6.9	79
x	y	55	6	10.91	79
x	y	69	7	10.14	79
x	y	44	3	6.82	79
x	y	96	11	11.46	79
x	y	32	4	12.5	79
x	y	18	2	11.11	79
x	y	98	6	6.12	79
x	y	2	0	0	79
x	y	1	0	0	79
x	y	28	2	7.14	79
x	y	0	0	0	79
x	y	9	2	22.22	79
x	y	179	11	6.15	79
x	y	9	0	0	79
x	y	29	4	13.79	79
x	y	59	2	3.39	79
x	y	88	5	5.68	79
x	y	8	1	12.5	79
x	y	7	0	0	79
x	y	0	0	0	79
x	y	187	11	5.88	79
x	y	16	0	0	79
x	y	275	12	4.36	79
x	y	8	0	0	79
x	y	50	1	2	79
x	y	5	1	20	79
x	y	32	2	6.25	79
x	y	3	0	0	79
x	y	28	0	0	79
x	y	10	0	0	79
x	y	32	1	3.12	79
x	y	20	4	20	79
x	y	31	4	12.9	79
x	y	59	4	6.78	79
x	y	23	0	0	79
x	y	3	2	66.67	79
x	y	7	0	0	79
x	y	5	0	0	79
x	y	12	0	0	79

APPENDIX A

Appendix-A 4 Cell Handover Type Report

CELL ID	BSC ID	MSC ID	Daily Total Number of Successful Intra Cell Handovers	Daily Total Number of Failed Intra Cell Handovers	Daily Total Number of Intra cell Handover Attempts where MS returns to Old Channel	Daily Total Number of Successful Inter Cell Handovers (Outgoing)
x	y	z	0	1	0	94
x	y	z	1	0	0	76
x	y	z	0	0	0	76
x	y	z	0	0	0	98
x	y	z	3	0	0	332
x	y	z	1	0	0	867
x	y	z	4	0	0	495
x	y	z	0	0	0	1848
x	y	z	9	1	0	1798
x	y	z	0	0	0	656
x	y	z	0	0	0	665
x	y	z	0	0	0	854
x	y	z	4	0	0	520
x	y	z	3	0	0	1345
x	y	z	6	1	0	1850
x	y	z	7	7	2	191
x	y	z	0	0	0	214
x	y	z	1	0	0	856
x	y	z	12	0	0	1193
x	y	z	0	1	0	397
x	y	z	52	4	0	1993
x	y	z	4	3	0	1378
x	y	z	15	0	0	1101
x	y	z	0	2	0	521
x	y	z	7	0	0	898
x	y	z	2	11	0	345
x	y	z	1	0	0	530
x	y	z	2	0	0	463
x	y	z	0	0	0	1048
x	y	z	1	0	0	821
x	y	z	0	0	0	574
x	y	z	1	0	0	1527
x	y	z	0	0	0	654
x	y	z	8	0	0	659
x	y	z	0	0	0	171
x	y	z	0	0	0	447
x	y	z	0	0	0	593

Appendix-A 4 Cell Handover Type Report (Continued)

Daily Total Number of Failed Inter-Cell Handovers (Outgoing)	Daily Total Number of Inter-cell Handover Attempts where MS returns to Old Channel	Inter-Cell Handover Failure Rate %	Inter-Cell Handover Attempt Old Channel Return Rate %	Daily Total Number of Successful External Handovers	Daily Total Number of Failed External Handovers
2	2	2.08	2.08	0	0
0	0	0.00	0.00	0	0
2	1	2.56	1.28	0	0
1	0	1.01	0.00	0	0
8	7	2.35	2.06	0	0
23	14	2.58	1.57	0	0
13	8	2.56	1.57	0	0
50	34	2.63	1.79	0	0
74	46	3.95	2.46	0	0
13	3	1.94	0.45	0	0
19	9	2.78	1.32	0	0
33	19	3.72	2.14	0	0
12	6	2.26	1.13	0	0
81	59	5.68	4.14	0	0
83	63	4.29	3.26	0	0
14	8	6.83	3.90	0	0
10	3	4.46	1.34	0	0
17	8	1.95	0.92	0	0
43	24	3.48	1.94	0	0
8	5	1.98	1.23	0	0
53	32	2.59	1.56	0	0
34	22	2.41	1.56	0	0
14	11	1.26	0.99	0	0
42	38	7.46	6.75	0	0
29	21	3.13	2.27	0	0
31	15	8.24	3.99	0	0
11	9	2.03	1.66	0	0
23	18	4.73	3.70	0	0
40	27	3.68	2.48	0	0
35	25	4.09	2.92	0	0
20	15	3.37	2.53	0	0
49	27	3.11	1.71	0	0
17	10	2.53	1.49	0	0
30	21	4.35	3.05	0	0
11	10	6.04	5.49	0	0
13	10	2.83	2.17	0	0
29	18	4.66	2.89	0	0
21	19	11.73	10.61	0	0

APPENDIX A

Appendix-A 5 Cell Handover Reason Report

CELL ID	BSC ID	MSC ID	Number of Handovers at Bad Uplink Quality	Number of Handovers at Bad Downlink Quality	Number of Handovers to better K-Cell (Locating Algorithm) due to Downlink Level	Number of Handovers due to Exceeded Time Alignment (Distance)
x	y	z	8	3	50	0
x	y	z	4	1	42	0
x	y	z	1	1	59	0
x	y	z	2	0	73	0
x	y	z	14	3	203	0
x	y	z	49	41	286	0
x	y	z	23	2	225	0
x	y	z	87	30	955	1
x	y	z	203	43	870	0
x	y	z	31	7	264	0
x	y	z	46	16	271	0
x	y	z	47	2	307	0
x	y	z	22	11	119	0
x	y	z	91	23	477	0
x	y	z	130	47	854	0
x	y	z	9	5	43	0
x	y	z	38	25	212	0
x	y	z	47	10	311	0
x	y	z	54	22	524	0
x	y	z	23	6	126	0
x	y	z	125	35	758	0
x	y	z	72	20	593	0
x	y	z	41	28	469	0
x	y	z	24	10	282	0
x	y	z	34	15	381	0
x	y	z	26	14	164	0
x	y	z	32	13	69	0
x	y	z	37	3	49	0
x	y	z	80	32	207	0
x	y	z	69	18	104	0
x	y	z	49	18	106	0
x	y	z	133	26	235	0
x	y	z	54	19	142	0
x	y	z	82	12	137	0
x	y	z	27	9	50	0

Appendix-A 5 Cell Handover Reason Report (Continued)

Number of Handovers to better L-Cell (Locating Algorithm) due to Power Budget	Handover Attempts due to Operation and Maintenance Intervention	Handover Attempts due to Cell Load Sharing (Other Reasons)
38	0	0
25	0	0
17	0	0
24	0	0
123	0	0
516	0	0
260	0	0
834	0	0
756	0	0
369	0	0
353	0	0
531	0	0
382	0	0
841	0	0
900	0	0
150	0	0
361	0	0
506	0	0
641	0	0
250	0	0
1131	0	0
734	0	0
580	0	0
244	0	0
500	0	0
228	0	0
429	0	0
399	0	0
768	0	0
667	0	0
421	0	0
1186	0	0
454	0	0
457	0	0
96	0	0
307	0	0
430	0	0
91	0	0

APPENDIX A

Appendix-A 6 Cell TCH Traffic Channel Report

CELL ID	BSC ID	MSC ID	Cell Busy Hour	Cell Busy Hour Number of Attempts	Cell Busy Hour Number of Handover Attempts	Cell Busy Hour Number of Blocks (Congestion at Assignment)	Cell Busy Hour Successful MS Channel Establishment on TCHs
x	y	z	19:00	86	10	0	84
x	y	z	18:00	119	4	2	117
x	y	z	12:00	38	10	0	35
x	y	z	11:00	50	17	0	48
x	y	z	20:00	258	29	0	257
x	y	z	20:00	274	87	0	265
x	y	z	22:00	228	30	0	227
x	y	z	19:00	685	148	0	680
x	y	z	19:00	1355	170	0	1312
x	y	z	19:00	358	56	0	357
x	y	z	19:00	343	80	0	338
x	y	z	19:00	402	51	0	402
x	y	z	22:00	131	27	0	130
x	y	z	15:00	791	96	0	778
x	y	z	19:00	908	130	0	901
x	y	z	13:00	88	24	0	84
x	y	z	22:00	124	18	0	124
x	y	z	20:00	272	64	0	268
x	y	z	20:00	532	57	0	528
x	y	z	21:00	151	25	0	150
x	y	z	19:00	1138	168	0	1126
x	y	z	16:00	662	105	0	653
x	y	z	14:00	479	96	0	475
x	y	z	13:00	174	31	0	173
x	y	z	19:00	513	109	0	511
x	y	z	22:00	93	31	0	91
x	y	z	10:00	244	47	0	238
x	y	z	14:00	296	50	0	294
x	y	z	13:00	545	84	0	537
x	y	z	21:00	532	127	0	481
x	y	z	17:00	336	46	0	334
x	y	z	18:00	573	101	0	556
x	y	z	13:00	158	52	0	152
x	y	z	20:00	253	83	0	247
x	y	z	13:00	122	8	0	121
x	y	z	14:00	158	32	0	156
x	y	z	20:00	238	72	0	235
x	y	z	19:00	207	21	0	202
x	y	z	22:00	133	46	0	125

Appendix-A 6 Cell TCH Traffic Channel Report (Continued)

