Performance Modelling of Wireless Cellular Communication Networks --- Effect of Heterogeneity and Cell Residence Time

Dissertation submitted to Jawaharlal Nehru University in partial fulfilment of the requirements for the award of the degree of

Master of Technology

in

Computer Science & Technology

By

V.S.H.A. DEEPAK NARAYANAM

SCHOOL OF COMPUTER AND SYSTEMS SCIENCES
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CERTIFICATE

This is to certify that the dissertation entitled "**Performance Modelling of Wireless Cellular Communication Networks --- Effect of Heterogeneity and Cell Residence Time**" being submitted by **V.S.H.A.Deepak Narayanam** to the School of Computer and Systems Sciences, ***Jawaharlal Nehru University***, New Delhi in partial fulfilment of the requirements for the award of the degree of ***Master of Technology*** in ***Computer Science and Technology***, is a bonafide work carried out by him under the guidance of **Prof. Karmeshu**. The matter embodied in the dissertation has not been submitted to any University or Institution for the award of any degree or diploma.

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V.S.H.A. Deepak Narayanam

… … … … … … … … *dedicated to my parents and family members*

ABSTRACT

In Wireless cellular communication networks, the mobility of the users plays a significant role. Call Admission Control (CAC) schemes are used to decide whether an incoming call is admitted for network service or not. These schemes play a prominent role in the measurement of QoS. Several CAC schemes have been proposed based on mobility of the user. The mobile users can be classified into high-speed users and low-speed users based on the velocity. There exists lot of variability in each class of users. There is a need to study the effect of heterogeneity arising due to the variability amongst mobile users on the performance of the cellular system. It is difficult to capture the heterogeneity by using the general class of statistical distributions.

In this work, we have proposed a new approach based on two-point distribution through which, one captures heterogeneity by specifying a partial information in terms of statistical moments. This analysis enables one to study the effect of heterogeneity on CAC schemes.

Another important performance measure in the teletraffic analysis is the cell residence time. Through existing methods, it is difficult to compute the cell residence time distribution for the specific mobility models. We have explored the concept of first passage time for different mobility models. We also have shown the FPT distribution.

CONTENTS

CHAPTER 1

INTRODUCTION

1.1 General Introduction

Wireless Communications is undergoing a rapid growth phase providing mobile users seamless access to the fixed information such as Internet.

Wireless Communications can be divided into two broad categories:

- Mobile Celluar Communications and
- Fixed Wireless Communications

Mobile connectivity offers anytime, anywhere communication link. Mobile communications technology must allow roaming feature i.e. the ability to provide service to a mobile phone user over outside their home system.

On the other hand, fixed wireless is simply an alternative to wired communications. The fixed wireless user does not need mobility. Instead, the user needs cost effective telecommunications from fixed locations. Each of the service has its own merits and demerits in certain geographical condition and demand of the users.

The cellular phone slowly becoming part and parcel of personal communications. It is no more luxurious, readily available and a cheaper tool to access the world of communications. The main reason behind the phenomenal success and popularity of cellular mobile communications is due to the need for mobile access and reduced dependence on cumbersome physical connection

From the Fig.1.1, it is clear that there exists an exponential increasing trend in the mobile subscribers' base [1].

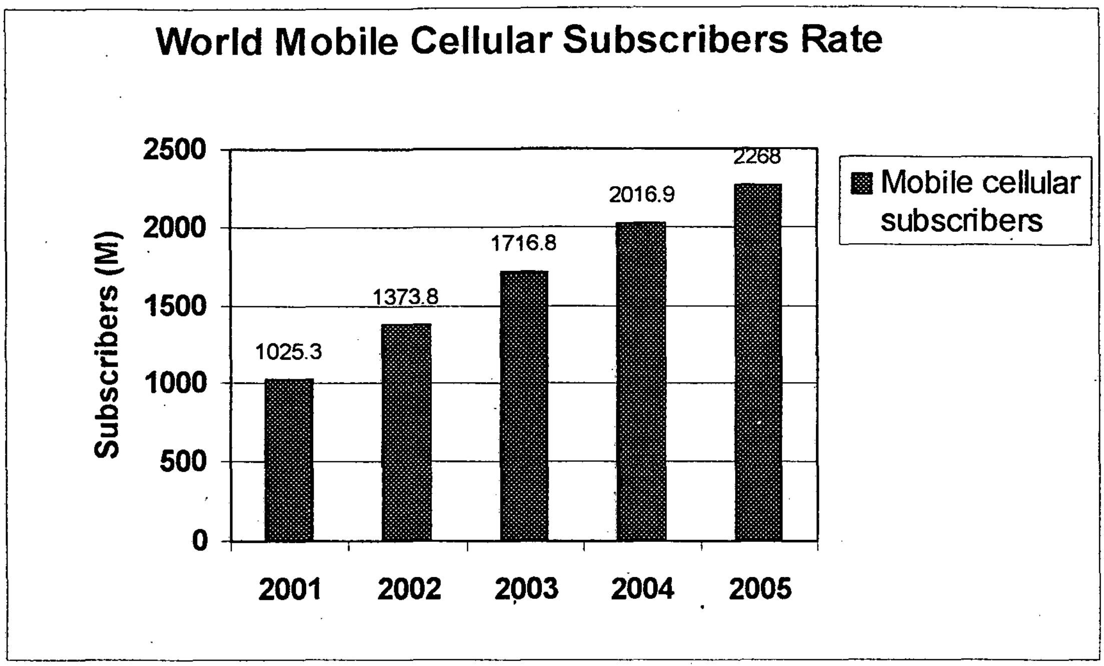


Fig. 1.1 Forecasted World Cellular Mobile Subscribers Growth

1.2 Cellular System Architecture

The cellular architecture consists of several *cells* with a fixed base station (see fig.1.2). These fixed base stations interconnected through a fixed network (usually wired) and of mobile stations that communicate with the base stations via wireless links [30]. The basic cellular system consists of Mobile Stations, Base Stations and Mobile Switching Center (MSC) (see Fig.1.3). The MSC is also called as a Mobile Telephone Switching Office (MTSO), since it is responsible for connecting all mobiles to the PSTN (Public Switched Telephone Network, a formal name for the worldwide telephone network) in a cellular system [26].

The type of wireless communication that is most familiar to mobile phone users is Cellular System. The basic building block of cellular architecture is referred as Cells. These can be grouped suitably to provide services. Cellular calls are transferred from base station to base station as a user travels from cell to cell.

Base Station: A fixed station in a mobile radio system used for radio communication with mobile stations. Base stations are located at the center or on the edge of a coverage area and consists of radio channels, transmitter and receiver antennas mounted on a tower.

Mobile Station: A station in the cellular radio service intended for use while in the motion at unspecified locations. Mobile stations may be hand-held personal units (portable) or installed in vehicles (mobiles).

Cell site: The transmission and reception equipment, including the base station antenna, which connects a cellular phone to the network.

Cell: The area surrounding a cell site. The area in which calls are handled by a particular cell site. Or the geographic area with in which mobile stations can communicate with a particular base station is referred to a Cell.

Mobile Switching Center (or Mobile Telephone Switching Office): An office housing switches and computers to which all cell sites in an area are connected for the purpose of ensuring connection to the PSTN. The MTSO handles the connection, tracking, status and billing of all wireless call activity in an assigned area.

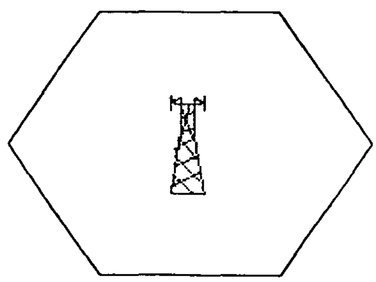


Fig. 1.2 Cell with a Base station (Tower)

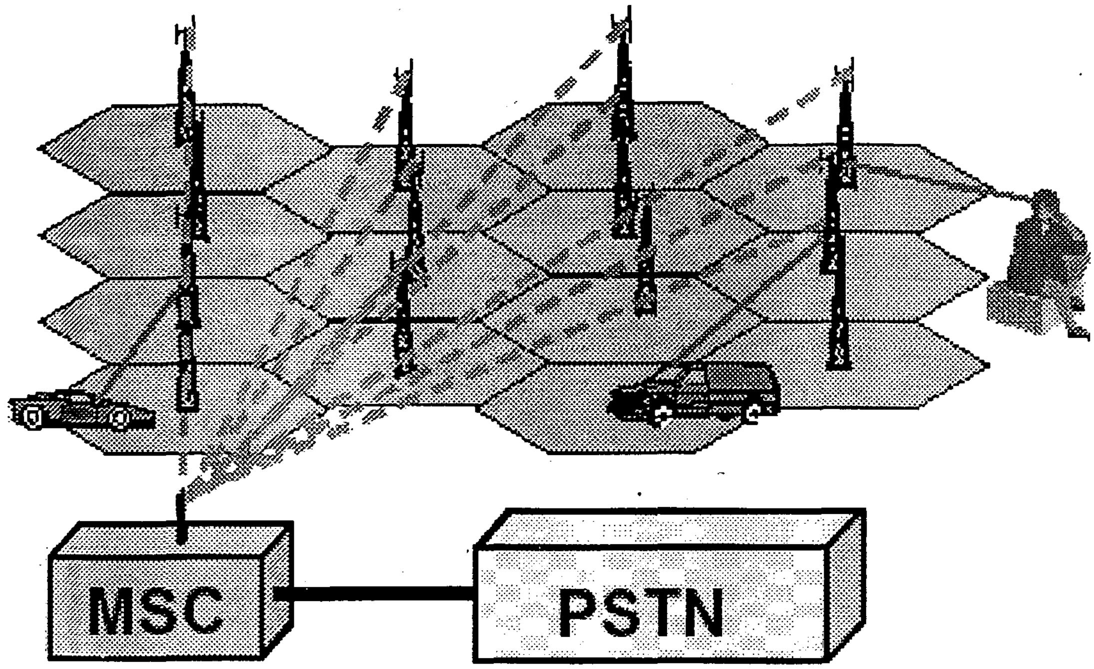


Fig. 1.3 Basic Cellular System. Towers represent Base stations, which provide wireless access between mobile users and the Mobile Switching Center (MSC).

1.3 Frequency Reuse or Frequency Planning

In the Public Switched Telephone Network (PSTN), a *channel* is one of multiple transmission paths within a single link between network points.

Frequency reuse is the core concept of the cellular mobile system. In this, users in different geographic locations (different cells) may simultaneously use the same frequency channel. The frequency reuse system can drastically increase the spectrum efficiency, but if the system is not properly designed, serious interference may occur. Interference due to the common use of same channel is called *co-channel interference*.

To allow a large number of users spread across a country to use a system with a small number of channels, frequency reuse is employed, this works as follows [2].

- Split number of channels into groups
- Assign frequencies in each group to a cell

The channel frequencies in each group are assigned to a cell, which is a physical area on the ground. A small cell may have a radius of around 1km, while a larger one may have a radius of 10km. The cells are drawn as a hexagon, although in practice their shape may be irregular. It depends on the radio waves propagate in each direction from the base station at the centre of the cell.

- Group cells into cluster containing all frequencies

The cells are then grouped together into a cluster. The reuse cluster of size N can be constructed if N = $i^2 + ij + j^2$, where i, j are non- negative integers and $i \geq j$. So, the allowable sizes are N = 1,3,4,7,9,12... In this example the frequency spectrum is split into 7 groups. So we have a cluster of 7 cells.

- Repeat cluster across area to be covered

This cluster can then be repeated as many times as required to cover the area. In a frequency reuse system the same frequencies are used in different parts of the cellular system. It is important that users on these same frequencies do not interfere with each other. We can ensure that this does not happen by specifying the reuse distance. Because of the way that the clusters are repeated, the same frequencies are not used in adjacent cells. *The distance between same frequency cells is called the reuse distance*. The reuse distance depends on the number of cells in the cluster. The reuse distance will then be smaller than in the picture (from A in one cluster to A in another cluster, fig. 1.4). If the reuse distance is large then the mutual interference will be small. Because reuse and interference are a critical part of the system, Cellular Mobile Communications is sometimes called as Interference Limited System.