Cell Busy Hour Successful Handover Establishment on TCHs	Cell Busy Hour TCH Dropped Connections due to RF-Losses (TA, Low Signal Strength, Bad Quality, Suddenly Lost Connections)	Cell Busy Hour TCH Dropped Connections due to Failures	Cell Busy Hour Traffic (Erlangs)	Cell Busy Hour Number of Dropped TCH Connections per Erlang	Cell Busy Hour Mean Holding Time (Seconds)
9	16	0	0.45	35.556	19.4
6	4	1	1.06	4.717	32.74
8	2	0	0.18	11.111	18.86
15	1	0	0.46	2.174	34.58
26	4	0	1.32	3.030	18.56
75	2	0	1.01	1.980	13.66
28	2	0	0.92	2.174	14.54
143	9	0	3.04	2.961	16.12
134	24	0	6.08	3.947	16.68
55	3	0	1.11	2.703	11.15
74	1	0	1.35	0.741	14.41
51	0	0	2.01	0.000	17.99
27	0	0	0.74	0.000	20.54
85	2	0	2.58	0.775	11.94
123	6	0	4.1	1.463	16.37
21	1	0	0.57	1.754	24.29
18	3	0	1.12	2.679	32.58
61	1	0	1.46	0.685	19.63
56	1	0	2.12	0.472	14.45
28	0	0	0.79	0.000	18.87
155	7	0	4.63	1.512	14.81
97	4	0	2.73	1.465	15.07
91	0	0	2.57	0.000	19.49
29	2	0	0.99	2.020	20.58
103	4	0	2.19	1.826	15.46
30	2	0	0.69	2.899	27.25
43	2	0	1.04	1.923	15.67
46	0	0	1.46	0.000	17.86
75	0	0	2.7	0.000	18.08
82	5	0	2.34	2.137	17.53
42	4	0	1.39	2.878	15
92	10	0	3.13	3.195	20.27
47	4	0	0.8	5.000	18.88
80	2	0	1.45	1.379	21.09
8	0	0	0.76	0.000	22.56
29	1	0	0.64	1.563	14.74
73	4	0	1.31	3.053	20.04
16	0	0	1.18	0.000	21.09
38	0	0	0.59	0.000	16.96

Appendix-A 6 Cell TCH Traffic Channel Report (Continued)

Cell Busy Hour Number of Available Channels	Cell Busy Hour Blocked Calls %	Cell Busy Hour Dropped Calls %	Cell Busy Hour TCH Assignment Success Rate %	Cell Daily Total Number of Attempts	Cell Daily Total Number of Handover Attempts	Cell Daily Total Number of Blocks (Congestion at Assignment)
13.8	0.00	21.33	97.67	846	156	31
12.5	1.68	4.50	98.32	1491	113	16
14	0.00	7.41	92.11	317	54	0
14	0.00	3.03	96.00	712	123	0
14	0.00	1.73	99.61	2740	309	0
14	0.00	1.05	96.72	3501	785	0
14	0.00	1.01	99.56	2574	481	0
14	0.00	1.68	99.27	8913	1649	0
22	0.00	2.04	96.83	16910	1955	0
14	0.00	0.99	99.72	3236	627	0
14	0.00	0.38	98.54	3060	626	0
14	0.00	0.00	100.00	5907	768	0
14	0.00	0.00	99.24	1820	421	0
14	0.00	0.29	98.36	8021	1259	0
14	0.00	0.77	99.23	12017	1710	0
14	0.00	1.59	95.45	1170	170	0
14	0.00	2.83	100.00	1266	178	0
14	0.00	0.48	98.53	3570	782	0
14	0.00	0.21	99.25	7006	1150	0
14	0.00	0.00	99.34	1981	372	0
14	0.00	0.72	98.95	13575	1942	12
14	0.00	0.72	98.64	8597	1373	0
14	0.00	0.00	99.16	6119	1001	0
14	0.00	1.39	99.43	2441	492	0
14	0.00	0.98	99.61	6195	826	0
14	0.00	3.28	97.85	1149	317	0
14	0.00	1.03	97.54	3591	522	0
14	0.00	0.00	99.32	3222	510	0
14	0.00	0.00	98.53	7066	949	0
14	0.00	1.25	90.41	4156	768	0
14	0.00	1.37	99.40	4528	538	0
14	0.00	2.16	97.03	8121	1412	0
14	0.00	3.81	96.20	2597	598	0
14	0.00	1.20	97.63	3131	689	0
14	0.00	0.00	99.18	1429	206	0
14	0.00	0.79	98.73	2185	387	0
14	0.00	2.47	98.74	2266	499	0
14	0.00	0.00	97.58	2126	159	0
14	0.00	0.00	93.98	1865	459	0

Appendix-A 6 Cell TCH Traffic Channel Report (Continued)

Cell Daily Total TCH Congestion Time	Cell Daily Total Successful MS Channel Establish-ment on TCHs	Cell Daily Total Successful Handover Establish-ment on TCHs	Cell Daily Total TCH Dropped Connections due to RF-Losses (TA, Low Signal Strength, Bad Quality, Suddenly Lost Connections)	Cell Daily Total TCH Dropped Connections due to Failures	Cell Daily Total Traffic (Erlangs)
13	796	113	36	6	3.91
12	1446	76	35	13	8.19
0	308	48	5	0	1.35
0	701	112	6	0	3.97
0	2727	302	24	0	14.26
0	3403	696	29	0	11.11
0	2542	456	12	0	9.53
0	8756	1539	118	1	34.86
0	16410	1555	228	1	73.43
0	3190	581	13	0	12.51
0	3008	588	35	0	12.81
0	5864	755	19	1	24.18
0	1792	399	7	0	8.12
0	7950	1204	31	1	30
0	11914	1612	78	2	47.3
0	1146	157	15	0	4.99
0	1246	166	15	0	6.35
0	3531	762	16	0	14.62
0	6940	1091	50	0	25.86
0	1956	349	10	0	7.62
5	13426	1808	107	0	52.77
0	8504	1299	56	0	34.62
0	6055	955	43	0	26.1
0	2395	455	21	0	10.62
0	6091	755	38	0	25.64
0	1112	286	32	0	6.31
0	3540	486	20	0	12.67
0	3202	495	26	0	15.84
0	6982	882	45	1	30.9
0	4035	676	34	0	16.27
0	4476	491	25	0	15.55
0	7973	1281	73	0	39.65
0	2561	575	24	2	9.76
0	3062	627	26	0	12.22
0	1385	172	15	0	6.73
0	2150	360	16	0	7.05
0	2218	461	18	0	8.56
0	2090	130	32	0	10.01
0	1823	422	10	0	6.16

Appendix-A 6 Cell TCH Traffic Channel Report (Continued)

Cell Daily Total Number of Dropped TCH Connections per Erlang	Cell Daily Total Mean Holding Time (Sec)	Cell Daily Total Number of Available Channels	Cell Daily Total Number of Defined Channels	Cell Daily Total Blocked Calls %	Cell Daily Total Dropped Calls %	Cell Daily Total TCH Assign-ment Success Rate %
0.518	17.7	12.7	14	3.66	6.15	94.09
0.282	20.39	12.7	14	1.07	3.50	96.98
0.178	15.81	14	14	0.00	1.92	97.16
0.073	20.4	14	14	0.00	1.02	98.46
0.081	18.82	14	14	0.00	0.99	99.53
0.126	11.75	14	14	0.00	1.07	97.20
0.061	13.5	14	14	0.00	0.58	98.76
0.165	14.33	14	14	0.00	1.65	98.24
0.150	16.11	22	22	0.00	1.54	97.04
0.050	14.12	14	14	0.00	0.50	98.58
0.132	15.33	14	14	0.00	1.45	98.30
0.040	14.84	14	14	0.00	0.39	99.27
0.042	16.31	14	14	0.00	0.50	98.46
0.051	13.59	14	14	0.00	0.47	99.11
0.082	14.29	14	14	0.00	0.78	99.14
0.145	15.69	14	14	0.00	1.52	97.95
0.114	18.34	14	14	0.00	1.39	98.42
0.053	14.91	14	14	0.00	0.58	98.91
0.093	13.41	14	14	0.00	0.85	99.06
0.063	14.03	14	14	0.00	0.62	98.74
0.098	14.15	14	14	0.09	0.92	98.90
0.078	14.65	14	14	0.00	0.78	98.92
0.079	15.52	14	14	0.00	0.84	98.95
0.095	15.96	14	14	0.00	1.08	98.12
0.071	15.15	14	14	0.00	0.71	98.32
0.244	20.44	14	14	0.00	3.87	96.78
0.076	12.89	14	14	0.00	0.65	98.58
0.079	17.8	14	14	0.00	0.96	99.38
0.072	15.93	14	14	0.00	0.75	98.81
0.101	14.52	14	14	0.00	1.01	97.09
0.077	12.5	14	14	0.00	0.63	98.85
0.089	17.9	14	14	0.00	1.09	98.18
0.128	13.72	14	14	0.00	1.31	98.61
0.103	14.37	14	14	0.00	1.07	97.80
0.107	17.49	14	14	0.00	1.24	96.92
0.109	11.81	14	14	0.00	0.89	98.40
0.101	13.89	14	14	0.00	1.02	97.88
0.154	17.24	14	14	0.00	1.63	98.31
0.078	12.16	14	14	0.00	0.71	97.75