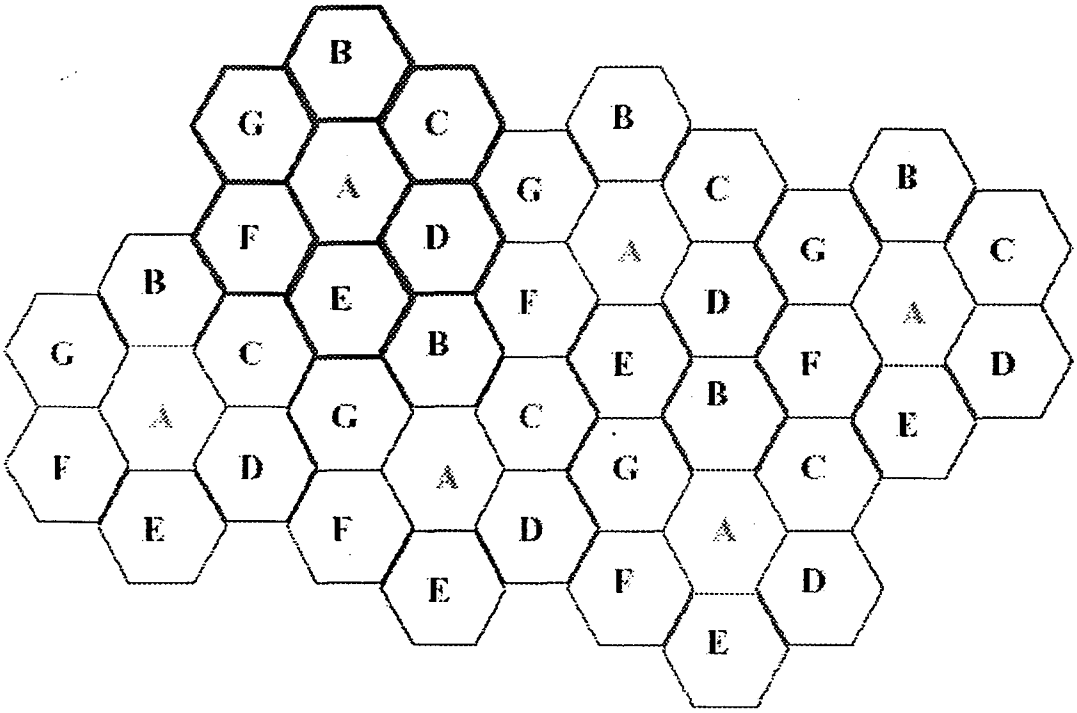


Fig. 1.4 Frequency reuse in the cluster of cells

1.4 Cellular System Design

To improve the capacity of in cellular system, one has to design the cellular system using techniques such as cell splitting, sectoring and microcell zone concepts [26].

(1) Cell Splitting

Cell splitting is the process of subdividing a congested cell into smaller cells, each with its own base station and a corresponding reduction in antenna height and transmitter power (see fig. 1.5(a)). Cell splitting increases the capacity of a cellular system since it increases the number of times that channels are reused. The increased number of channels would increase the number of clusters over the coverage region, which increases the number of channels, and thus capacity, in the coverage area.

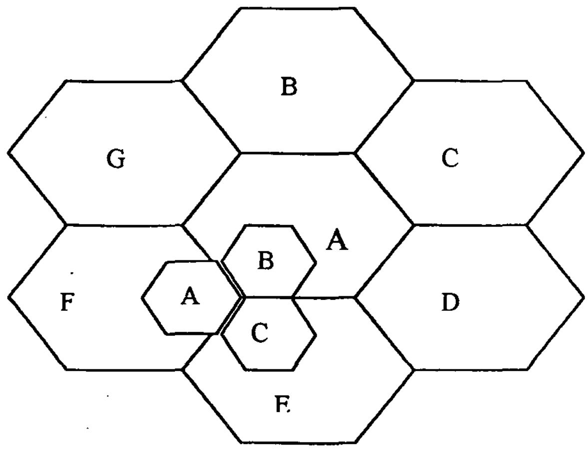
The cell splitting can be done in two ways: Permanent cell splitting and Dynamic cell splitting [17]. It has been pointed out that decreasing the cell size *increases capacity* but causes other problems such as *increased interference* and *time to handle handover (handoffs)*. However, one can increase channel capacity without causing these problems with an intelligent cell that can monitor the exact place of mobile unit and finds a way to deliver confined power to that mobile unit.

(2) Cell Sectoring

The co-channel interference in a cellular system may be decreased by replacing a single omni-directional antenna at the base station by several directional antennas, each radiating within a specified sector. The technique for decreasing co-channel interference and thus increasing the system capacity by using directional antennas is called *sectoring*. The factor by which the co-channel interference is reduced depends on the amount of sectoring used. Usually the cell sectoring is done either with 60^0 or 120^0 (see fig.1.5 (b)).

(3) Micro Cellular System

In a micro cellular system, each cell is divided into a number of microcells; each microcell (or zone) has a zone site and the cell itself has one base station. It is necessary to note that all the microcells, within a cell, use the same frequency used by that cell; that is no handovers (handoffs) occur between microcells. Using this technique, the interference and handovers (handoffs) can be reduced (compared to decreasing the cell size). Since the microcells within the cell operate at the same frequency, no handover occurs when the mobile unit moves between the microcells. Since the signal power is reduced, the microcells can be closer and therefore increase capacity. However, in microcellular system, the transmitted power to a mobile phone within a microcell has to be precise; too much power results in interference between microcells, while too little power and the signal might not reach the mobile phone. This is a drawback of microcellular systems, since a change in the surrounding will require a change of the transmission power (see fig. 1.5(c)).



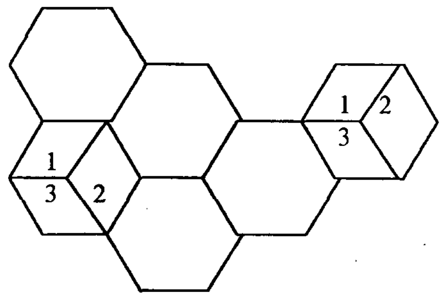


Fig. 1.5 (b)Sectoring 120^0

Fig.1.5 (a) Example of Cell splitting

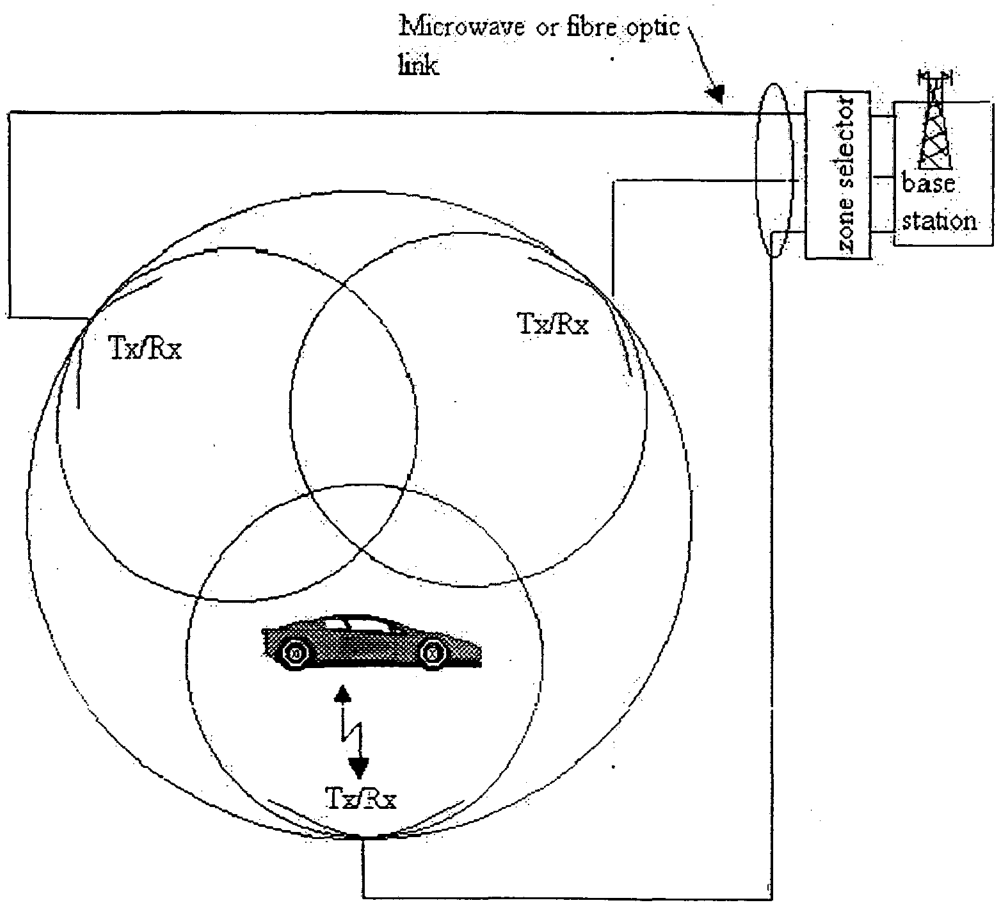


Fig. 1.5 (c) Micro Cellular System

1.5 Channel Allocation(Assignment) Schemes

A frequency reuse scheme, which is consistent with the objectives of increasing capacity and minimizing interference, is needed for efficient utilization of the radio spectrum. There are many methods of allocating a channel upon a new arrival or handoff attempt. There are many Channel Allocation (Channel Assignment) schemes for achieving these objectives. They can be broadly classified into Fixed, Dynamic and Flexible Channel Assignment schemes (see fig. 1.6) [32].

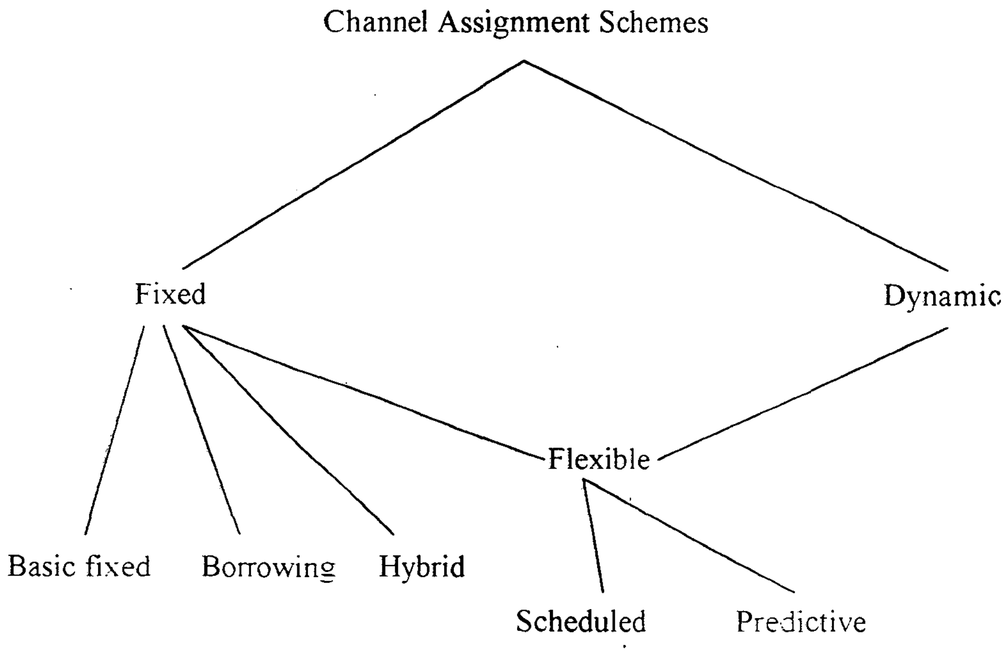


Fig. 1.6 Channel Allocation (Assignment) Schemes

(1) Fixed schemes

- **Basic:** A permanent set of channels is allocated to each cell. 'Full' cells imply blocked calls and dropped calls during handoff.

- **Simple Borrowing:** If all the permanent channels in a cell are busy, unutilized channels can be borrowed from a neighbour cell, assuming this doesn't cause interference. Using the borrowed frequency, the calculation of additional cells is not allowed. In high traffic situations, this implies degraded channel utilization.
- **Hybrid:** Permanent channels of a cell are split into two groups - one can only be used locally, a second can be lent to other cells. Benefits of borrowing but mitigates degradation by limiting extra frequency restrictions.
- **Borrowing with Channel Ordering:** This is like hybrid, but with dynamic variation of local-to-borrowable channel ratio according to current traffic condition.

(2) Flexible schemes

- **Flexible (Scheduled):** Each cell has allocated permanent channels. The MSC (mobile switching center) also has a pool of flexible channels that it can assign to cells that need extra. The allocation is done on a scheduled basis according to some known traffic distributions over time.
- **Flexible (Predictive):** It is same as scheduled, but allocation is done based on current measurements of traffic intensity. This requires the MSC to have latest information about traffic patterns.

(3) Dynamic (call-by-call): All handoffs and call attempts are referred to the MSC, which allocates frequencies on a case-by-case basis according to a minimum cost function. Again, the MSC must have load information and radio channel measurements of MS's (mobile stations).