APPENDIX B

Appendix-B.1 NCR Source Code

```
; GPSS World Simulation Program, NCR Case
;*****************************************************************
;         No Channel Reservation Model
;*****************************************************************
;         Time Unit is one second
;*****************************************************************
;         Initialization Part
;*****************************************************************
INITIAL X$NLossC,0                  ;New Call Loss Count
INITIAL X$HLossC,0                  ;Handoff Call Loss Count
INITIAL X$Ncount,0                  ;New Call Arrival Count
INITIAL X$Hcount,0                  ;Handoff Call Arrival Count
INITIAL X$Pb,0
;New call blocking probability
INITIAL x$Pf,0
;Handoff call dropping probability
INITIAL X$nn,1                      ;Average new call arrival
INITIAL X$nh,1                      ;Average handoff call arrival
INITIAL X$alpha,1                   ;User Mobility
INITIAL X$Erl,0                     ;Traffic Load
Alpha EQU nh/nn                     ;User Mobility
nsd EQU 60
;Average new call service duration
hsd EQU 40
;Average handoff call service duration
Cmax EQU 44                         ;Number of channels
Thmax EQU Cmax                      ;Upper Limit for Threhold
Thmin EQU Cmax#(3/4)                ;Lower Limit for Threhold
Thi EQU 44                          ;Threshold
Channels  STORAGE    44
;Storage Capacity is number of channels
Ch_Usage   TABLE      S$Channels,1,1,45
;Channel usage frequency
TPb        TABLE      X$Pb,0,0.05,20         ;Pb distribution
TPf        TABLE      X$Pf,0,0.05,20         ;Pf distribution
Talpha     TABLE      X$Alpha,0,0.1,30       ;Alpha distribution
TErl       TABLE      X$Erl,0,2,32
;Traffic Load distribution
;*****************************************************************
;         Simulation Part
;*****************************************************************
Begh       SAVEVALUE  Hcount+,1
;Increment arrived handoff call
           SAVEVALUE  alpha,(X$nn/X$nh)
;User Mobility reverse ratio of interarrivals
           SAVEVALUE
Erl,(((60/X$nn)/(60/nsd))+((60/X$nh)/(60/hsd)))
;Traffic Load - all in per min
           GATE SNF   Channels,Handloss      ;Try for a line
           ENTER      Channels               ;Connect call
           ADVANCE    (Exponential(1,0,hsd)) ;Speak for sd seconds
           LEAVE      Channels               ;Free a Channel
           TRANSFER   ,TerminH
;Increase losscount only when channels are full
```

```
Handloss  SAVEVALUE  HLossC+,1
;Increment Handoff Losscount
TerminH   SAVEVALUE  Pf,(X$HLossC/X$Hcount)
;Calculate handoff call drop probability
          TABULATE   Ch_Usage
;Tabulate Channel Usage
          TABULATE   TPb
;Tabulate Pb
          TABULATE   TPf
;Tabulate Pf
          TABULATE   TErl
;Tabulate Erl
          TABULATE   Talpha
;Tabulate alpha
          TRANSFER  ,Fin
;Remove a transaction
;************************************************************
Begn      SAVEVALUE  Ncount+,1
;Increment arrived new call
          SAVEVALUE  alpha,(X$nn/X$nh)
;User Mobility reverse ratio of interarrivals
SAVEVALUEErl,(((60/X$nn)/(60/nsd))+((60/X$nh)/(60/hsd)))
;Traffic Load - all in per min
          TEST LE S$Channels,Thi,Newloss
;Block new calls when Th is reached
          GATE SNF   Channels,Newloss
;Try for a line since threshold not reached
          ENTER      Channels
;Connect call
          ADVANCE    (Exponential(1,0,nsd))
;Speak for sd seconds
          LEAVE      Channels
;Free a Channel
          TRANSFER   ,TerminN
;Increase losscount only when channels are full
Newloss   SAVEVALUE  NLossC+,1
;Increment New call Losscount
TerminN   SAVEVALUE  Pb,(X$NLossC/X$Ncount)
;Calculate handoff call drop probability
          TABULATE   Ch_Usage
;Tabulate Channel Usage
          TABULATE   TPb
;Tabulate Pb
          TABULATE   TPf
;Tabulate Pf
          TABULATE   Talpha
;Tabulate alpha
          TABULATE   TErl
;Tabulate Erl
Fin       TERMINATE
;Remove a transaction
;************************************************************
;         Scenario and Traffic Generation Part
;************************************************************
; Call arrivals for 00:00-01:59
          GENERATE  (Exponential(1,0,2.5)),,,2880
          ;Handoff Call arrivals for one hour
          SAVEVALUE nh,2.5
          SAVEVALUE nn,5
```

```
          TRANSFER  ,Begh
          GENERATE  (Exponential(1,0,5)),,,1440
          ;New Calls arrivals for one hour
          TRANSFER  ,Begn

; Call arrivals for 02:00-03:59
          GENERATE  (Exponential(1,0,40)),,(2#3600),180
          ;Handoff Call arrivals for one hour
          SAVEVALUE nh,40
          SAVEVALUE nn,20
          TRANSFER  ,Begh
          GENERATE  (Exponential(1,0,20)),,(2#3600),360
          ;New Calls arrivals for one hour
          TRANSFER  ,Begn
; Call arrivals for 04:00-05:59
          GENERATE  (Exponential(1,0,80)),,(4#3600),90
          ;Handoff Call arrivals for one hour
          SAVEVALUE nh,80
          SAVEVALUE nn,40
          TRANSFER  ,Begh
          GENERATE  (Exponential(1,0,40)),,(4#3600),180
          ;New Calls arrivals for one hour
          TRANSFER  ,Begn
; Call arrivals for 06:00-07:59
          GENERATE  (Exponential(1,0,20)),,(6#3600),360
          ;Handoff Call arrivals for one hour
          SAVEVALUE nh,20
          SAVEVALUE nn,40
          TRANSFER  ,Begh
          GENERATE  (Exponential(1,0,40)),,(6#3600),180
          ;New Calls arrivals for one hour
          TRANSFER  ,Begn
; Call arrivals for 08:00-09:59
          GENERATE  (Exponential(1,0,2)),,(8#3600),3600
          ;Handoff Call arrivals for one hour
          SAVEVALUE nh,2
          SAVEVALUE nn,6
          TRANSFER  ,Begh
          GENERATE  (Exponential(1,0,6)),,(8#3600),1200
          ;New Calls arrivals for one hour
          TRANSFER  ,Begn
; Call arrivals for 10:00-11:59
          GENERATE  (Exponential(1,0,2)),,(10#3600),3600
          ;Handoff Call arrivals for one hour
          SAVEVALUE nh,2
          SAVEVALUE nn,2
          TRANSFER  ,Begh
          GENERATE  (Exponential(1,0,2)),,(10#3600),3600
          ;New Calls arrivals for one hour
          TRANSFER  ,Begn
; Call arrivals for 12:00-13:59
          GENERATE  (Exponential(1,0,1.25)),,(12#3600),5670
          ;Handoff Call arrivals for one hour
          SAVEVALUE nh,1.25
          SAVEVALUE nn,2.5
          TRANSFER  ,Begh
          GENERATE  (Exponential(1,0,2.5)),,(12#3600),2880
          ;New Calls arrivals for one hour
          TRANSFER  ,Begn
```

```
; Call arrivals for 14:00-15:59
          GENERATE  (Exponential(1,0,2)),,(14#3600),3600
          ;Handoff Call arrivals for one hour
          SAVEVALUE nh,2
          SAVEVALUE nn,2
          TRANSFER  ,Begh
          GENERATE  (Exponential(1,0,2)),,(14#3600),3600
          ;New Calls arrivals for one hour
          TRANSFER  ,Begn
; Call arrivals for 16:00-17:59
          GENERATE  (Exponential(1,0,1.25)),,(16#3600),5760
          ;Handoff Call arrivals for one hour
          SAVEVALUE nh,1.25
          SAVEVALUE nn,2.5
          TRANSFER  ,Begh
          GENERATE  (Exponential(1,0,2.5)),,(16#3600),2880
          ;New Calls arrivals for one hour
          TRANSFER  ,Begn
; Call arrivals for 18:00-19:59
          GENERATE  (Exponential(1,0,1)),,(18#3600),7200
          ;Handoff Call arrivals for one hour
          SAVEVALUE nh,1
          SAVEVALUE nn,4
          TRANSFER  ,Begh
          GENERATE  (Exponential(1,0,4)),,(18#3600),1800
          ;New Calls arrivals for one hour
          TRANSFER  ,Begn
; Call arrivals for 20:00-21:59
          GENERATE  (Exponential(1,0,2)),,(20#3600),3600
          ;Handoff Call arrivals for one hour
          SAVEVALUE nh,2
          SAVEVALUE nn,6
          TRANSFER  ,Begh
          GENERATE  (Exponential(1,0,6)),,(20#3600),1200
          ;New Calls arrivals for one hour
          TRANSFER  ,Begn
; Call arrivals for 22:00-23:59
          GENERATE  (Exponential(1,0,5)),,(22#3600),1440
          ;Handoff Call arrivals for one hour
          SAVEVALUE nh,5
          SAVEVALUE nn,10
          TRANSFER  ,Begh
          GENERATE  (Exponential(1,0,10)),,(22#3600),720
          ;New Calls arrivals for one hour
          TRANSFER  ,Begn
;*****************************************************************
;         Timing Part
;*****************************************************************
          GENERATE  3600
;Xact each hour (Sim Couter in Hours)
          TERMINATE 1
;*****************************************************
;         INCLUDE   "seed45.txt"
; Include-file to run the successive simulations
;*****************************************************************
;         End NCR
;*****************************************************************
```

Appendix-B.2 FCR Source Code

```
; GPSS World Simulation Program, FCR Case
;*****************************************************************
;         Fixed Channel Reservation Model
;*****************************************************************
;         Time Unit is one second
;*****************************************************************
;         Initialization Part
;*****************************************************************
INITIAL X$NLossC,0  ;New Call Loss Count
INITIAL X$HLossC,0  ;Handoff Call Loss Count
INITIAL X$Ncount,0  ;New Call Arrival Count
INITIAL X$Hcount,0  ;Handoff Call Arrival Count
INITIAL X$alpha,1   ;User Mobility
INITIAL X$Erl,0     ;Traffic Load
INITIAL X$Pb,0      ;New call blocking probability
INITIAL X$Pf,0      ;Handoff call dropping probability
INITIAL X$nn,1      ;Average new call arrival
INITIAL X$nh,1      ;Average handoff call arrival
Alpha EQU nh/nn     ;User Mobility
nsd EQU 60          ;Average new call service duration
hsd EQU 40          ;Average handoff call service duration
Cmax EQU 44         ;Number of channels
Thmax EQU Cmax      ;Upper Limit for Threhold
Thmin EQU Cmax#(1/2);Lower Limit for Threhold
Thi EQU Cmax#(3/4)  ;Threshold
Channels  STORAGE    44
;Storage Capacity is number of channels
Ch_Usage   TABLE      S$Channels,1,1,45
;Channel usage frequency
TPb       TABLE      X$Pb,0,0.05,20         ;Pb distribution
TPf       TABLE      X$Pf,0,0.05,20         ;Pf distribution
Talpha    TABLE      X$Alpha,0,0.1,30       ;Alpha distribution
TErl      TABLE      X$Erl,0,2,32
;Traffic Load distribution
;*****************************************************************
;         Simulation Part
;*****************************************************************
Begh      SAVEVALUE  Hcount+,1
;Increment arrived handoff call
Begh      SAVEVALUE  Hcount+,1
;Increment arrived handoff call
          SAVEVALUE  Alpha,(X$nn/X$nh)
;User Mobility reverse ratio of interarrivals
          SAVEVALUE
Erl,(((60/X$nn)/(60/nsd))+((60/X$nh)/(60/hsd)))
;Traffic Load - all in per min
          GATE SNF   Channels,Handloss      ;Try for a line
          ENTER      Channels               ;Connect call
          ADVANCE    (Exponential(1,0,hsd)) ;Speak for sd seconds
          LEAVE      Channels               ;Free a Channel
          TRANSFER   ,TerminH
;Increase losscount only when channels are full
Handloss  SAVEVALUE  HLossC+,1
;Increment Handoff Losscount
TerminH   SAVEVALUE  Pf,(X$HLossC/X$Hcount)
```

```
;Calculate handoff call drop probability
          TABULATE   Ch_Usage
;Tabulate Channel Usage
          TABULATE   TPb
;Tabulate Pb
          TABULATE   TPf
;Tabulate Pf
          TABULATE   Talpha
;Tabulate alpha
          TABULATE   TErl
;Tabulate Erl
          TRANSFER  ,Fin
;Remove a transaction
;*****************************************************************
Begn      SAVEVALUE  Ncount+,1
;Increment arrived new call
          SAVEVALUE  Alpha,(X$nn/X$nh)
;User Mobility reverse ratio of interarrivals
          SAVEVALUE
Erl,(((60/X$nn)/(60/nsd))+((60/X$nh)/(60/hsd)))
;Traffic Load - all in per min
          TEST LE S$Channels,Thi,Newloss
;Block new calls when Thi is reached
          GATE SNF   Channels,Newloss
;Try for a line since threshold not reached
          ENTER      Channels
;Connect call
          ADVANCE    (Exponential(1,0,nsd))
;Speak for sd seconds
          LEAVE      Channels
;Free a Channel
          TRANSFER   ,TerminN
;Increase losscount only when channels are full
Newloss   SAVEVALUE  NLossC+,1
;Increment New call Losscount
TerminN   SAVEVALUE  Pb,(X$NLossC/X$Ncount)
;Calculate handoff call drop probability
          TABULATE   Ch_Usage
;Tabulate Channel Usage
          TABULATE   TPb
;Tabulate Pb
          TABULATE   TPf
;Tabulate Pf
          TABULATE   Talpha
;Tabulate alpha
          TABULATE   TErl
;Tabulate Erl
Fin       TERMINATE
;Remove a transaction
;*****************************************************************
;         Scenario and Traffic Generation Part
;*****************************************************************
; Call arrivals for 00:00-01:59
          GENERATE  (Exponential(1,0,2.5)),,,2880
          ;Handoff Call arrivals for one hour
          SAVEVALUE nh,2.5
          SAVEVALUE nn,5
          TRANSFER  ,Begh
          GENERATE  (Exponential(1,0,5)),,,1440
```

```
          ;New Calls arrivals for one hour
          TRANSFER  ,Begn

; Call arrivals for 02:00-03:59
          GENERATE  (Exponential(1,0,40)),,(2#3600),180
          ;Handoff Call arrivals for one hour
          SAVEVALUE nh,40
          SAVEVALUE nn,20
          TRANSFER  ,Begh
          GENERATE  (Exponential(1,0,20)),,(2#3600),360
          ;New Calls arrivals for one hour
          TRANSFER  ,Begn
; Call arrivals for 04:00-05:59
          GENERATE  (Exponential(1,0,80)),,(4#3600),90
          ;Handoff Call arrivals for one hour
          SAVEVALUE nh,80
          SAVEVALUE nn,40
          TRANSFER  ,Begh
          GENERATE  (Exponential(1,0,40)),,(4#3600),180
          ;New Calls arrivals for one hour
          TRANSFER  ,Begn
; Call arrivals for 06:00-07:59
          GENERATE  (Exponential(1,0,20)),,(6#3600),360
          ;Handoff Call arrivals for one hour
          SAVEVALUE nh,20
          SAVEVALUE nn,40
          TRANSFER  ,Begh
          GENERATE  (Exponential(1,0,40)),,(6#3600),180
          ;New Calls arrivals for one hour
          TRANSFER  ,Begn
; Call arrivals for 08:00-09:59
          GENERATE  (Exponential(1,0,2)),,(8#3600),3600
          ;Handoff Call arrivals for one hour
          SAVEVALUE nh,2
          SAVEVALUE nn,6
          TRANSFER  ,Begh
          GENERATE  (Exponential(1,0,6)),,(8#3600),1200
          ;New Calls arrivals for one hour
          TRANSFER  ,Begn
; Call arrivals for 10:00-11:59
          GENERATE  (Exponential(1,0,2)),,(10#3600),3600
          ;Handoff Call arrivals for one hour
          SAVEVALUE nh,2
          SAVEVALUE nn,2
          TRANSFER  ,Begh
          GENERATE  (Exponential(1,0,2)),,(10#3600),3600
          ;New Calls arrivals for one hour
          TRANSFER  ,Begn
; Call arrivals for 12:00-13:59
          GENERATE  (Exponential(1,0,1.25)),,(12#3600),5670
          ;Handoff Call arrivals for one hour
          SAVEVALUE nh,1.25
          SAVEVALUE nn,2.5
          TRANSFER  ,Begh
          GENERATE  (Exponential(1,0,2.5)),,(12#3600),2880
          ;New Calls arrivals for one hour
          TRANSFER  ,Begn
; Call arrivals for 14:00-15:59
```

```
          GENERATE  (Exponential(1,0,2)),,(14#3600),3600
          ;Handoff Call arrivals for one hour
          SAVEVALUE nh,2
          SAVEVALUE nn,2
          TRANSFER  ,Begh
          GENERATE  (Exponential(1,0,2)),,(14#3600),3600
          ;New Calls arrivals for one hour
          TRANSFER  ,Begn
; Call arrivals for 16:00-17:59
          GENERATE  (Exponential(1,0,1.25)),,(16#3600),5760
          ;Handoff Call arrivals for one hour
          SAVEVALUE nh,1.25
          SAVEVALUE nn,2.5
          TRANSFER  ,Begh
          GENERATE  (Exponential(1,0,2.5)),,(16#3600),2880
          ;New Calls arrivals for one hour
          TRANSFER  ,Begn
; Call arrivals for 18:00-19:59
          GENERATE  (Exponential(1,0,1)),,(18#3600),7200
          ;Handoff Call arrivals for one hour
          SAVEVALUE nh,1
          SAVEVALUE nn,4
          TRANSFER  ,Begh
          GENERATE  (Exponential(1,0,4)),,(18#3600),1800
          ;New Calls arrivals for one hour
          TRANSFER  ,Begn
; Call arrivals for 20:00-21:59
          GENERATE  (Exponential(1,0,2)),,(20#3600),3600
          ;Handoff Call arrivals for one hour
          SAVEVALUE nh,2
          SAVEVALUE nn,6
          TRANSFER  ,Begh
          GENERATE  (Exponential(1,0,6)),,(20#3600),1200
          ;New Calls arrivals for one hour
          TRANSFER  ,Begn
; Call arrivals for 22:00-23:59
          GENERATE  (Exponential(1,0,5)),,(22#3600),1440
          ;Handoff Call arrivals for one hour
          SAVEVALUE nh,5
          SAVEVALUE nn,10
          TRANSFER  ,Begh
          GENERATE  (Exponential(1,0,10)),,(22#3600),720
          ;New Calls arrivals for one hour
          TRANSFER  ,Begn
;*****************************************************************
;         Timing Part
;*****************************************************************
          GENERATE  3600
;Xact each hour (Sim Couter in Hours)
          TERMINATE 1
;*****************************************************************
;         INCLUDE   "seed45.txt"
; Include-file to run the successive simulations
;*****************************************************************
;         End FCR
;*****************************************************************
```