1.6 Handoff (Handover) Concepts

The geographic area where the mobile units can communicate with a particular base station is referred to a cell. One should ensure the continuity of communications when the users move from one cell to another cell since neighboring cells overlap with each other. The mobile units communicate with each other, as well as with other networks, through the base stations and the mobile switching center. A set of channels (frequencies) is allocated to each base station. Neighboring cells have to use different channels in order to avoid intolerable interferences. For communicating with another user or a base station, the mobile user must first obtain a channel from one of the base stations that is very nearby. If a channel is available, it is allocated to the user. If all the channels are busy, the new call is blocked. This type of blocking is called *new call blocking* and it refers to blocking of new calls. The mobile user releases the channel under either of the following two scenarios: (i) when the user completes the call (ii) when the user moves to another cell before the call is completed. The process of moving from one cell to another cell, while a call is in progress, is called *handoff (handover)* in which the MSC automatically transfers the call to a new channel belonging to the new base station When the handoff operation is going on, the mobile user requires that the base station in the cell that it moves into will allocate it a channel. If no channel is available in the new cell, the handoff call is blocked. This type of blocking is called *handoff blocking* which refers to the blocking of ongoing calls due to the mobility of the users [30]. The major problem in mobile communication networks is the continuity of service during handoff without any data loss, as the user moves from cell to cell which is called seamless handoff. The new call and handoff blocking probabilities are the two important measures of Quality of Service (QoS) for current cellular networks.

Handoff (Handover): When a Mobile user moves across a cell boundary, the channel in the old base station is released and an idle channel is required in the new base station.(see fig. 1.7(a) and 1.7(b))

Hard handoff: The old radio link is broken before the new radio link is established

Soft handoff: A mobile user may communicate with the outside world using multiple radio links through different base stations at the same time [33].

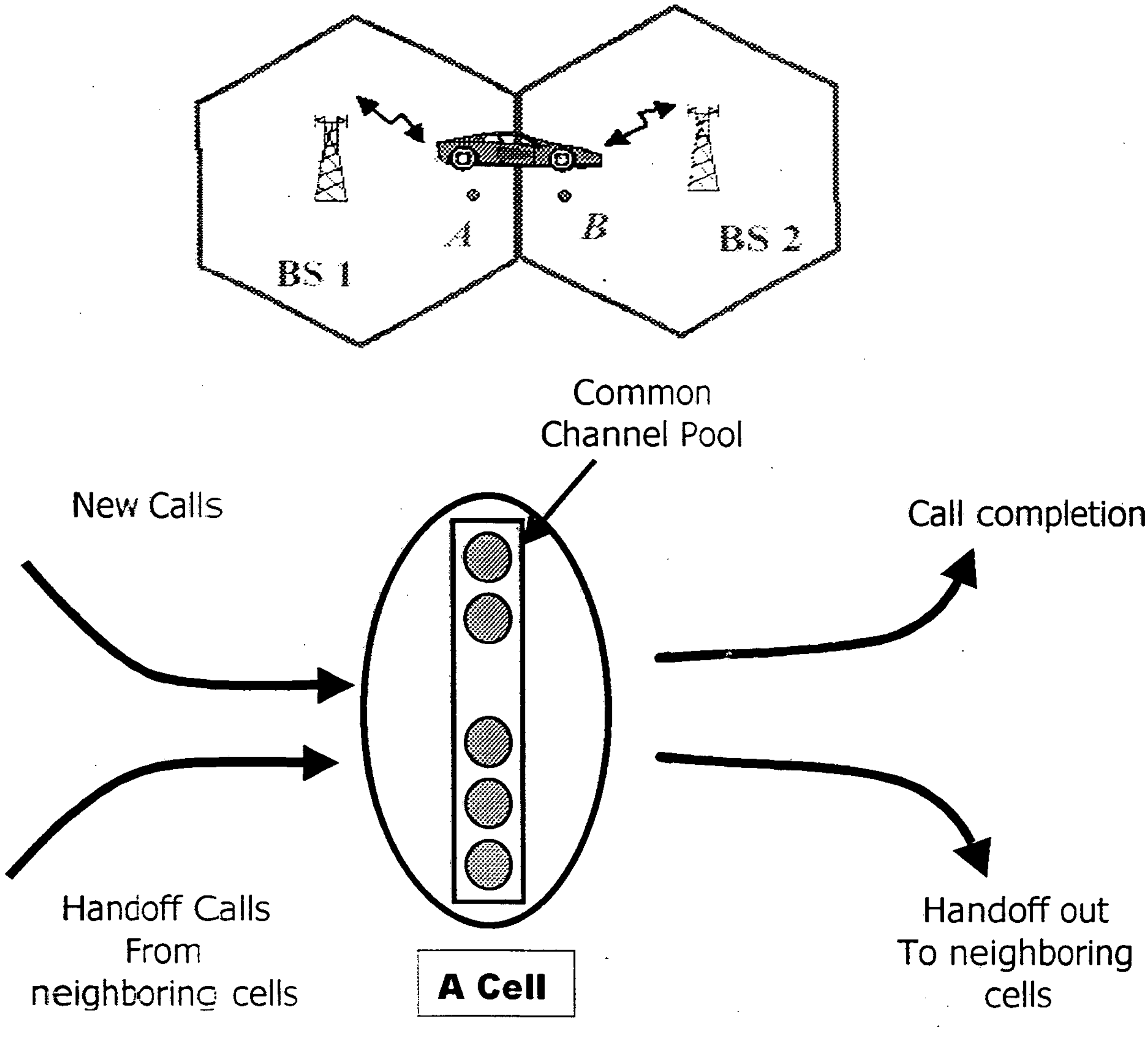


Fig. 1.7 (a) Handoff from Cell A to Cell B,

(b) Handoff mechanism in Cellular Networks (with channels)

Handoff decisions: These can be made by both the mobile station (MS) and base station (BS) by monitoring channel quality, or by MS alone. The new BS is determined by the MSC or MS. Measurements must discriminate against temporary fades, but still react quickly enough to avoid call dropping or interruption. Policy may dictate that BS's accept handoffs with more priority than call initiation to avoid irritating customers.

Thresholds: The handoff (handover) threshold is defined as the time at which a new BS's signal strength is greater than the current BS's. The *receiver* threshold is the time at which the current BS's signal is too weak to be usable. An MS must handover during the interval between these thresholds; handover requests may be queued during this interval [32].

1.7 Handoff prioritization

In a cellular system forced termination of an ongoing call is less desirable than blocking of new calls. In order to reduce the failure of handoff, one way is to prioritise handoff. Two prioritising schemes are guard channels and queueing [19].

Guard channel scheme:

"Guard" channels may be reserved for handoff traffic, although this may decrease spectrum utilization. The guard channel approach improves the probability of successful handoffs by simply reserving a number of channels exclusively for handoffs in each cell. The remaining channels can be shared equally by new calls and handoff calls (see fig.1.8).

Handoff queueing scheme:

This is another handoff prioritizing scheme in which the queueing of handoff requests is done with or without the employment of the guard channels. In this scheme no new call is granted a channel before the handoff requests in the queue are served. This scheme reduces the probability of forced termination of handoff calls by increasing the call blocking probability.

Loss Formulas

Handoff call dropping probability, P_d :

Percentage of calls forcefully terminated while crossing cells

New call blocking probability, P_b :

Percentage of new calls rejected [33].

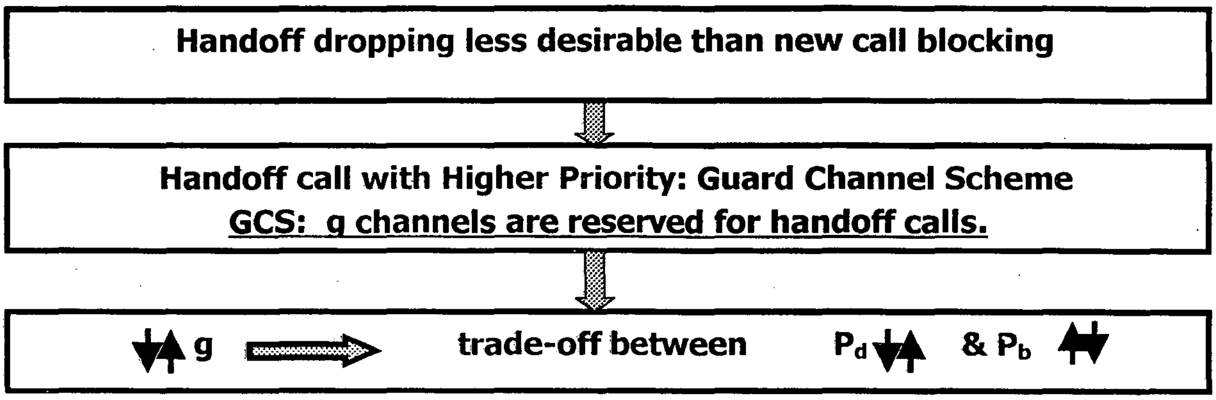


Fig. 1.8 Guard channel scheme for loss formulas

1.7 Organization of the dissertation

In this chapter we have provided a brief introduction to the basic concepts of wireless cellular communication networks related to this work. These include Frequency Reuse, Cellular System Design, Channel Allocation Schemes and Handoff Concepts in detailed. In chapter 2, a brief introduction to Mobility based Call Admission Control Schemes. Also the existing schemes and previous works are reviewed. In chapter 3, we explored the effect of Heterogeneity of mobile users and the two-point distribution. We have seen the effect of heterogeneity of mobile users for the existing mobility based call admission control schemes using the proposed approach. In chapter 4, we explored the concept of first passage time (FPT) in mobility models. We tried to see the relation between the FPT and cell residence time in cellular system. Conclusions and Remarks are presented at the last.

CHAPTER 2

MOBILITY BASED CALL ADMISSION CONTROL SCHEMES

2.1 Cell Residence Time (Dwell time)

Cell residence time is the time a mobile user stays, or dwells, in a cell. The users' mobility can be characterized by the cell residence time and the channel holding time (the time a call spends in a cell) depends on the users' mobility. In order to characterize the channel holding time, it is necessary to have good mobility model for the cell residence (dwell) time. In the literature [10,23], cell residence time (dwell) is modeled by having probability density functions as SOHYP (sum of hyperexponential) distribution and Hyper-Erlang distribution models, which will be discussed in later chapters.

2.2 Channel Holding Time

The channel holding time of a cell is one of the major parameters that needs to be accurately modeled in the teletraffic analysis. The channel holding time is defined as the time during which a new or handoff call occupies a radio channel in a given cell, and it is dependent on the mobility of the user. It is similar to the call holding time in the fixed telephone network, but is a fraction of the total call duration in a wireless cellular network and may not have the same statistical properties [9,14]. Most research work on Call Admission Control (CAC) and bandwidth reservation assumes the channel holding times in all cells as independent and identically distributed (i.i.d.) exponential random variables [4,18,25]. This assumption of exponential distribution simplifies the analyses, but does not give an accurate representation of the real characteristics of cellular networks. In [4], the channel holding time follows a general distribution, which allows the exponential channel holding time assumption to be relaxed.

2.3 Mobility Call Admission Control Schemes (CAC)

Future mobile communication systems should support broadband multimedia services with diverse quality of service (QoS) requirements. For efficient utilization of the radio spectrum the cellular architecture has been used in wireless networks. Since mobile users may change cells a number of times during the lifetime of their connections, availability of wireless network resources at the connection setup time does not necessarily guarantee that wireless network resources are available through out the life time of a connection In wireless cellular networks, the service area is divided into cells each of the cell is equipped with a number of channels. There are two types of calls, which share these channels; new calls and handoff calls. New calls are those which are originated by the mobile users in the current cell; the handoff calls are the calls which are originated in other cells and handover to the current cell. When a call is arrived and there are no channels available then the call may be blocked or queued depending on the CAC used. CAC schemes are used to decide whether an incoming call (may be new call or handoff call) is allowed for the access of network service or not. The probability that a new call is blocked is called New Call Blocking Probability (P_{nb}), the probability that a handoff call is blocked is called Handoff Call blocking probability (P_{hb}). Since forced call terminations due to handoff blocking are generally more objectionable than new call blocking and the probability of handoff dropping (P_{hd}), as the key connection-level QoS metric provisioned by CAC in wireless cellular networks. These quantities are significant in determining QoS in wireless cellular networks [12,34].

From the mobile user's point of view, termination of an ongoing call during the service is more significant than blocking of the call at its origination, hence the handoff call blocking is much more important than the new call blocking probability. So, handoff calls are given higher priority in assigning the channels. This can be clearly seen in the handoff prioritized CAC schemes. Different handoff priority-based CAC schemes have been proposed in the literature [16].