Appendix-B.3 DCR Source Code

```
; GPSS World Simulation Program, DCR Case
;*****************************************************************
;         Dynamic Channel Reservation Model
;*****************************************************************
;         Time Unit is one second
;*****************************************************************
;         Initialization Part
;*****************************************************************
INITIAL X$NLossC,0  ;New Call Loss Count
INITIAL X$HLossC,0  ;Handoff Call Loss Count
INITIAL X$Ncount,0  ;New Call Arrival Count
INITIAL X$Hcount,0  ;Handoff Call Arrival Count
INITIAL X$Pb,0      ;New call blocking probability
INITIAL X$Pf,0      ;Handoff call dropping probability
INITIAL X$Thi,35    ;Instantaneous Value on Th
INITIAL X$alpha,1   ;User Mobility
INITIAL X$nn,1      ;Average new call arrival rate
INITIAL X$nh,1      ;Average handoff call arrival rate
INITIAL X$Erl,0     ;Traffic Load
INITIAL X$Loga,0    ;Log of user mobility
*INITIAL X$Pfi,0    ;A temporary variable
*INITIAL X$Pac,0    ;Accept probability
*Check VARIABLE (RN1/1000);Check is a r.v. between 0 and 1
nsd EQU 60          ;Average new call service duration
hsd EQU 40          ;Average handoff service duration
Cmax EQU 44         ;Number of channels
Thmax EQU Cmax      ;Upper Limit for Threhold
Thmin EQU Cmax#(1/2);Lower Limit for Threhold
Thi EQU Cmax#(3/4)  ;Threshold
Channels  STORAGE    44 ;Storage Capacity is number of channels
Ch_Usage  TABLE      S$Channels,1,1,45      ;Channel usage
distribution
Threshold TABLE      X$Thi,1,1,45       ;Threshold distribution
Talpha    TABLE      X$alpha,0,0.1,30   ;Alpha distribution
TErl      TABLE      X$Erl,0,2,32    ;Traffic Load distribution
TPb       TABLE      X$Pb,0,0.05,20         ;Pb distribution
TPf       TABLE      X$Pf,0,0.05,20         ;Pf distribution
*Tcheck   TABLE      V$check,0,0.05,20      ;r.v.
*Taccept  TABLE      X$Pac,0,0.05,20  ;Accept Prob. distribution
;*****************************************************************
;         Simulation Part
;*****************************************************************
Begh      SAVEVALUE  Hcount+,1
;Increment arrived handoff call
          SAVEVALUE  Alpha,(X$nn/X$nh)
;User Mobility reverse ratio of interarrivals
          SAVEVALUE
          Erl,(((60/X$nn)/(60/nsd))+((60/X$nh)/(60/hsd)))
;Traffic Load - all in per min
          SAVEVALUE  Loga,(LOG(X$alpha))
;Calculate Log of user mobility
          SAVEVALUE  Thi,(X$Thi-(((Cmax-
Thmin)/Cmax)#(0.001#X$Loga)))
;Update Threshold
          TEST LE X$Thi,Thmin,Notlow
```

```
;Check threshold not to be too low
          SAVEVALUE  Thi,Thmin
;Limit it if too low, skip otherwise
Notlow    TEST G X$Thi,Thmax,Nothigh
;Check threshold not to be too high
          SAVEVALUE  Thi,Thmax
;limit it if too high, skip otherwise
Nothigh   GATE SNF   Channels,Handloss      ;Try for a line
          ENTER      Channels               ;Connect call
          ADVANCE    (Exponential(1,0,hsd)) ;Speak for sd seconds
          LEAVE      Channels               ;Free a Channel
          TRANSFER   ,TerminH
;Increase losscount only when channels are full
Handloss  SAVEVALUE  HLossC+,1              ;Increment Handoff
Losscount
TerminH   SAVEVALUE  Pf,(X$HLossC/X$Hcount)
;Calculate handoff call drop probability
          TABULATE   Ch_Usage
;Tabulate Channel Usage
          TABULATE   Threshold
;Tabulate Threshold Value
          TABULATE   Talpha
;Tabulate alpha
          TABULATE   TErl
;Tabulate Erl
          TABULATE   TPb
;Tabulate Pb
          TABULATE   TPf
;Tabulate Pf
          TRANSFER   ,Fin
;Terminate a handoff call transaction
          Begn      SAVEVALUE  Ncount+,1
;Increment arrived new call
          SAVEVALUE  Alpha,(X$nn/X$nh)
;User Mobility reverse ratio of interarrivals
          SAVEVALUE
Erl,(((60/X$nn)/(60/nsd))+((60/X$nh)/(60/hsd)))
;Traffic Load - all in per min
          SAVEVALUE  Thi,(X$Thi-(((Cmax-Thmin)/Cmax)#(X$Loga)))
;Update Threshold
          TEST LE X$Thi,Thmin,Notlow2
;Check threshold not to be too low
          SAVEVALUE  Thi,Thmin
;Limit it if too low, skip otherwise
Notlow2   TEST G X$Thi,Thmax,Nothigh2
;Check threshold not to be too high
          SAVEVALUE  Thi,Thmax
;limit it if too high, skip otherwise
Nothigh2  TEST LE S$Channels,X$Thi,Newloss
;Pac is one if threshold not reached
          GATE SNF   Channels,Newloss       ;Try for a line
          ENTER      Channels               ;Connect call
          ADVANCE    (Exponential(1,0,nsd)) ;Speak for sd seconds
          LEAVE      Channels               ;Free a Channel
          TRANSFER   ,TerminN
;Increase losscount only when channels are full
Newloss   SAVEVALUE  NLossC+,1
;Increment New call Losscount
TerminN   SAVEVALUE  Thi,(X$Thi-(((Cmax-Thmin)/Cmax)#(X$Loga)))
```

```
;Update Threshold
          SAVEVALUE  Pb,(X$NLossC/X$Ncount)
;Calculate handoff call drop probability
          TABULATE   Ch_Usage
;Tabulate Channel Usage
          TABULATE   Threshold
;Tabulate Threshold Value
          TABULATE   Talpha
;Tabulate alpha
          TABULATE   TErl
;Tabulate Erl
          TABULATE   TPb
;Tabulate Pb
          TABULATE   TPf
;Tabulate Pf
Fin       TERMINATE
;Terminate a new call transaction
;*****************************************************************
;         Scenario and Traffic Generation Part
;*****************************************************************
; Call arrivals for 00:00-01:59
          GENERATE  (Exponential(1,0,2.5)),,,2880
          ;Handoff Call arrivals for one hour
          SAVEVALUE nh,2.5
          SAVEVALUE nn,5
          TRANSFER  ,Begh
          GENERATE  (Exponential(1,0,5)),,,1440
          ;New Calls arrivals for one hour
          TRANSFER  ,Begn

; Call arrivals for 02:00-03:59
          GENERATE  (Exponential(1,0,40)),,(2#3600),180
          ;Handoff Call arrivals for one hour
          SAVEVALUE nh,40
          SAVEVALUE nn,20
          TRANSFER  ,Begh
          GENERATE  (Exponential(1,0,20)),,(2#3600),360
          ;New Calls arrivals for one hour
          TRANSFER  ,Begn
; Call arrivals for 04:00-05:59
          GENERATE  (Exponential(1,0,80)),,(4#3600),90
          ;Handoff Call arrivals for one hour
          SAVEVALUE nh,80
          SAVEVALUE nn,40
          TRANSFER  ,Begh
          GENERATE  (Exponential(1,0,40)),,(4#3600),180
          ;New Calls arrivals for one hour
          TRANSFER  ,Begn
; Call arrivals for 06:00-07:59
          GENERATE  (Exponential(1,0,20)),,(6#3600),360
          ;Handoff Call arrivals for one hour
          SAVEVALUE nh,20
          SAVEVALUE nn,40
          TRANSFER  ,Begh
          GENERATE  (Exponential(1,0,40)),,(6#3600),180
          ;New Calls arrivals for one hour
          TRANSFER  ,Begn
; Call arrivals for 08:00-09:59
```

```
          GENERATE  (Exponential(1,0,2)),,(8#3600),3600
          ;Handoff Call arrivals for one hour
          SAVEVALUE nh,2
          SAVEVALUE nn,6
          TRANSFER  ,Begh
          GENERATE  (Exponential(1,0,6)),,(8#3600),1200
          ;New Calls arrivals for one hour
          TRANSFER  ,Begn
; Call arrivals for 10:00-11:59
          GENERATE  (Exponential(1,0,2)),,(10#3600),3600
          ;Handoff Call arrivals for one hour
          SAVEVALUE nh,2
          SAVEVALUE nn,2
          TRANSFER  ,Begh
          GENERATE  (Exponential(1,0,2)),,(10#3600),3600
          ;New Calls arrivals for one hour
          TRANSFER  ,Begn
; Call arrivals for 12:00-13:59
          GENERATE  (Exponential(1,0,1.25)),,(12#3600),5670
          ;Handoff Call arrivals for one hour
          SAVEVALUE nh,1.25
          SAVEVALUE nn,2.5
          TRANSFER  ,Begh
          GENERATE  (Exponential(1,0,2.5)),,(12#3600),2880
          ;New Calls arrivals for one hour
          TRANSFER  ,Begn
; Call arrivals for 14:00-15:59
          GENERATE  (Exponential(1,0,2)),,(14#3600),3600
          ;Handoff Call arrivals for one hour
          SAVEVALUE nh,2
          SAVEVALUE nn,2
          TRANSFER  ,Begh
          GENERATE  (Exponential(1,0,2)),,(14#3600),3600
          ;New Calls arrivals for one hour
          TRANSFER  ,Begn
; Call arrivals for 16:00-17:59
          GENERATE  (Exponential(1,0,1.25)),,(16#3600),5760
          ;Handoff Call arrivals for one hour
          SAVEVALUE nh,1.25
          SAVEVALUE nn,2.5
          TRANSFER  ,Begh
          GENERATE  (Exponential(1,0,2.5)),,(16#3600),2880
          ;New Calls arrivals for one hour
          TRANSFER  ,Begn
; Call arrivals for 18:00-19:59
          GENERATE  (Exponential(1,0,1)),,(18#3600),7200
          ;Handoff Call arrivals for one hour
          SAVEVALUE nh,1
          SAVEVALUE nn,4
          TRANSFER  ,Begh
          GENERATE  (Exponential(1,0,4)),,(18#3600),1800
          ;New Calls arrivals for one hour
          TRANSFER  ,Begn
; Call arrivals for 20:00-21:59
          GENERATE  (Exponential(1,0,2)),,(20#3600),3600
          ;Handoff Call arrivals for one hour
          SAVEVALUE nh,2
          SAVEVALUE nn,6
          TRANSFER  ,Begh
```

```
          GENERATE  (Exponential(1,0,6)),,(20#3600),1200
          ;New Calls arrivals for one hour
          TRANSFER  ,Begn
; Call arrivals for 22:00-23:59
          GENERATE  (Exponential(1,0,5)),,(22#3600),1440
          ;Handoff Call arrivals for one hour
          SAVEVALUE nh,5
          SAVEVALUE nn,10
          TRANSFER  ,Begh
          GENERATE  (Exponential(1,0,10)),,(22#3600),720
          ;New Calls arrivals for one hour
          TRANSFER  ,Begn
;*****************************************************************
;         Timing Part
;*****************************************************************
          GENERATE  3600
;Xact each hour (Sim Couter in Hours)
          TERMINATE 1
;*****************************************************
;         INCLUDE   "seed45.txt"
; Include-file to run the successive simulations
;*****************************************************************
;         End DCR
;*****************************************************************
```