They are broadly divided into two categories

Guard Channel Schemes and Queuing Priority Schemes

Various combinations of these two schemes also have been discussed in the literature. CAC schemes should frame in such way that there should be a trade off between the new call blocking and handoff call blocking in order to provide the QoS requirements. As it is impractical to completely eliminate handoff call dropping, the best one could do is to keep the P_{hd} below a target level. Moreover, maximizing resource utilization while keeping P_{nb}, the probability of new call blocking, below a target value, is another critical factor for evaluating CAC algorithms.

Based on the above considerations, several schemes have recently been proposed for CAC in wireless cellular networks that may be either Guard Channel Schemes or Queuing Priority Schemes. We can see some of those CAC schemes below.

2.3.1. The Guard Channel and Fractional Guard Channel Policy

The guard channel policy and fractional guard channel policy proposed by Ramjee et al. [25] determine the number of guard channels reserved for handoffs by considering just the status of the local cell. Users are assumed uniformly located in any cell of the mobile network under these policies.

Consider a cellular network with C channels in a given cell. T is a threshold such that the guard channel policy rejects all new calls whenever channel occupancy exceeds the threshold T. λ_1, λ_2 are the Poisson arrival rates of new and handoff calls. The channel holding time for both calls is exponentially distributed with mean $1/\mu$. In fractional guard channel policy new calls are accepted with a certain probability β that depends on the current channel occupancy.

These channel schemes are given in the following figure 2.1 in algorithmic form; state transition diagrams are depicted in figures 2.2(a) and 2.2(b).

```
********************************************
        /* Guard Channel Policy */
********************************************
    if ( NEW CALL) then
        if ( NumberOfOccupiedChannels < T)
            admit call;
        else
            reject call;
    if (HANDOFF CALL) then
        if (NumberOfOccupiedChannels < C)
            admit call;
        else
            reject call;

********************************************
     /* Fractional Guard Channel Policy */
********************************************
   /* random(0,1) returns a uniformly
     generated random number in the interval [0,1]
*/
    if ( NEW CALL) then
        if (random(0,1) ≤
                β(NumberOfOccupiedChannels))
            admit call;
        else
            reject call;
    if ( HANDOFF CALL) then
        if (NumberOfOccupiedChannels < C)
            admit call;
        else
            reject call;
```

Fig 2.1 Call Admission Policies

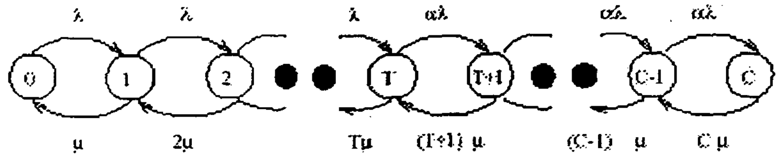


Fig 2.2(a) State transition diagram (Guard channel scheme)

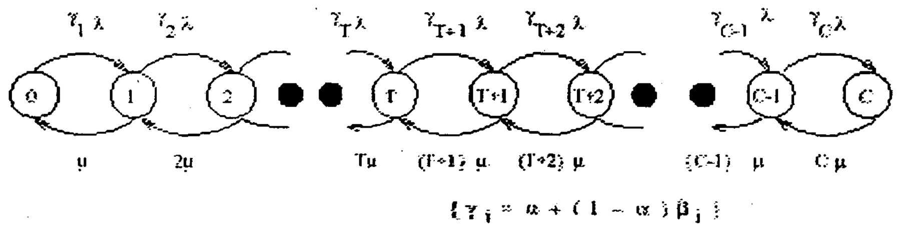


Fig 2.2(b) State transition diagram (Fractional channel scheme)

2.3.2 Distributed CAC

The distributed call admission control scheme [19, 21] considers not only the status of the local cell but also that of adjacent cells. In distributed CAC, one considers the overload probability of the concerned cell when a new call arrives or a handoff call is about to take place and also the overload probability of the adjacent cells surrounding the concerned cell. The overload probability is the probability that the cell cannot support any more calls after all the channels available is used up. The advantage of the distributed CAC is that it takes into account future overload probability of the cell concerned and its adjacent cells before accepting a new call or handoff call and yet it does not seek to reserve any channel specially for handoff calls [19].

In the scheme [21] Naghshineh et al. denoted P_{QoS} as the user-declared Qos and the overload probability as the probability that a call is terminated during a handoff at any given time. An approximation of the overload probability is shown in [21].

In both one-dimensional and two-dimensional systems, a new call is admitted at time t_0 only when the following conditions met:

Condition 1: At time t_0+T, the overload probability of cell C_0 must be small than P_{QoS}.

Condition 2: At time t_0+T, the overload probability of each cell adjacent to the originating cell must be smaller than P_{QoS}

For some arbitrary value of T that must be determined experimentally. According to Naghshineh et al. [21], the first condition is intended to maintain the desired P_{QoS} of calls that are underway in the system, and the second admission condition is intended to provide the desired P_{QoS} of the newly admitted call. This approach required approximating the overload probability at time t_0+T. This depends on the new call arrival rate into each cell α, and the expected number E[n] of calls in a cell. Let SUM denote the sum of the number of ongoing calls in the cells adjacent to the originating cell. For each cell C_i that is adjacent to C_0. Let $E_i[n]$ be the total expected number of calls in the cells adjacent to C_i when the new call arrives, excluding those calls underway in C_0. For a marked mobile in the originating cell C_0, the authors derive p_s that approximate the probability that this mobile remains in the same cell during a period of duration T, and a p_m that approximates the probability that mobile handoff during the same period. Furthermore, it is assumed that the mobile is equally like to move to either adjacent cell.

The authors [21], have approximated the overload probability as follows. For a given P_{QoS}, the value a is found such that P_{QoS} = Q(a), where Q(.) is the integral over the tail of a Gaussian distribution. We denote by N, the maximum number of simultaneous calls in a single cell and N_i is the number of calls underway in C_i.

To satisfy conditions (1) & (2),

$$N_0 < \frac{1}{2p}\left[\begin{array}{l} a^2(1-p_s) + 2\mathrm{N} - \frac{p_m}{3}(SUM) - \\ a\sqrt{a^2(1-p_s)^2 + 4\mathrm{N}(1-p_s) - \frac{p_m^2}{9}(SUM) + 2\frac{p_m}{3}p\;(SUM)} \end{array}\right]$$

and $$N_0 < \frac{1}{2\frac{p_m}{3}}\left[\begin{array}{l} a^2\left(2-\frac{p_m}{3}\right) + 4\mathrm{N} - 4\alpha T - 2E_i[\mathrm{N}]\frac{p_m}{3} - 4\mathrm{N}_i p_s - \\ a\sqrt{a^2\left(2-\frac{p_m}{3}\right)^2 + 16\mathrm{N} + 8\frac{p_m}{3}(\alpha T + \mathrm{N}_i p_s - \mathrm{N}) - 16\mathrm{N}_i p_s^2} \end{array}\right]$$

The total required bandwidth for both handoff and existing connections is calculated under the assumptions of exponentially distributed channel holding time and perfect knowledge of the rate of handoff. As there is a lot of evidence that exponential holding time is not realistic [23,24], the assumption made by Naghshineh et al. is unrealistic.

2.3.3 The Shadow Cluster Scheme

Levine et al. [18] have proposed the shadow cluster scheme which estimates future resource requirements in a collection of cells in which a mobile is likely to visit in the future. Admission control is performed based on this estimate. However, this proposal lacks a mechanism to determine the shadow cluster in real networks, as it assumes either precise knowledge of user mobility or totally random user movements.

2.3.4 Predictive and Adaptive CAC

Some research efforts have been made to predict user mobility. The predictive and adaptive scheme proposed by Lu and Bhargavan [20], estimates user mobility based on an aggregate history of handoffs observed in each cell and it predicts (probabilistically) mobiles' directions and handoff times in a cell. This scheme enables the design and evaluation of predictive, adaptive bandwidth reservation for handoffs and admission control so as to keep the handoff dropping probability below a pre-specified value. This scheme [20] utilize the following two components to reserve bandwidth for handoffs: (1) handoff estimation functions which are used to predict a mobile's next cell and estimate its sojourn time probabilistically based on its previously-resided cell and the observed history of handoffs in each cell; and (2) mobility estimation time window control scheme in which, depending on the observed handoff drops, the estimation time window size is controlled adaptively for efficient use of bandwidth and effective response to the first two components considering time-varying traffic/mobility and inaccuracy of mobility estimation. In this scheme, the next cell to which a mobile will move is predicted in an indoor environment. But this scheme does not estimate channel holding time and therefore cannot be directly applied for efficient bandwidth reservation [20].

Choi and Shin [6] argue that as handoff histories of mobile users are observed over time the mobile's movement can be predicted by utilizing this observation. However, in this scheme, prediction of each specific mobile's movement is based on the aggregate history of all users, and may not be accurate for each individual user.

2.3.5. Mobility based Predictive CAC

Under the realistic assumptions, Yu and Leung [34] propose CAC and bandwidth reservation schemes based on the probabilistic prediction of each individual user's movements. This mobility prediction approach is derived from data compression techniques that are both theoretically optimal and good in practice. Similar prediction approaches were applied previously to the problems of prefetching in large-scale database system and location management of mobile users in cellular networks. The possibility of applying these approaches to QoS provisioning was mentioned in [3]. This scheme extends that idea to the context of CAC and bandwidth reservation and predicts not only to which cell a mobile terminal will handoff but also when the handoff will occur. These data compression techniques may not be suitable for large cellular system [34].

2.4 Channel Reservation Strategies

The major problem in the guard channel schemes is Channel Reservation. Channel reservation strategies are designed by either reserving a fixed number of channels or assigning dynamically.

The fixed reservation schemes are also called cut off priority schemes [11]. They do not have communication and computation complexities but they are not flexible to handle the moving traffic situations. These schemes can not be adapted in the real time networks as they do not use the traffic information in the current cell and neighbouring cells. We should use the information available for achieving better performance. So, the dynamic reservation schemes [6,18,22] have been proposed to overcome the drawbacks of the fixed channel reservation schemes.

In [22], the number of channels to be reserved is calculated according to the number of ongoing connections or the requested bandwidth of all ongoing connections. Each base station keeps tracks the handoff call blocking probability and the usage of channels in its cell and uses this information to the proper assignment.

In [6], a scheme is proposed based on the prediction of the probability that a call will be handed off to a neighbouring cell from the aggregate history of handoffs in each cell and determines the number of reserved channels; also each base station records the number of handoff failures and adjusts the reservation by changing the estimation window size.

In [18], the shadow cluster concept is introduced to estimate the future resource requirements based on the current movement pattern of mobile users. But the strength of this scheme depends on the accuracy of the knowledge of users' movement patterns like the trajectory of a mobile user, which is difficult to predict in the real system.

In [5], the scheme shows that user mobility has a greater effect on QoS provisioning.

In [13], the channel reservation is made on the basis of users' mobility pattern. Users' mobility patterns are determined by many factors like mobile users' destination, the layout of the wireless network, the traffic condition in the network.

2.5 User Mobility Pattern

The symmetric random walk model has been quite popular among researchers in characterizing individual movement behaviour [21,25]. In such a model, a mobile user will move to any of the neighbouring cells with equal probability after leaving a cell. This model does not take into account the trajectory and channel holding time of a mobile.

In cellular mobile networks, the mobility of a user during a call can be represented by a sequence of events, N, H_1, H_2, H_3, ..., H_n, ... E, where N represents the event that a new call is admitted, H_n represents the events of a mobile's nth handoff and E represents the call termination event. There may be possible that no handoff events during the lifetime of a call and thus no H_n in the sequence of events. In this sequence, N=(m,i,t,), where m represents the mobile requesting the call, I represents the original cell and t represents the time when the call arrives; $H_n=(T_k, i)$, where T_k is the k^{th} time slot since beginning of the call.

In general, a mobile user usually travels with a specific destination in mind. So, the mobile's location and channel holding time in the future are likely to be correlated with its movement history. Yu and Leung [34] assumed the sequence of events N, H_1, H_2, H_3,..., H_n, ... E to be generated by an m^{th} order Markov source, in which the states correspond to the contexts of the previous m events. The probabilities of possible next events can depend on a list of m previous events.