Appendix-B.4 DRCM Source Code

```
; GPSS World Simulation Program, DRCM Case
;*****************************************************************
;         Dynamic Radio Channel Management Model
;*****************************************************************
;         Time Unit is one second
;*****************************************************************
;         Initialization Part
;*****************************************************************
INITIAL X$NLossC,0  ;New Call Loss Count
INITIAL X$HLossC,0  ;Handoff Call Loss Count
INITIAL X$Ncount,0  ;New Call Arrival Count
INITIAL X$Hcount,0  ;Handoff Call Arrival Count
INITIAL X$Pb,0      ;New call blocking probability
INITIAL X$Pf,0      ;Handoff call dropping probability
INITIAL X$Thi,35    ;Instantaneous Value on Th
INITIAL X$alpha,1   ;User Mobility
INITIAL X$nn,1      ;Average new call arrival rate
INITIAL X$nh,1      ;Average handoff call arrival rate
INITIAL X$Erl,0     ;Traffic Load
INITIAL X$Loga,0    ;Log of user mobility
INITIAL X$Pfi,0     ;A temporary variable
INITIAL X$Pac,0     ;Accept probability
Check VARIABLE (RN1/1000)
;Check is a r.v. between 0 and 1
nsd EQU 60          ;Average new call service duration
hsd EQU 40          ;Average handoff call service duration
Cmax EQU 44         ;Number of channels
Thmax EQU Cmax      ;Upper Limit for Threhold
Thmin EQU Cmax#(1/2);Lower Limit for Threhold
Thi EQU Cmax#(3/4)  ;Threshold
Channels  STORAGE    44
;Storage Capacity is number of channels
Ch_Usage  TABLE      S$Channels,1,1,45
;Channel usage distribution
Threshold TABLE      X$Thi,1,1,45
;Threshold distribution
Talpha    TABLE      X$Alpha,0,0.1,30
;Alpha distribution
TErl      TABLE      X$Erl,0,2,32
;Traffic Load distribution
Tcheck    TABLE      V$check,0,0.05,20      ;r.v.
Taccept   TABLE      X$Pac,0,0.05,20
;Accept Probability distribution
TPb       TABLE      X$Pb,0,0.05,20
;Pb Probability distribution
TPf       TABLE      X$Pf,0,0.05,20
;Pf Probability distribution
;*****************************************************************
;         Simulation Part
;*****************************************************************
Begh      SAVEVALUE  Hcount+,1
;Increment arrived handoff call
          SAVEVALUE  alpha,(X$nn/X$nh)
;User Mobility reverse ratio of interarrivals
          SAVEVALUE
Erl,(((60/X$nn)/(60/nsd))+((60/X$nh)/(60/hsd)))
```

```
;Traffic Load - all in per min
          SAVEVALUE  Loga,(LOG(X$alpha))
;Calculate Log of user mobility
          SAVEVALUE  Thi,(X$Thi-(((Cmax-Thmin)/Cmax)#(X$Loga)))
;Update Threshold
          TEST LE X$Thi,Thmin,Notlow
;Check threshold not to be too low
          SAVEVALUE  Thi,Thmin
;Limit it if too low, skip otherwise
Notlow    TEST G X$Thi,Thmax,Nothigh
;Check threshold not to be too high
          SAVEVALUE  Thi,Thmax
;limit it if too high, skip otherwise
Nothigh   GATE SNF   Channels,Handloss
;Try for a line
          ENTER      Channels               ;Connect call
          ADVANCE    (Exponential(1,0,hsd))
;Speak for sd seconds
          LEAVE      Channels
;Free a Channel
          TRANSFER   ,TerminH
;Increase losscount only when channels are full
Handloss  SAVEVALUE  HLossC+,1
;Increment Handoff Losscount
TerminH   SAVEVALUE  Pf,(X$HLossC/X$Hcount)
;Calculate handoff call drop probability
          TABULATE   Ch_Usage
;Tabulate Channel Usage
          TABULATE   Threshold
;Tabulate Threshold Value
          TABULATE   Talpha
;Tabulate alpha
          TABULATE   TErl
;Tabulate Erl
          TABULATE   Tcheck
;Tabulate r.v. check
          TABULATE   Taccept
;Tabulate accept probability
          TABULATE   TPb
;Tabulate Pb probability
          TABULATE   TPf
;Tabulate Pf probability
          Transfer  ,Fin
;*************************************************************
Begn      SAVEVALUE  Ncount+,1
;Increment arrived new call
          SAVEVALUE  alpha,(X$nn/X$nh)
;User Mobility reverse ratio of interarrivals
          SAVEVALUE
Erl,(((60/X$nn)/(60/nsd))+((60/X$nh)/(60/hsd)))
;Traffic Load - all in per min
          SAVEVALUE  Thi,(X$Thi-(((Cmax-Thmin)/Cmax)#(X$Loga)))
;Update Threshold
          TEST LE X$Thi,Thmin,Notlow2
;Check threshold not to be too low
          SAVEVALUE  Thi,Thmin
;Limit it if too low, skip otherwise
Notlow2   TEST G X$Thi,Thmax,Nothigh2
;Check threshold not to be too high
```

```
          SAVEVALUE  Thi,Thmax
;limit it if too high, skip otherwise
Nothigh2  SAVEVALUE  Pac,(1)
;Pac is one if threshold not reached
          TEST G S$Channels,X$Thi,Pacisok
;Pac is one if threshold not reached
          SAVEVALUE  Pfi,(SQR(COS((2#3.14#(S$Channels-
X$Thi))/(4#(Cmax-X$Thi)))))
;Calculate accept probability
          SAVEVALUE  Pac,((X$Alpha#((Cmax-S$Channels)/(Cmax-
X$Thi)))+((1-X$Alpha)#(X$Pfi)))
          TEST L X$Pac,0,Pacisok
;don't let Pac become negative
          SAVEVALUE  Pac,(0)
;don't let Pac become negative
Pacisok   TEST LE V$check,X$Pac,Newloss
;generate a r.n and check r.n with Pac
;accept the call if generated number is less than Pac
          GATE SNF   Channels,Newloss
;Try for a line
          ENTER      Channels
;Connect call
          ADVANCE    (Exponential(1,0,nsd))
;Speak for sd seconds
          LEAVE      Channels
;Free a Channel
          TRANSFER   ,TerminN
;Increase losscount only when channels are full
Newloss   SAVEVALUE  NLossC+,1
;Increment New call Losscount
TerminN   SAVEVALUE  Thi,(X$Thi-(((Cmax-
Thmin)/Cmax)#(0.001#X$Loga)))
;Update Threshold
          SAVEVALUE  Pb,(X$NLossC/X$Ncount)
;Calculate handoff call drop probability
          TABULATE   Ch_Usage
;Tabulate Channel Usage
          TABULATE   Threshold
;Tabulate Threshold Value
          TABULATE   Talpha
;Tabulate alpha
          TABULATE   TErl
;Tabulate Erl
          TABULATE   Tcheck
;Tabulate r.v. check
          TABULATE   Taccept
;Tabulate accept probability
          TABULATE   TPb
;Tabulate Pb probability
          TABULATE   TPf
;Tabulate Pf probability
Fin       TERMINATE
;Terminate a new or handoff call transaction
;*****************************************************************
;         Scenario and Traffic Generation Part
;*****************************************************************
; Call arrivals for 00:00-01:59
          GENERATE  (Exponential(1,0,2.5)),,,2880
          ;Handoff Call arrivals for one hour
```

```
          SAVEVALUE nh,2.5
          SAVEVALUE nn,5
          TRANSFER  ,Begh
          GENERATE  (Exponential(1,0,5)),,,1440
          ;New Calls arrivals for one hour
          TRANSFER  ,Begn
; Call arrivals for 02:00-03:59
          GENERATE  (Exponential(1,0,40)),,(2#3600),180
          ;Handoff Call arrivals for one hour
          SAVEVALUE nh,40
          SAVEVALUE nn,20
          TRANSFER  ,Begh
          GENERATE  (Exponential(1,0,20)),,(2#3600),360
          ;New Calls arrivals for one hour
          TRANSFER  ,Begn
; Call arrivals for 04:00-05:59
          GENERATE  (Exponential(1,0,80)),,(4#3600),90
          ;Handoff Call arrivals for one hour
          SAVEVALUE nh,80
          SAVEVALUE nn,40
          TRANSFER  ,Begh
          GENERATE  (Exponential(1,0,40)),,(4#3600),180
          ;New Calls arrivals for one hour
          TRANSFER  ,Begn
; Call arrivals for 06:00-07:59
          GENERATE  (Exponential(1,0,20)),,(6#3600),360
          ;Handoff Call arrivals for one hour
          SAVEVALUE nh,20
          SAVEVALUE nn,40
          TRANSFER  ,Begh
          GENERATE  (Exponential(1,0,40)),,(6#3600),180
          ;New Calls arrivals for one hour
          TRANSFER  ,Begn
; Call arrivals for 08:00-09:59
          GENERATE  (Exponential(1,0,2)),,(8#3600),3600
          ;Handoff Call arrivals for one hour
          SAVEVALUE nh,2
          SAVEVALUE nn,6
          TRANSFER  ,Begh
          GENERATE  (Exponential(1,0,6)),,(8#3600),1200
          ;New Calls arrivals for one hour
          TRANSFER  ,Begn
; Call arrivals for 10:00-11:59
          GENERATE  (Exponential(1,0,2)),,(10#3600),3600
          ;Handoff Call arrivals for one hour
          SAVEVALUE nh,2
          SAVEVALUE nn,2
          TRANSFER  ,Begh
          GENERATE  (Exponential(1,0,2)),,(10#3600),3600
          ;New Calls arrivals for one hour
          TRANSFER  ,Begn
; Call arrivals for 12:00-13:59
          GENERATE  (Exponential(1,0,1.25)),,(12#3600),5670
          ;Handoff Call arrivals for one hour
          SAVEVALUE nh,1.25
          SAVEVALUE nn,2.5
          TRANSFER  ,Begh
          GENERATE  (Exponential(1,0,2.5)),,(12#3600),2880
          ;New Calls arrivals for one hour
```

```
          TRANSFER  ,Begn
; Call arrivals for 14:00-15:59
          GENERATE  (Exponential(1,0,2)),,(14#3600),3600
          ;Handoff Call arrivals for one hour
          SAVEVALUE nh,2
          SAVEVALUE nn,2
          TRANSFER  ,Begh
          GENERATE  (Exponential(1,0,2)),,(14#3600),3600
          ;New Calls arrivals for one hour
          TRANSFER  ,Begn
; Call arrivals for 16:00-17:59
          GENERATE  (Exponential(1,0,1.25)),,(16#3600),5760
          ;Handoff Call arrivals for one hour
          SAVEVALUE nh,1.25
          SAVEVALUE nn,2.5
          TRANSFER  ,Begh
          GENERATE  (Exponential(1,0,2.5)),,(16#3600),2880
          ;New Calls arrivals for one hour
          TRANSFER  ,Begn
; Call arrivals for 18:00-19:59
          GENERATE  (Exponential(1,0,1)),,(18#3600),7200
          ;Handoff Call arrivals for one hour
          SAVEVALUE nh,1
          SAVEVALUE nn,4
          TRANSFER  ,Begh
          GENERATE  (Exponential(1,0,4)),,(18#3600),1800
          ;New Calls arrivals for one hour
          TRANSFER  ,Begn
; Call arrivals for 20:00-21:59
          GENERATE  (Exponential(1,0,2)),,(20#3600),3600
          ;Handoff Call arrivals for one hour
          SAVEVALUE nh,2
          SAVEVALUE nn,6
          TRANSFER  ,Begh
          GENERATE  (Exponential(1,0,6)),,(20#3600),1200
          ;New Calls arrivals for one hour
          TRANSFER  ,Begn
; Call arrivals for 22:00-23:59
          GENERATE  (Exponential(1,0,5)),,(22#3600),1440
          ;Handoff Call arrivals for one hour
          SAVEVALUE nh,5
          SAVEVALUE nn,10
          TRANSFER  ,Begh
          GENERATE  (Exponential(1,0,10)),,(22#3600),720
          ;New Calls arrivals for one hour
          TRANSFER  ,Begn
;*****************************************************
;         Timing Part
;*****************************************************
          GENERATE  3600
;Xact each hour (Sim Couter in Hours)
          TERMINATE 1
;*****************************************************
;         INCLUDE   "seed45.txt"
; Include-file to run the successive simulations
;*****************************************************
;         End DRCM
;*****************************************************
```