2.6 New Mobility based CAC

Hou and Fang [12] have presented some new CAC schemes. They are mobility-based call admission schemes and new call bounding schemes for wireless mobile networks providing services to multiple classes of mobile users (pedestrians and vehicular travelers). Since the salient feature of wireless mobile networks is mobility, an active call in one place may have a potential effect on resource usage in another place in the future. The concept of influence curve is introduced to characterize the influence an active call imparts on adjacent cells, according to which the channel reservation can be adjusted dynamically and mobility-based CAC schemes can be designed. To overcome possible congestion, the authors have also proposed a new call-bounding scheme to put a direct limitation on the number of new calls admitted to a cell. Four CAC schemes are proposed and analyzed via analytical modeling and simulation study. The authors [12] have shown that the proposed schemes are more effective in providing QoS than other previously known schemes. But in this scheme, the heterogeneity concept has not been discussed, which exists amongst all the mobile users.

2.7 Influence curves

1) A user is more likely to request a handoff in the far future than in the near future after it enters a cell (here enter means either the initiation of a new call or a successful handoff of an ongoing call into this cell), which implies that the

handoff probability (the probability that a call needs at least one handoff during remaining call life) is a function of the time elapsed after a call enters a cell;

2) In a cell residence (dwell) time of same time length, a high-speed user is more likely to request a handoff compared to a low-speed user, which shows that the handoff probability is also related to the speed class of a user [12].

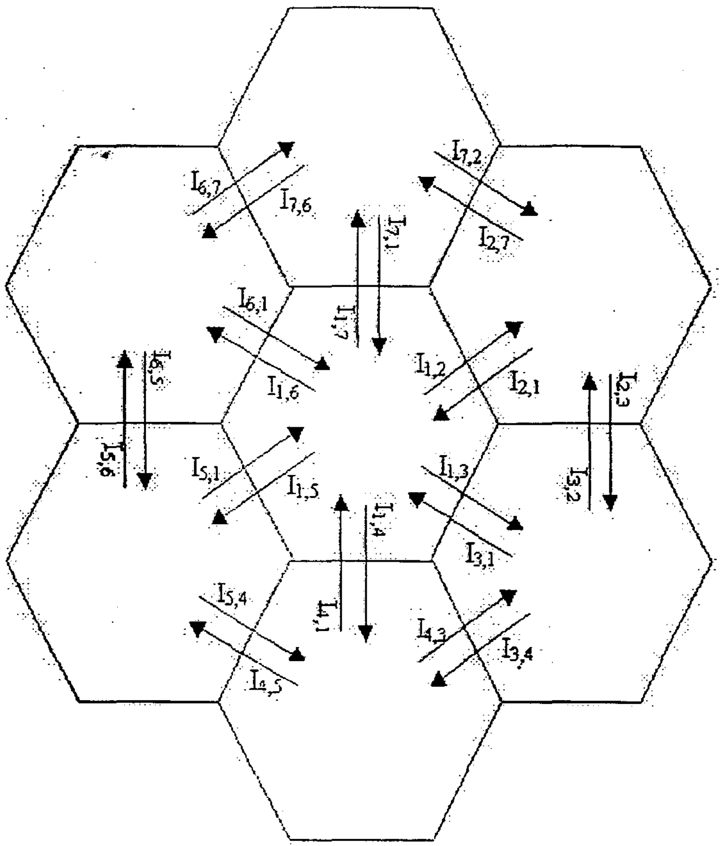


Fig 2.3 Influence curves

Due to the call handoffs, traffic among cells is not independent. When a call enters a cell, it not only accesses the channel of current cell, but also requests a certain requirement on the neighbouring cell (with certain probability). The ongoing call in the current cell imparts some influence on the channel assignment in the neighbouring cells. Both elapsed time and the velocity class characterize this influence. The more influence a call shows on its neighbouring cells, the more likely a channel should be reserved in the neighbouring cells in order to keep the QoS requirements of this cell. The total influence that all ongoing calls in cell i, imparts on the cell j is $I_{i,j}$, $i,j=1,2,\ldots,6$. These curves include the directional factor along with the probability of the users' movement. This is seen in the above figure 2.3 and can explained mathematically in the next chapter.

CHAPTER 3

EFFECT OF HETEROGENEITY OF MOBILE USERS ON CALL ADMISSION CONTROL SCHEMES

3.1 Heterogeneity of the Mobile users

In recent paper [12] by Hou and Fang, the mobile users are classified into two classes according to the velocities: high-speed users (vehicular users) and low-speed users (pedestrians). But in reality, among the high-speed users there is lot of variability and similarly this is also true in case of low-speed users. The question which, one could like to address is concerned with the issue of incorporating this variability. One way to account for this variability, is to assume that both high-speed and low-speed users are distributed according to some statistical distribution. This statistical distribution can be regarded as resulting from heterogeneous nature of mobile users with regard to their speeds. The cell residence time (dwell) time is also effected by the variability of the mobile users in both cases. So, there is a need to study the heterogeneity of the mobile users in each class. Due to the rapid growth in the cellular subscribers, the study of heterogeneity gained much importance. The capturing of heterogeneity in the user population is a difficult task using the general class of statistical distributions, as analysis would become analytically intractable.

The heterogeneity in the user population is captured through randomly varying parameters like the cell residence time. So, we will assume the parameter characterizing cell residence time and random variable, which would enable us to study the effect of heterogeneity in both classes of mobile users. In general, it is not possible to completely specify the statistical distribution of velocities of mobile users, but one might provide information of these users in the form of first few moments, namely, the mean speed, variance and skewness of the distribution.

Given partial information, is it possible to construct the probability distribution? Rosenblueth [29] proposed a two-point distribution (TPD) which is carried out with the available information. In this method, approximations to the moments of the function are obtained using a 'linear combination of the powers of the point estimates of the functions defined in terms of the first few moments of the random variable.

In this chapter, we will study the effect of heterogeneity in both high-speed users and low-speed users of the cellular system.

3.2 TPD formalism

The advantage of using the TPD is based on the fact that one is able to carry out approximate analytical analysis of the model. We need to obtain the approximations to the moments of the real function $f(Y)$ of the real random variable Y when the first three moments of Y are specified. If the first three moments are μ_Y, σ_Y and υ_Y denoting the mean, standard deviation and skewness of the variable Y resulting the probability density function of Y is chosen as

$$\psi(y) = P_Y^1 \delta(Y - y_1) + P_Y^2 \delta(Y - y_2) \qquad (1)$$

where $\delta(.)$ is well known Dirac's delta function and $P_Y^1 + P_Y^2 = 1$.

Clearly, P_Y^1, P_Y^2, y_1, y_2 will be estimated in such a way that P_Y^1, P_Y^2 is normalized, and they satisfy the appropriate equations for μ_Y, σ_Y and υ_Y, namely

$$\mu_Y = P_Y^1 y_1 + P_Y^2 y_2 \qquad (2)$$

$$\sigma_Y = P_Y^1 (y_1 - \mu_Y)^2 + P_Y^2 (y_2 - \mu_Y)^2 \qquad (3)$$

$$\upsilon_Y (\sigma_Y)^3 = P_Y^1 (y_1 - \mu_Y)^3 + P_Y^2 (y_2 - \mu_Y)^3 \qquad (4)$$

For details one may refer to Rosenblueth [29], Karmeshu and D.Goswami [15].
Equations (2) - (4) yield

$$P_Y^1 = \frac{1}{2}\left[1 + \frac{\upsilon_Y}{\sqrt{4+(\upsilon_Y)^2}}\right] \text{ and}$$

$$P_Y^2 = \frac{1}{2}\left[1 - \frac{\upsilon_Y}{\sqrt{4+(\upsilon_Y)^2}}\right] \tag{5}$$

$$y_1 = \mu_Y + \frac{1}{2}\left(\upsilon_Y - \sqrt{4+(\upsilon_Y)^2}\right)\sigma_Y \quad \text{and}$$

$$y_2 = \mu_Y + \frac{1}{2}\left(\upsilon_Y + \sqrt{4+(\upsilon_Y)^2}\right)\sigma_Y \tag{6}$$

Following Rosenblueth [29], on using (5), (6), the estimates of μ_Y, σ_Y and υ_Y are obtained as

$$\mu_Y = P_Y^1 y_1 + P_Y^2 y_2 \tag{7}$$

$$\sigma_Y = (P_Y^1 - P_Y^2)^{1/2} |y_1 - y_2| \tag{8}$$

$$\upsilon_Y \sigma_Y = (P_Y^2 - P_Y^1)(y_1 - y_2) \tag{9}$$

Consequently, an estimate of the rth moment of the function f is given by

$$E\,[f(Y)]^r = \int f^r(y)\psi(y)dy \quad r = 1,2,\ldots$$

For any symmetric distribution i.e. $\upsilon_Y = 0$, the equations (5) and (6) reduce to

$$P_Y^1 = P_Y^2 = \frac{1}{2}$$

$$y_1 = \mu_Y - \sigma_Y$$

And $y_2 = \mu_Y + \sigma_Y$

Correlated Random Variables

Another case worth mentioning when $f = f\,(Y_1, Y2)$ is a function of two correlated random variables.

Following Rosenblueth [29] the joint probability density function of Y_1 and Y_2 having the correlation coefficient ρ can be expressed as

$$\phi(Y_1, Y_2) = \begin{array}{l} P_{Y_1Y_2}^{11}\delta(Y_1 - \mu_{Y_1}^1)\delta(Y_2 - \mu_{Y_2}^1) + P_{Y_1Y_2}^{22}\delta(Y_1 - \mu_{Y_1}^2)\delta(Y_2 - \mu_{Y_2}^2) \\ + P_{Y_1Y_2}^{12}\delta(Y_1 - \mu_{Y_1}^1)\delta(Y_2 - \mu_{Y_2}^2) + P_{Y_1Y_2}^{21}\delta(Y_1 - \mu_{Y_1}^2)\delta(Y_2 - \mu_{Y_2}^1) \end{array}$$

where

$$P_{Y_1Y_2}^{11} = P_{Y_1Y_2}^{22} = \frac{1+\rho}{4} \qquad P_{Y_1Y_2}^{12} = P_{Y_1Y_2}^{21} = \frac{1-\rho}{4}$$

and

$$\mu_i^1 = \mu_i - \sigma_i \;, \quad \mu_i^2 = \mu_i + \sigma_i \qquad \text{for } i = Y_1, Y_2 .$$

We shall consider in the following sections, the effect of heterogeneity of mobile users in Call Admission Control Schemes.

3.3 Heterogeneity in the CAC

As we explained in section 1, the heterogeneity of the mobile users gained importance in the schemes proposed in [12]. Now we will consider and analyze the effect in the heterogeneity among the randomly varying parameters using the two-point distribution approximation to cell residence (dwell) time R_m.

Following Hou and Fang [12], $f_h(t)$ and $f_l(t)$ denote the cell dwell time probability density functions (pdf) of the high-speed users and low-speed users respectively.

If a high-speed user enters this cell at time t, the probability that it will request a handoff after time T is

Pr (this call will request a handoff some time after T)

$$= \text{Pr (this call will stay in current cell before T)}$$

$$= \int_0^{T-1} f_h(\tau)d\tau$$

$$= L_h(t,T/R_m)$$

The notation $L_h(t,T/R_m)$ denotes that for a given value of parameter R_m, one can capture the probability $L_h(t,T)$.

In a similar manner one can express $L_l(t,T)$ in terms of $f_l(t)$.

The parameter R_m characterizes the mobile users. In capturing heterogeneity of mobile user, the parameter R_m is regarded as a random variable. For the convenience, we shall write R_m=Y.

The formalism, which we have proposed, is quite general and one needs specific form of $\psi_Y(y)$. However, not much progress can be made as one requires to evaluate these values.

As discussed in previous sections, if the first three moments are specified then the p.d.f. corresponding to the random variable R_m is

$$\psi_{R_m}(r_m)=\psi_Y(y)=P_Y^1\delta(Y-y_1)+P_Y^2\delta(Y-y_2) \tag{10}$$

If we consider the heterogeneity of the mobile users in each class, the above probability becomes

$$L_h(t,T)=\mathrm{E}_Y\left[L_h(t,T/Y)\right]=\int_{y>0} L_h(t,T/y)\,\psi_Y(y)dy \tag{11}$$

and

$$L_l(t,T)=\mathrm{E}_Y\left[L_l(t,T/Y)\right]=\int_{y>0} L_l(t,T/y)\,\psi_Y(y)dy$$

where $\psi_Y(y)$ is given (10). $P_Y^1+P_Y^2=$ and $\delta(.)$ is well known Dirac's delta function

Let $\beta_{i,j}$ $(j\in N_i)$ be the directional factor, i.e., the probability that the handoff target cell is cell j when the call is being served in the cell i,

Where $\sum_{j\in N_i}\beta_{i,j}=1$, N_i is the set of neighboring cells to the cell i.