APPENDIX C

GPSS World Simulation Report - C4L4M05DRCM.342.1

Sunday, January 23, 2005 02:56:52

START TIME	END TIME	BLOCKS	FACILITIES	STORAGES
0.000	86400.000	131	0	1

NAME	VALUE
ALPHA	10007.000
BEGH	1.000
BEGN	26.000
CHANNELS	10020.000
CHECK	10014.000
CH_USAGE	10021.000
CMAX	44.000
ERL	10010.000
FIN	57.000
HANDLOSS	15.000
HCOUNT	10003.000
HLOSSC	10001.000
HSD	40.000
LOGA	10011.000
NCOUNT	10002.000
NEWLOSS	46.000
NH	10009.000
NLOSSC	10000.000
NN	10008.000
NOTHIGH	10.000
NOTHIGH2	34.000
NOTLOW	8.000
NOTLOW2	32.000
NSD	60.000
PAC	10013.000
PACISOK	40.000
PB	10004.000
PF	10005.000
PFI	10012.000
TACCEPT	10026.000
TALPHA	10023.000
TCHECK	10025.000
TERL	10024.000
TERMINH	16.000
TERMINN	47.000
THI	10006.000
THMAX	44.000
THMIN	25.000
THRESHOLD	10022.000
TPB	10027.000
TPF	10028.000

LABEL	LOC	BLOCK TYPE	ENTRY COUNT	CURRENT COUNT	RETRY
BEGH	1	SAVEVALUE	22800	0	0
	2	SAVEVALUE	22800	0	0
	3	SAVEVALUE	22800	0	0
	4	SAVEVALUE	22800	0	0
	5	SAVEVALUE	22800	0	0

	6	TEST	22800	0	0
	7	SAVEVALUE	0	0	0
NOTLOW	8	TEST	22800	0	0
	9	SAVEVALUE	5612	0	0
NOTHIGH	10	GATE	22800	0	0
	11	ENTER	19235	0	0
	12	ADVANCE	19235	0	0
	13	LEAVE	19235	0	0
	14	TRANSFER	19235	0	0
HANDLOSS	15	SAVEVALUE	3565	0	0
TERMINH	16	SAVEVALUE	22800	0	0
	17	TABULATE	22800	0	0
	18	TABULATE	22800	0	0
	19	TABULATE	22800	0	0
	20	TABULATE	22800	0	0
	21	TABULATE	22800	0	0
	22	TABULATE	22800	0	0
	23	TABULATE	22800	0	0
	24	TABULATE	22800	0	0
	25	TRANSFER	22800	0	0
BEGN	26	SAVEVALUE	38389	0	0
	27	SAVEVALUE	38389	0	0
	28	SAVEVALUE	38389	0	0
	29	SAVEVALUE	38389	0	0
	30	TEST	38389	0	0
	31	SAVEVALUE	0	0	0
NOTLOW2	32	TEST	38389	0	0
	33	SAVEVALUE	12353	0	0
NOTHIGH2	34	SAVEVALUE	38389	0	0
	35	TEST	38389	0	0
	36	SAVEVALUE	12707	0	0
	37	SAVEVALUE	12707	0	0
	38	TEST	12707	0	0
	39	SAVEVALUE	0	0	0
PACISOK	40	TEST	38389	0	0
	41	GATE	31132	0	0
	42	ENTER	28482	0	0
	43	ADVANCE	28482	12	0
	44	LEAVE	28470	0	0
	45	TRANSFER	28470	0	0
NEWLOSS	46	SAVEVALUE	9907	0	0
TERMINN	47	SAVEVALUE	38377	0	0
	48	SAVEVALUE	38377	0	0
	49	TABULATE	38377	0	0
	50	TABULATE	38377	0	0
	51	TABULATE	38377	0	0
	52	TABULATE	38377	0	0
	53	TABULATE	38377	0	0
	54	TABULATE	38377	0	0
	55	TABULATE	38377	0	0
	56	TABULATE	38377	0	0
FIN	57	TERMINATE	61177	0	0
	58	GENERATE	1200	0	0
	59	SAVEVALUE	1200	0	0
	60	SAVEVALUE	1200	0	0
	61	TRANSFER	1200	0	0
	62	GENERATE	2400	0	0
	63	TRANSFER	2400	0	0
	64	GENERATE	600	0	0

65	SAVEVALUE	600	0	0
66	SAVEVALUE	600	0	0
67	TRANSFER	600	0	0
68	GENERATE	1200	0	0
69	TRANSFER	1200	0	0
70	GENERATE	600	0	0
71	SAVEVALUE	600	0	0
72	SAVEVALUE	600	0	0
73	TRANSFER	600	0	0
74	GENERATE	1200	0	0
75	TRANSFER	1200	0	0
76	GENERATE	900	0	0
77	SAVEVALUE	900	0	0
78	SAVEVALUE	900	0	0
79	TRANSFER	900	0	0
80	GENERATE	1800	0	0
81	TRANSFER	1800	0	0
82	GENERATE	4800	0	0
83	SAVEVALUE	4800	0	0
84	SAVEVALUE	4800	0	0
85	TRANSFER	4800	0	0
86	GENERATE	4800	0	0
87	TRANSFER	4800	0	0
88	GENERATE	3600	0	0
89	SAVEVALUE	3600	0	0
90	SAVEVALUE	3600	0	0
91	TRANSFER	3600	0	0
92	GENERATE	7200	0	0
93	TRANSFER	7200	0	0
94	GENERATE	1200	0	0
95	SAVEVALUE	1200	0	0
96	SAVEVALUE	1200	0	0
97	TRANSFER	1200	0	0
98	GENERATE	4800	0	0
99	TRANSFER	4800	0	0
100	GENERATE	1800	0	0
101	SAVEVALUE	1800	0	0
102	SAVEVALUE	1800	0	0
103	TRANSFER	1800	0	0
104	GENERATE	3600	0	0
105	TRANSFER	3600	0	0
106	GENERATE	4800	0	0
107	SAVEVALUE	4800	0	0
108	SAVEVALUE	4800	0	0
109	TRANSFER	4800	0	0
110	GENERATE	4800	0	0
111	TRANSFER	4800	0	0
112	GENERATE	1800	0	0
113	SAVEVALUE	1800	0	0
114	SAVEVALUE	1800	0	0
115	TRANSFER	1800	0	0
116	GENERATE	3600	0	0
117	TRANSFER	3600	0	0
118	GENERATE	900	0	0
119	SAVEVALUE	900	0	0
120	SAVEVALUE	900	0	0
121	TRANSFER	900	0	0
122	GENERATE	1800	0	0
123	TRANSFER	1800	0	0

124	GENERATE	600	0	0
125	SAVEVALUE	600	0	0
126	SAVEVALUE	600	0	0
127	TRANSFER	600	0	0
128	GENERATE	1189	0	0
129	TRANSFER	1189	0	0
130	GENERATE	24	0	0
131	TERMINATE	24	0	0