For a totally random movement pattern in a homogeneous cellular network, the users move to all possible directions with equal probabilities, $\beta_{i,j}=\frac{1}{|N_i|}$ for all the $j\in N_i$, where $|N_i|$ denotes the cardinality of the set N_i. For a cellular network which is hexagonal, each cell has six neighbours, the directional factor for this case will be 1/6. In an environment (such as highway) that users' movements follow a highly directional pattern, some factors can be much greater than others can.

With $L_l(t,T)$, $L_h(t,T)$ and $\beta_{i,j}$, the influence curve can be defined for an ongoing high-speed call or low-speed call as follows:

$$I^*(i,j,t,T) = \begin{cases} \beta_{i,j} L_h(t,T) & \text{for a high-speed call} \\ \beta_{i,j} L_h(t,T) & \text{for a low-speed call} \end{cases} \qquad (12)$$

The influence curve characterizes the influence put on cell *j* at time *T* by an ongoing high-speed call or a low-speed call which enters the cell *i* at time *t*.

Using this influence curve for every ongoing call, one can determine the number of channels needed to be reserved in each cell. The total influence that all the ongoing calls in cell *i* imparts on cell *j* is

$$I^*_{i,j} = \sum_{k \in S} \beta_{i,j} L(t_k, T) \qquad (13)$$

where S is the set of all the currently ongoing calls in cell *i*, $L(t_k, T)$ can be either $L_l(t,T)$ or $L_h(t,T)$ depending on the velocity class of the call.

We define the number of reserved channels in cell *j* for calls in cell *i* as

$$R^*_{i,j} = B\, I^*_{i,j} \qquad (14)$$

where B is the tunable constant. Hence at time T, cell j needs to reserve

$$R^*_j = \sum_{i \in N_j} R^*_{i,j} \qquad (15)$$

channels for possible handoff calls from its neighbouring cells. In this scheme, cell *i* should report $R_{i,j}$ to all its neighbours. Due to the mobility of the users, the information exchange must be done periodically to make sure that a cell is always having the latest information about the reservation needs of its neighbours.

3.3.1 Study of a Special Case

If the cell dwell times for both classes of users have negative exponential distributions, then

$f_h(\tau)=\mu_h e^{-\mu_h \tau}$ and $f_l(\tau)=\mu_l e^{-\mu_l \tau}$

where $\frac{1}{\mu_h}$ and $\frac{1}{\mu_l}$ are the average cell dwell times for high speed and low-speed users, respectively. For convenience, take the random variable Y corresponding to μ_h and random variable Z corresponding to μ_l respectively. Also assumption of random movement pattern of moving users gives

$$L_h(t,T/\mu_h)=L_h(t,T/Y)=1-e^{-y(T-t)}$$

$$L_l(t,T/\mu_l)=L_l(t,T/Z)=1-e^{-z(T-t)}$$

For high-speed users,

$$L_h(t,T) = \mathrm{E}_Y\left[L_h(t,T/Y)\right] = \int_{y>0} L_h(t,T/y)\,\psi_Y(y)\,dy$$

$$\begin{aligned}
L_h(t,T) &= \int_{y>0} L_h(t,T/y)\,\psi(y)\,dy \\
&= \int_{y>0} L(t,T/y)\left[P_Y^1\delta(Y-y_1)+P_Y^2\delta(Y-y_2)\right]dy \\
&= \int_{y>0} \left(1-e^{-y(T-t)}\right)\left[P_Y^1\delta(Y-y_1)+P_Y^2\delta(Y-y_2)\right]dy \\
&= \int_{y>0} \left(1-e^{-y(T-t)}\right)P_Y^1\delta(Y-y_1)dy+\int_{y>0}\left(1-e^{-y(T-t)}\right)P_Y^2\delta(Y-y_2)dy \qquad (16)
\end{aligned}$$

In a similar way, for low-speed users,

$$L_l(t,T) = \mathrm{E}_Z\left[L_h(t,T/Z)\right] = \int_{z>0} L_h(t,T/z)\,\psi_Z(z)\,dz$$

$$\begin{aligned} L_l(t,T) &= \int_{z>0} L_l(t,T/z)\,\psi(z)\,dz \\ &= \int_{z>0}\left(1-e^{-z(T-t)}\right)P_Z^1\delta(Z-z_1)\,dz + \int_{z>0}\left(1-e^{-z(T-t)}\right)P_Z^2\delta(Z-z_2)\,dz \end{aligned} \qquad (17)$$

$$I^*(i,j,t,T) =$$

$$\begin{cases} \dfrac{1}{6}\left[\displaystyle\int_{y>0}\left(1-e^{-y(T-t)}\right)P_Y^1\delta(Y-y_1)\,dy + \int_{y>0}\left(1-e^{-y(T-t)}\right)P_Y^2\delta(Y-y_2)\,dy\right] & \text{for high speed user} \\[2ex] \dfrac{1}{6}\left[\displaystyle\int_{z>0}\left(1-e^{-z(T-t)}\right)P_Z^1\delta(Z-z_1)\,dz + \int_{z>0}\left(1-e^{-z(T-t)}\right)P_Z^2\delta(Z-z_2)\,dz\right] & \text{for low speed user} \end{cases} \qquad (18)$$

$$R^*_{i,j} = \frac{B}{6}\left[\begin{array}{l}\sum_{k\in S_h}\left(\int_{y>0}\left(1-e^{-y(T-t_k)}\right)P_Y^1\delta(Y-y_1)dy + \int_{y>0}\left(1-e^{-y(T-t_k)}\right)P_Y^2\delta(Y-y_2)dy\right) \\ +\sum_{k\in S_l}\left(\int_{z>0}\left(1-e^{-z(T-t_k)}\right)P_Z^1\delta(Z-z_1)dz + \int_{z>0}\left(1-e^{-z(T-t_k)}\right)P_Z^2\delta(Z-z_2)dz\right)\end{array}\right] \tag{19}$$

$$R^*_j = \sum_{i\in N_j} R^*_{i,j} \tag{20}$$

where t_k is the enter time of ongoing call k to the current cell of interest, S_h is the set of al ongoing high-speed calls and S_l is set of all ongoing low-speed calls.

For demonstration purpose, if we assume both the skewness of random variable Y (i.e μ_h), υ_Y =0 and random variable Z (i.e. μ_l),υ_Z=0 then we get

$$P_Y^1 = P_Y^2 = \frac{1}{2} \text{ and } P_Z^1 = P_Z^2 = \frac{1}{2}$$

$$y_1 = \mu_Y - \sigma_Y,\ y_2 = \mu_Y + \sigma_Y$$

and $z_1 = \mu_Z - \sigma_Z,\ z_2 = \mu_Z + \sigma_Z$

then the equations (16) and (17) become,

$$\begin{aligned} L_h(t,T) &= \int_{y>0}\left(1-e^{-y(T-t)}\right)P_Y^1\delta(Y-y_1)dy + \int_{y>0}\left(1-e^{-y(T-t)}\right)P_Y^2\delta(Y-y_2)dy \\ &= \frac{1}{2}\left(1-e^{-y_1(T-t)}\right) + \frac{1}{2}\left(1-e^{-y_2(T-t)}\right) \end{aligned} \tag{21}$$

In a similar way,

$$L_l(t,T) = \frac{1}{2}\left(1 - e^{-z_1(T-t)}\right) + \frac{1}{2}\left(1 - e^{-z_2(T-t)}\right) \qquad (22)$$

It is important to examine effect of random variability of parameters characterizing high and low speed users.

For different arbitrary values of y_1 , y_2 and z_1 , z_2 (depending on the arbitrary values of μ_Y , σ_Y and μ_Z , σ_Z) we can see the following graph,

Table 1

T	μ_Y	σ_Y		determn	Stochastic
0.2	1	0.7		$L_h(t,T)$	$L^*_h(t,T)$
0.4	det y1	stoc y1	stoc y2	0.181269	0.173233
0.6	1	0.3	1.7	0.32968	0.303231
0.8				0.451188	0.402067
1	t=0			0.550671	0.478356
1.2				0.632121	0.538249
1.4				0.698806	0.586147
1.6				0.753403	0.625201
1.8				0.798103	0.657671
2				0.834701	0.685182
				0.864665	0.708908

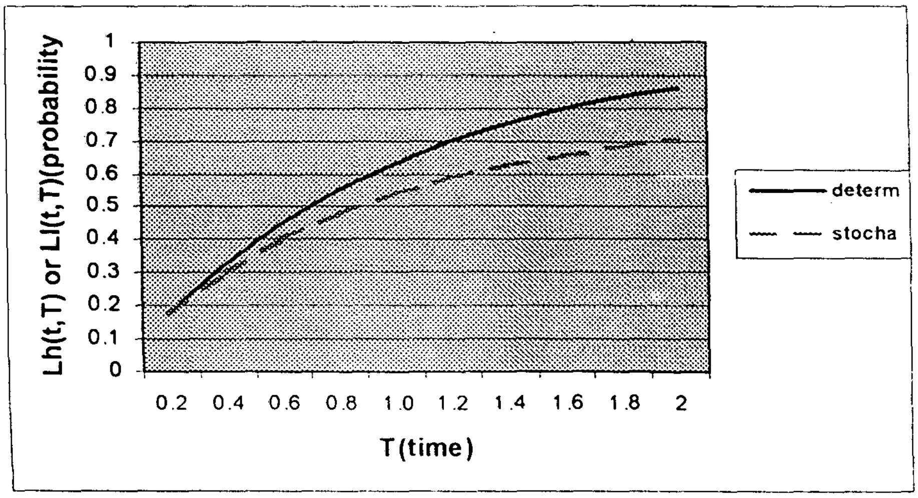


Fig 3.1 Effect of Heterogeneity in the mobile users

In the above table 1, we have taken arbitrary values for μ_Y, σ_Y and calculated y_1 and y_2. In the case of σ_Y=0, i.e. without variation, both y_1 and y_2 are equal which is deterministic. And if we consider some variation i.e. $\sigma_Y \neq 0$ then we have the stochastic values for y_1 and y_2, which are shown in the table. We have assumed that the time from t=0 to T on the X-axis and the probability calculated from (21) shown on Y-axis. From the fig. 3.1, one can easily see that the variation between deterministic and stochastic probabilities which shows that the effect of heterogeneity makes a lot. One can see for different arbitrary values of μ_Y, σ_Y the variability between both the cases. In a similar way, we can draw the graphs for probability (22).

$$R^*_{i,j} = \frac{B}{6}\left[\sum_{k \in S_h}\left(\frac{1}{2}\left(1-e^{-y_1(T-t_k)}\right)+\frac{1}{2}\left(1-e^{-y_2(T-t_k)}\right)\right)+\sum_{k \in S_l}\left(\frac{1}{2}\left(1-e^{-z_1(T-t_k)}\right)+\frac{1}{2}\left(1-e^{-z_2(T-t_k)}\right)\right)\right] \tag{23}$$

$$R^*_j = \sum_{i \in N_j} R^*_{i,j} \tag{24}$$

This effect of heterogeneity can be seen in the equations (23) and (24) by drawing graphs. When compared to the quantity R_j of [12], the new quantity R^*_j, that we have calculated based on the two-point distribution, one can easily see the effect of heterogeneity amongst mobile users and how it varies. It also effects the CAC schemes discussed in [12].

3.3.2 Effect on CAC Schemes

In this section we can see four different CAC schemes of [12] based on the approach that we have discussed. Schemes 1 and 2 are two different implementations of MBCR; scheme 3 is based on limitation of the number of new calls admitted, called new call bounding scheme, and scheme 4 is a combination of the new call bounding scheme and MBCR scheme [12].

(1) Integral MBCR

At time T, cell j computes R^*_j according to (24). R^*j may not be an integer. In this scheme, R^*j is rounded to the nearest integer $\bar{R}^*_j$. Now the final target number of reserved channels becomes $\bar{R}^*_j$. The following policy can be seen

$$P_{new} = \begin{cases} 1 & B_{used} \le C - \bar{R}^*_j - B_{new} \\ 0 & B_{used} > C - \bar{R}^*_j - B_{new} \end{cases}$$

where P_{new} is the admission probability for new calls, B_{used} and B_{new} are the number of used channels and the number channels required by the incoming new call, respectively [12]. One can easily see that the bounds of [12] is effected with the heterogeneity.

(2) Fractional MBCR

In the above scheme, rounding scheme is used for reservation request. However, some information carried by the fractional part may be lost during the rounding. In order to fully use the information fractional reservation scheme is introduced. If R^*_j has integral part R^{*I}_j and fractional part R^{*F}_j and it has also effected by the heterogeneity, one can easily see the modified one as follows

$$P_{new} = \begin{cases} 1 & B_{used} \le C - R^{*I}_{j} - B_{new} - 1 \\ 1 - R^{*F}_{j} & B_{used} = C - R^{*I}_{j} - B_{new} \\ 0 & B_{used} > C - R^{*I}_{j} - B_{new} \end{cases}$$

(3) New Call Bounding (NCB) scheme

The decision variable for CAC can be the number of totally occupied channels. There may happen that too many calls are accepted into the system, which may result in congestion in neighbouring cells due to the handoffs of these new calls. To overcome this occurrence, in the NCB scheme, the number of channels that are currently occupied by new call is used as a decision variable for CAC. The scheme works as follows

$$P_{new} = \begin{cases} 1 & B_{usednew} \le N_{bnd} \;\&\; B_{used} \le C - B_{new} \\ 0 & \text{otherwise} \end{cases}$$

where $B_{usednew}$ is the number of channels that is used by new calls, N_{nbd} is a given bound for new calls. In this scheme the heterogeneity of the mobile users may not effect much.

(4) Hybrid scheme

This is the combination of schemes 1 and 3. The new call admission probability for this scheme is shown as below, which is also effected by the heterogeneity,

$$P_{new} = \begin{cases} 1 & B_{used} \le C - \bar{R}^{*}_{j} - B_{new} \;\&\; B_{usednew} \le N_{nbd} \\ 0 & \text{otherwise} \end{cases}$$

CHAPTER 4

FIRST PASSAGE TIME AND CELL RESIDENCE TIME BASED ON USERS' MOBILITY

In literature, the concept of cell residence time (dwell time) has been used for obtaining performance measures for mobile communications [9,10,11,23]. Attempt has also been made to link the cell residence time and the mobility model [34]. We find that it is not easy to assign cell dwell times when the mobility models are specified for example, if the mobility model corresponding to a random walk type. The dwell time distribution has not been discussed much in the literature corresponding to the mobility models. We wish to propose a related concept of First Passage Time (FPT) in place of dwell time distribution. It is easy to see that FPT distribution can be computed for any underlined mobility model. However, a relevant question could be to establish connection between FPT and cell dwell time if any. We shall briefly discuss the notion of FPT and dwell time.

4.1 First Passage Time:

The time at which a process, X_n, originating at t=0 in state X_0, first enters a particular state. If we denote our chosen state by k, we can define a random variable, N, by requiring:

i) $X_N = k$

ii) $X_j \neq k$, for $j < N$.

The random variable N is conventionally called the *first passage time* from state X_0 to state k [7,27].

4.2 Various approaches for Determination of Cell Residence (Dwell) Time

Channel holding (occupancy) time is a very important parameter in teletraffic analysis of mobile cellular networks. This is needed to compute the key parameters in the mobile cellular networks like new call blocking probability and the handoff call blocking probability [11]. It is important to characterize the channel holding time in cellular networks and to investigate how its distribution affects the cellular traffic in reality.

The channel holding time is the amount of time a call holds a channel in a cell (the time a call spends in a cell). The channel holding time depends on the users' mobility, which can be characterized by the cell residence time (the time a mobile user stays, or dwells, in a cell). In order to characterize the channel holding time appropriately, it is necessary to have a good mobility model for the cell residence time. Due to [8,11], by assuming the specific cell shape (either hexagonal or circular) and combining the distributions of speed and movement direction of a mobile user, one can determine the probability distribution of cell residence time. But in practical systems the cell shapes are irregular, and the speed and direction of mobile users may be difficult to characterize. Therefore, it is better to directly model the cell residence time as a random variable with an appropriate probability distribution to capture the overall effects of the cellular shape and users' mobility patterns.

Previously, analyses used exponential distributions to model channel holding time for the sake of tractability. But experimental data showed that actual channel occupancy distributions are significantly different from exponential distributions used in these analyses [10, 23, 24].

4.2.1 Sum Of Hyperexponential (SOHYP) model

Rappaport and Orlik [23] modeled cell residence time with probability density function as the Sum of Hyperexponential (SOHYP). The weighted sum of negative exponential functions is the Hyperexponential density and the sum of independent Hyperexponential variates is the SOHYP. The advantage of using the SOHYP distribution is the preservation of the Markovian property in the queueing network model but it is unknown whether the SOHYP models have the capability of approximations. Moreover, the Laplace transform of the SOHYP distribution remains a complex rational function.

4.2.2 Hyper-Erlang Model

Y.Fang and I. Chlamtac [10], the channel holding time is denoted as t_c, cell residence time as t_m, r_1 is the time between the instant a new call is originated and the instant the new call moves out of the cell if the new call is not completed, and r_m (m>1) be the residual life time distribution of call holding time when the call finishes m^{th} handoff successfully. Also, t_{nh} and t_{hh} denote the channel holding time for a new call and a handoff call respectively. From the fig. 4.1, the channel holding time for a new call will be $t_{nh} = \min\{t_c, r_1\}$ and the channel holding time for a handoff call is $t_{hh} = \min\{r_m, t_m\}$.

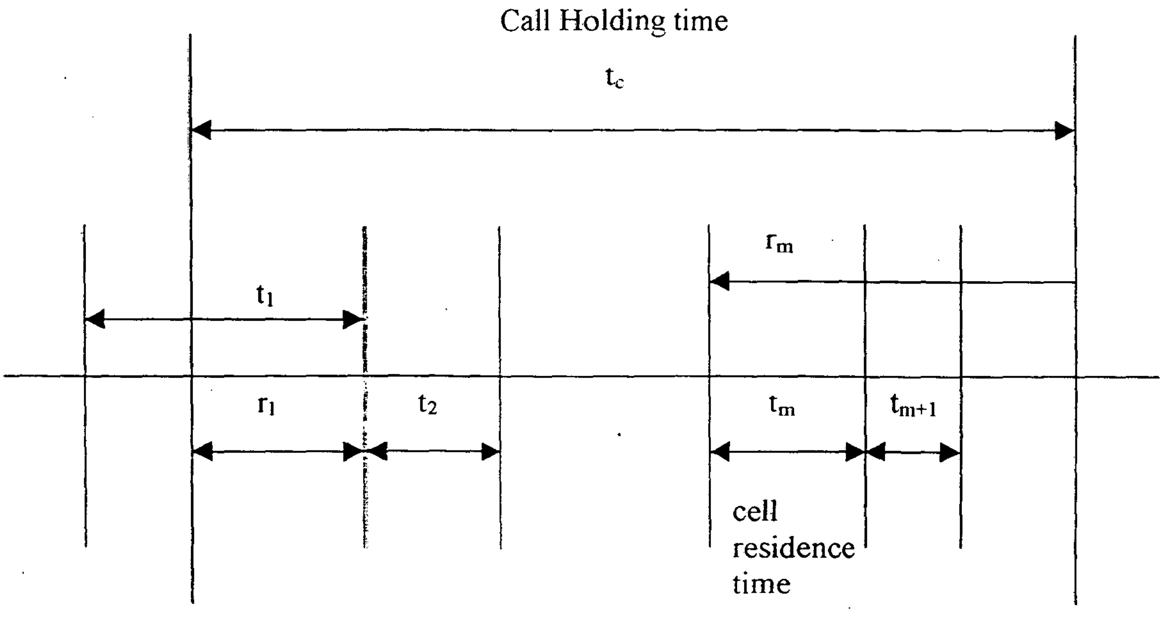


Fig. 4.1 The time diagram for call holding time and cell residence time

In [10], Authors have assumed the call duration (t_c) as exponential random variable with parameter μ, showed that the Laplace transform of the distribution of service time for new users, f_{nh}^*, and the Laplace transform of the distribution of service time for handoff users, f_{hh}^*, are given by $f_{nh}^*(s) = \frac{\mu}{s+\mu} + \frac{s}{s+\mu} f_r^*(s+\mu)$, where $f_r^*(s)$ is the Laplace transform of the distribution of time between the start of a call and the first handoff, and

$f_{hh}^*(s) = \frac{\mu}{s+\mu} + \frac{s}{s+\mu} f_c^*(s+\mu)$, where $f_c^*(s)$ is the Laplace transform of the distribution of cell residue time. Assuming new and handoff users have exponential inter-arrival time distributions with parameters λ_n and λ_h, then the channel holding time, t, in a cell can be expressed as

$$f_t^*(s) = \frac{\lambda_n}{\lambda_n - \lambda_h} f_{nh}^*(s) + \frac{\lambda_h}{\lambda_n + \lambda_h} f_{hh}^*(s).$$

where $f_t^*(s)$ is the Laplace transform of the distribution of t.

This result shows that the channel holding time in a cellular network can be expressed as a combination and convolution of several exponential distributions such as hyper-Erlang distribution.

4.3 First Passage Time (FPT) Formulation

To fix our ideas, we consider a single state S (accessible to the process X(t)) with the probability distribution of the time T at which X(t) enters state S for the first time. Clearly T is a random variable taking values in the interval (t_0, ∞), where t_0 is the initial time. This T is termed as the first passage time starting from initial state.
Fig 4.2 shows the times t_1,t_2 and t_3 at which three sample paths of the process X(t), with $X(t_0)=x_0$, reach S for the first time [27].

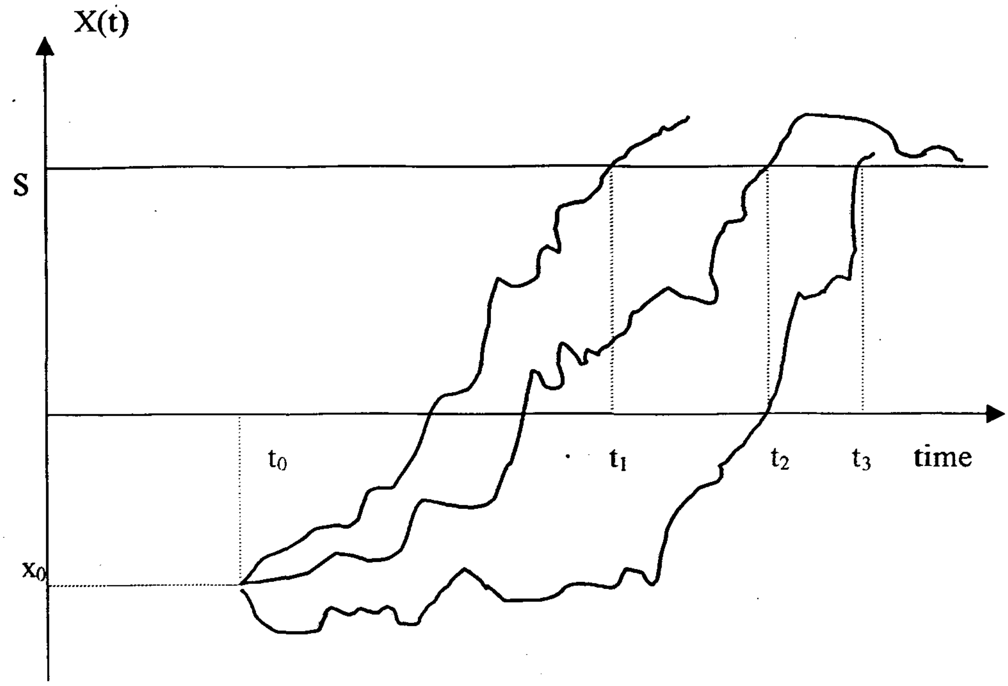


Fig. 4.2 Three values (t_1,t_2,t_3) of the random variable T corresponding to three sample paths of X(t)

In this formulation. S denotes the assigned state. S can be referred as the threshold or absorbing barrier. Also assume $t_0=0$. Since the time T is necessary for a process X(t), with $X(0)=x_0$ to attain the state S for the first time is a continuous random variable, the first passage time can be determined through the determination of the probability density function (p.d.f.) of T, i.e. a function $g(S,t/x_0)$ such that $g(S,t/x_0)dt$ gives the probability that in the time interval (t,t+dt) X(t) attains the threshold S for the first time, given $X(0)=x_0$.

Therefore, the important task is to determine the p.d.f. of the first passage time. Due to Siegert, for determining the first passage time p.d.f. for a homogeneous markov process with continuous sample paths, assume $x_0 < S$ and x be a state above S, but otherwise arbitrary.

Since every sample path which at time t lies between x and x+dx must necessarily have crossed S for the first time at some instant $\tau < t$,

$$f(x,t/x_0) = \int_0^t d\tau \, g(S, \tau/x_0) \, f(x, t - \tau/S) \tag{1}$$

where f is the transition p.d.f. of X(t) and first passage time is given by

$$g(S,t/x_0) = \frac{|S - x_0|}{\sqrt{2\pi}\sigma} t^{-3/2} \exp\left[-\frac{(S - x_0 - \mu t)^2}{2\sigma^2 t} \right] \tag{2}$$

We shall now consider a mobility model and give expressions for the first passage time distribution.