STORAGE CHANNELS

CAP.	REM.	MIN.	MAX.	ENTRIES	AVL.	AVE.C.	**UTIL.**	RETRY	DELAY
44	32	0	44	47717	1	28.669	**0.652**	0	0

TABLE	MEAN	STD.DEV.
CH_USAGE	35.606	3.960

RANGE			FREQUENCY	CUM.%
2.000	-	3.000	1	0.03
3.000	-	4.000	0	0.03
4.000	-	5.000	0	0.03
5.000	-	6.000	0	0.03
6.000	-	7.000	0	0.03
7.000	-	8.000	0	0.03
8.000	-	9.000	0	0.03
9.000	-	10.000	0	0.03
10.000	-	11.000	1	0.06
11.000	-	12.000	1	0.10
12.000	-	13.000	1	0.13
13.000	-	14.000	1	0.16
14.000	-	15.000	0	0.16
15.000	-	16.000	0	0.16
16.000	-	17.000	0	0.16
17.000	-	18.000	0	0.16
18.000	-	19.000	0	0.16
19.000	-	20.000	1	0.19
20.000	-	21.000	1	0.23
21.000	-	22.000	2	0.29
22.000	-	23.000	0	0.29
23.000	-	24.000	1	0.32
24.000	-	25.000	12	0.71
25.000	-	26.000	16	1.23
26.000	-	27.000	30	2.20
27.000	-	28.000	66	4.34
28.000	-	29.000	74	6.73
29.000	-	30.000	112	10.35
30.000	-	31.000	125	14.40
31.000	-	32.000	189	20.51
32.000	-	33.000	246	28.47
33.000	-	34.000	275	37.37
34.000	-	35.000	289	46.72
35.000	-	36.000	310	56.75
36.000	-	37.000	299	66.42
37.000	-	38.000	255	74.67
38.000	-	39.000	264	83.21
39.000	-	40.000	205	89.84
40.000	-	41.000	161	95.05
41.000	-	42.000	91	97.99
42.000	-	43.000	50	99.61

43.000	–	44.000	12	100.00

TABLE	MEAN	STD.DEV.		
THRESHOLD	23.678	0.959		
	RANGE		FREQUENCY	CUM.%
22.000 –		23.000	918	29.70
23.000 –		24.000	929	59.75
24.000 –		25.000	923	89.62
25.000 –		26.000	321	100.00

TABLE	MEAN	STD.DEV.		
TALPHA	0.300	0.000		
	RANGE		FREQUENCY	CUM.%
0.200 –		0.300	3091	100.00

TABLE	MEAN	STD.DEV.		
TERL	48.000	0.000		
	RANGE		FREQUENCY	CUM.%
46.000 –		48.000	3091	100.00

TABLE	MEAN	STD.DEV.		
TCHECK	0.504	0.287		
	RANGE		FREQUENCY	CUM.%
_ –		0.000	5	0.16
0.000 –		0.050	163	5.44
0.050 –		0.100	131	9.67
0.100 –		0.150	144	14.33
0.150 –		0.200	166	19.70
0.200 –		0.250	122	23.65
0.250 –		0.300	155	28.66
0.300 –		0.350	174	34.29
0.350 –		0.400	154	39.28
0.400 –		0.450	144	43.93
0.450 –		0.500	173	49.53
0.500 –		0.550	162	54.77
0.550 –		0.600	164	60.08
0.600 –		0.650	140	64.61
0.650 –		0.700	157	69.69
0.700 –		0.750	153	74.64
0.750 –		0.800	148	79.42
0.800 –		0.850	174	85.05
0.850 –		0.900	161	90.26
0.900 –	_		301	100.00

TABLE	MEAN	STD.DEV.		
TACCEPT	0.609	0.176		
	RANGE		FREQUENCY	CUM.%
0.000 –		0.050	29	0.94
0.050 –		0.100	0	0.94
0.100 –		0.150	0	0.94
0.150 –		0.200	0	0.94
0.200 –		0.250	76	3.40
0.250 –		0.300	35	4.53
0.300 –		0.350	123	8.51
0.350 –		0.400	174	14.14
0.400 –		0.450	128	18.28
0.450 –		0.500	236	25.91
0.500 –		0.550	209	32.68

0.550	-	0.600	328	43.29
0.600	-	0.650	387	55.81
0.650	-	0.700	336	66.68
0.700	-	0.750	359	78.29
0.750	-	0.800	256	86.57
0.800	-	0.850	198	92.98
0.850	-	0.900	143	97.61
0.900	-	_	74	100.00

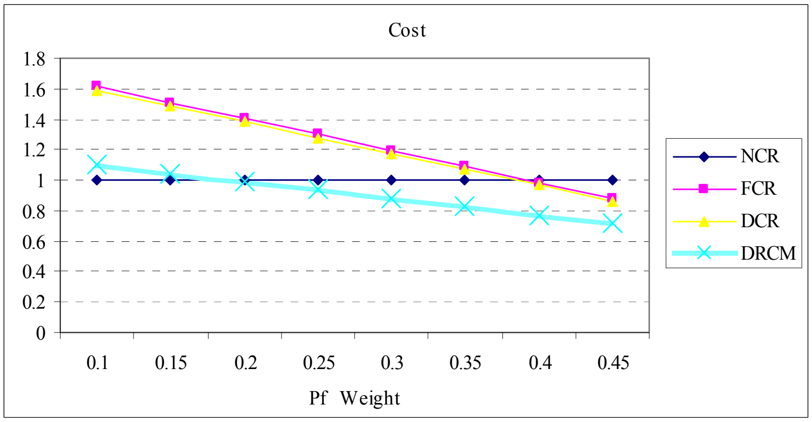
TABLE		MEAN	STD.DEV.		
TPB		0.318	0.049		
		RANGE		FREQUENCY	CUM.%
	_	-	0.000	12	0.39
	0.000	-	0.050	6	0.58
	0.050	-	0.100	31	1.59
	0.100	-	0.150	41	2.91
	0.150	-	0.200	14	3.36
	0.200	-	0.250	163	8.64
	0.250	-	0.300	60	10.58
	0.300	-	0.350	2701	97.96
	0.350	-	0.400	63	100.00

TABLE		MEAN	STD.DEV.		
TPF		0.005	0.002		
		RANGE		FREQUENCY	CUM.%
	_	-	0.000	277	8.96
	0.000	-	0.050	2814	100.00

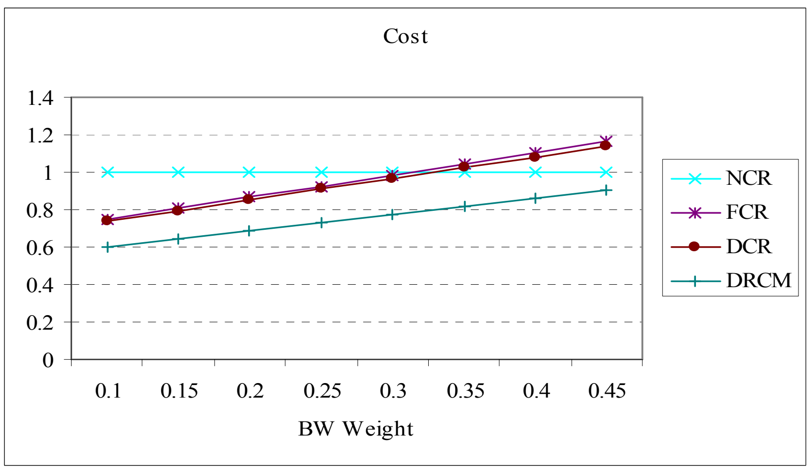
SAVEVALUE	RETRY	VALUE
THI	0	25.333
NLOSSC	**0**	**845.000**
HLOSSC	**0**	**2.000**
NCOUNT	**0**	**2438.000**
HCOUNT	**0**	**689.000**
PB	**0**	**0.347**
PF	**0**	**0.003**
THI	0	35.000
ALPHA	0	0.300
NN	0	1.500
NH	0	5.000
ERL	0	48.000
LOGA	0	-1.20397
PFI	0	0.790
PAC	0	0.681

APPENDIX D

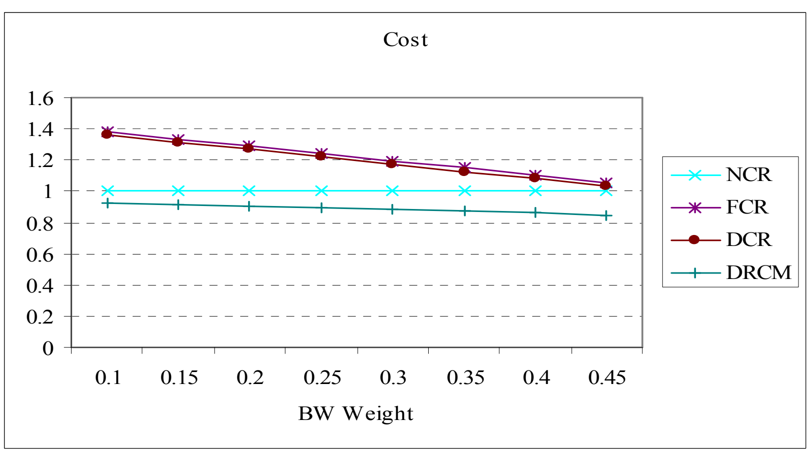
Appendix-D Cost Analysis Results



D.1 Cost functions of the under fixed BW weight, and increasing P_f weight (decreasing P_b weight)



D.2 Cost functions of the under fixed P_b weight (increasing BW weight, decreasing P_f weight)



D.3 Cost functions of the under fixed P_f weight (increasing BW weight, decreasing P_b weight)

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CURRICULUM VITAE

PERSONAL INFORMATION

Surname, Name: Yilmaz, Nusret
Nationality: Turkish (TC)
Date and Place of Birth: 16 November 1967, Sivas
Marital Status: Married
Phone: +90 312 2855938
Fax: +90 312 4022889
e-mail: nusret@ada.net.tr

EDUCATION

Degree	Institution	Year of Graduation
MS	METU Electrical and Electronic Engineering	1996
BS	METU Electrical and Electronic Engineering	1993
High School	Sivas High School, Sivas	1988

WORK EXPERIENCE

Year	Place	Enrollment
2000- Present	NATO	Senior Telecom Engineer
1997-2000	Defense Industries Engineering Inc.	Project Manager
1993-1997	State Airports Authority	System Engineer
1992 August	Turk Telekom A.S.	Intern Engineering Student

FOREIGN LANGUAGES

Advanced English, Fluent German

PUBLICATIONS

1. Yilmaz N., Ergul R. "Resource Management in Cellular Communication Networks with Subscriber Profile Prediction", International Conference in Communication Systems, ICCS 2004, Singapore

2. Yilmaz N., Ergul R. "Dynamic Radio Channel Management in Cellular Mobile Communication Systems", IEEE Vehicular Technology Conference, VTC'F2004, Los Angeles

HOBBIES

Computer Technologies, Movies, Football