4.4 Mobility based on Random walk model

Rose and Yates [28], denoted the possible unit locations by j = 1,2... The locations might be cells in a wireless system. Each unit m moves between locations j according to some stochastic process. Given that the unit was last in contact with the network at time $t = t_0$ and place $x(t_0)$, the time varying distribution on location is defined as $p_j(t, t_0, x(t_0))$. We assume that $p_j(t_0, t_0, x(t_0)) = \delta_{j,x(t_0)}$ where $\delta_{i,j}$ is unity for $i = j$ and zero otherwise. The implication is that successful paging, registration or calls initiated by the mobile unit inform the system of the unit location and essentially reset t_0.

Authors [28] assumed that an effective paging process is rapid compared to the rate of unit motion, i.e., the unit to be found does not change locations during the paging process. Thus, if a page request arrives at time $t \geq t_0$, the distribution is assumed fixed at $p_j(t_0, t_0, x(t_0)) = p_j$; also assumed that a mobile unit can always "hear" and will answer a page request at its current location.

Although any model of unit motion could in principle be reduced to its corresponding time-varying probability distribution, as a convenient, useful and concrete example, consider an isotropic Brownian motion process with drift. Drift is defined as mean velocity in a given direction and can be used to model directed traffic such as vehicles along a highway. In the one-dimensional version of Brownian motion, a particle moves to the right by one "space step" Δx with some probability p and to the left with probability q, and stays put with probability $1-p-q$ for each "time step" Δt. The simplest analogy is either pedestrian or vehicular traffic in a Manhattan street grid (confined to one avenue in the one-dimensional case). Given the particle started at time $\tau = 0$ from position $x = 0$, as the time and space steps are made infinitesimally small authors [28] obtained a Gaussian probability density function on particle location:

$$P_{X(\tau)}(x(\tau)) = \frac{1}{\sqrt{\pi D \tau}}\left[\exp(-(x-\upsilon\tau)^2)/D\tau\right]$$

where $\upsilon = (p-q)\,\Delta x/\Delta t$

is drift velocity and $D = 2((1-p)p + (1-q)q + 2pq)(\Delta x)^2/\Delta t$ is the diffusion constant, both functions of the relative values of time and space steps. One can see that equally likely steps left or right implies $p = q$ and therefore $\upsilon = 0$. The location probability p_j would be obtained by integrating the density function over the region associated with location j. Similarly, for n-dimensional isotropic motion we have

$$P_{X(\tau)}(x(\tau)) = \prod_{i=1}^{n} \frac{1}{\sqrt{\pi D \tau}^{1/2}}\left[\exp(-(x_i - \upsilon_i \tau)^2\right]/D\tau$$

$$= \frac{1}{(\pi D \tau)^{n/2}}\left[\exp(-|x-\upsilon\tau|^2\right]/D\tau$$

Of particular interest is the fact that the variance of the distributions $D\tau/2$, a measure of location uncertainty, does not depend on the mean drift velocity υ. This is an important feature since intuitively, and in some of the literature, higher unit velocity implies higher mobility. There is no such relationship for the probability distribution-based method proposed in [28] and considered only location uncertainty.

4.7 FPT in cellular networks based on mobility

In the previous section, we discussed the mobility model based on random walk. Now, we will write the FPT distribution for the model based on mobility.

If the starting point of the mobile user, x_0 is described by a random variable with in an interval [a, b]. Then the movement of the mobile user, x_0 as a random variable since the user moves randomly within an interval [a, b]. Then the first passage time distribution will follow from (1) and (2),

$$g(S,t) = \int_a^b g(S,t/x_0)\phi(x_0)dx_0 \tag{3}$$

If the user moves uniformly (assuming the distribution of x_0 is uniform) then the distribution of ϕ becomes uniform distribution with p.d.f. $\frac{1}{b-a}$, $a<x_0<b$

That is,

$$\phi(x_0) = \frac{1}{b-a} \quad , \quad a < x_0 < b \tag{4}$$

Now equation (3) becomes,

$$g(S,t) = \frac{1}{b-a}\int_a^b g(S,t/x_0)dx_0$$

In case, only first two moments of x_0 are specified then we can approximate this distribution (4) as two-point distribution,

$$\phi(x_0) = \frac{1}{2}\delta(x_0 - (\tilde{x}_0 - \tilde{\sigma}) + \frac{1}{2}\delta(x_0 - (\tilde{x}_0 + \tilde{\sigma})$$

Therefore, the first passage time distribution is given by

$$g(S,t) =$$

$$\frac{1}{2}\left[\frac{S-(\tilde{x}_0-\tilde{\sigma})}{\sqrt{2\pi\sigma}}t^{-3/2}\exp\left(\frac{S-(\tilde{x}_0-\tilde{\sigma})-\mu t}{2\sigma^2 t}\right)\right]+\frac{1}{2}\left[\frac{S-(\tilde{x}_0+\tilde{\sigma})}{\sqrt{2\pi\sigma}}t^{-3/2}\exp\left(\frac{S-(\tilde{x}_0+\tilde{\sigma})-\mu t}{2\sigma^2 t}\right)\right]$$

CONLCUSION AND REMARKS

In the cellular systems, there is a lot of variability amongst the mobile users. This variability can be seen through the effect of heterogeneity of the mobile users. Call admission control (CAC) schemes are used to decide whether an incoming call is admitted for network service or not. These schemes play a prominent role in the measurement of QoS. The existing methods have not been considered this feature of heterogeneity while constructing the CAC schemes. In this work, we have proposed a new approach based on two-point distribution (TPD) for the randomly varying parameters in the system. One can capture the heterogeneity of the mobile users through this approximation of TPD. The advantage of TPD is that it provides an approximate analytical analysis to the problem, which in general may not be feasible, when one considers the detailed statistical distribution of the users with respect to their velocities, high-speed and low-speed. We have also discussed the effect of heterogeneity in CAC using our approach based on TPD.

The cell residence time is one of the important measures of the performance of a cellular system. Finding the distribution of cell residence time in mobility models is very difficult. In this work, we have proposed first passage time (FPT) distribution to provide insight into the cell residence time in the cell. We have given an example of random walk model, which is based on mobility. We have given the distribution of FPT in cellular networks. It is an area of future inquiry to find the connection between FPT and cell residence time if any.

REFERENCES

[1] http://www.cellular.co.za/analysts/ 07182001-emc_forecasts_subscribers_to_top.htm

[2] http://web.bham.ac.uk/eee1roj8/websites_demo/g4c3.htm

[3] Bhattacharya A. and Das S.K.," LeZi-Update: An Information-theoretic Approach to Track Mobile Users in PCS Networks", *Proceedings of MOBICOM'99*, Seattle, WA, August 1999.

[4] Chao C. and Chen W., "Connection admission control for mobile multiple-class Personal Communication Networks", *IEEE Journal on Selected Areas in Communications*, Vol.15, No.8, pp.1618-1626, October 1997.

[5] Cheund M. and Mark J.W., "Effect of mobility on QoS provisioning in wireless communication networks", *Proceedings of IEEE WCNC'99*, New Orleans, September 1999.

[6] Choi S. and Shin K.G., "Predictive and Adaptive bandwidth reservation for handoffs in QoS-sensitive cellular networks", *Proceedings of ACM SIGCOMM'98*, Vancouver, BC, September 1998

[7] Cox D.R. and Miller H.D., *Theory of Stochastic Process*, Methuen & Co. Ltd., London, 1965

[8] Del Re E., Fantacci R. and Giambene G., "Efficient dynamic channel allocation techniques with handover queueing for mobile satellite networks", *IEEE Journal on Selected Areas in Communications*, Vol.13, No.2,Febraury 1995

[9] Fang Y. and Chlamtac I., " A new mobility model and its application in the channel holding time Characterization in PCS Networks", *Proceedings of IEEE INFOCOM'99*, New York, NY, March 1999.

[10] Fang Y. and Chlamtac I., "Teletraffic Analysis and Mobility Modeling of PCS Networks", *IEEE Transactions on Communications*, Vol.47, No.7, July 1999.

[11] Hong D. and Rappaport S.S., "Traffic Model and Performance Analysis for Cellular Mobile Radio Telephone Systems with Prioritized and Nonprioritized Handoff Procedures", *IEEE Trans. on Vehicular Technology*, Vol.35, No.3, August 1986

[12] Hou J. and Fang Y., "Mobility-Based Call Admission Control Schemes for Wireless mobile Networks", *Wireless Communications and Mobile Computing (WCMC)*, 1(3), 269-282, Jul-Sept 2001

[13] Hou J, Fang Y and Akansu A.N., "Mobility-based channel reservation schemes for wireless mobile networks", *Proceedings of IEEE WCNC'00*, Sept. 2000

[14] Jedrzycki C. and Leung V.C.M., "Probability distributions of channel holding time in Cellular telephony systems", *Proceedings of IEEE VTC'96*, Atlanta, May 1996.

[15] Karmeshu and D.Goswami, "Stochastic evolution of innovation diffusion in heterogeneous groups: study of life cycle patterns", *IMA Journal of Management Mathematics(2001)* 12, 107-126.

[16] Katzela I. and Naghshineh M., "Channel assignment schemes for cellular mobile telecommunication system: a comprehensive survey", *IEEE Personal Communications*, 1996.

[17] Lee W.C.Y, *Mobile Cellular Telecommunications - Analog and Digital Systems*, 2nd Edition, McGraw-Hill, Inc, February 1995

[18] Levine D.A., Akylidz I.F. and Naghshineh M., " A resource estimate and call admission algorithm for wireless multimedia networks using the shadow cluster concept", *IEEE/ACM Transaction on Networking*, Vol.5, pp.1-12, February 1997

[19] Lohi M., Baldo O.and AghvamiA.H., "Handover issues and Call Admission Control in Cellular System", IEEE Vehicular Technology Conference VTC' fall, Amsterdam, The Netherlands, September 1999.

[20] Lu S. and Bhargavan V., "Adaptive resource management algorithms for indoor mobile computing environment", *Proceedings of ACM SIGCOMM'96*, Stanford, CA, September 1996.

[21] Naghshineh M. and Schwartz M., "Distributed call admission control in mobile/wireless networks", *IEEE/ACM Transactions on Networking*, Vol.5, pp.1-12, February 1997.

[22] Oliveira C, Kim JB and Suda T, "An adaptive bandwidth reservation scheme for high-speed multimedia wireless network", *IEEE Journal on Selected Areas in Communications*, Vol.16, No.6, pp.858-874, 1998

[23] Orlik P.V. and Rappaport S.S., "A Model for Teletraffic Performance and Channel Holding Time Characterization in Wireless Cellular Communication with General Session and Dwell Time Distributions", *IEEE Journal on Selected Areas in Communications*, Vol.16, No.5, June 1998

[24] Rajaratnam M. and Takawira F., "Handoff Traffic Characterization in Cellular Networks under Nonclassical arrivals and service time distributions", *IEEE Transactions on Vehicular Technology*, Vol.50, No.4, July 2001

[25] Ramjee R, Towsley D, Nagarajan R, "On optimal call admission control in cellular networks", *ACM Journal on Wireless Networks*, Vol. 3, No. 1, pp.29-41, 1997

[26] Rappaport T. S., *Wireless Communications: Principles and Practice*, Printice-Hall Inc., N.J., 1996.

[27] Ricciardi Luigi M., *Lecture Notes in Biomathematics: Diffusion Processes and Related Topics in Biology*, Springer-Verlag, 1977

[28] Rose C. and Yates R., "Location uncertainty in mobile networks: a theoretical framework", *IEEE Communications Magazine*, 35(2):94-101, February 1997

[29] Rosenblueth E., "Point estimates for probability moments", Proc. Natl. Acad. Sci., USA, 72, pp.3912-3814, 1975.

[30] Sidi M. and Starobinski D, "New Call Blocking versus Handoff Blocking in Cellular Networks," *ACM Journal on Wireless Networks*, Vol. 3, No. 1, pp.15-27, 1997

[31] Siegert, A.J.F., "On the First Passage Time Probability Problem", *Phys. Rev., 81*, 617-623, 1951

[32] Tekinay S. and Jabbari B., "Handover and Channel Assignment in Mobile Cellular Networks", *IEEE Communications Magazine*, Vol. 30, No. 11, pp. 42-46, November 1991

[33] Trivedi K. S. and Ma Xiaomin, "Analytic Modeling of Handoffs in Wireless Cellular Networks", *CACC Research Review 2001*, November 2001

[34] Yu F. and Leung V.C.M., "Mobility-based predictive call admission control and bandwidth reservation in wireless cellular networks", *Proceedings of IEEE Infocom'01*, Anchorage, Alaska, April 2001