A NEW DISTRIBUTED CHANNEL ASSIGNMENT SCHEME FOR CELLULAR SYSTEMS

by

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Abstract

The number of cellular subscribers world-wide is expected to grow rapidly in the next decade. Since the radio spectrum available for a cellular system is limited, designing an effective channel assignment scheme is of great importance. In this thesis, a new channel assignment scheme, distributed MAXMIN with interference information (DMAXMIN_WI), is proposed. The new scheme is developed from the centralized MAXMIN scheme. By sharing interference information with neighboring cells, the host cell (the cell in which a channel needs to be assigned) performs a channel assignment which attempts to minimize the effect on other co-channel users. The performance of DMAXMIN_WI is compared with those of existing channel assignment schemes using computer simulation. Intra-cell reassignments are carried out in order to reduce the call dropping probability. Results show that DMAXMIN_WI has the best overall performance and requires few intra-cell reassignments.

The effectiveness of a performance analysis technique, the Snapshot Analysis, and its relationship to traditional analysis are studied. A new approach to performance analysis, the Slot Viewpoint Analysis, is proposed. This new approach is used to show that Snapshot Analysis cannot replace traditional analysis.

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Chapter 1 Introduction

The cellular telephone has become a necessity for many people. Twenty years ago, most people could not have imagined how easily they could make phone calls regardless of their physical locations. Since the cellular telephone was first introduced in the early 1980's, wireless communications has undergone tremendous changes. Reductions in subscription costs as well as the advent of user-friendly, pocket sized mobile units have led to ever growing demands for wireless services. Such demands have spurred interest in wireless communications research.

Advanced Mobile Phone System (AMPS), based on analog frequency modulation technology, was the first cellular system introduced in the United States [1]. There are several other types of analog cellular systems in the rest of the world. In Europe, these include Nordic Mobile Telephone (NMT) and Total Access Communications System (TACS) [2]. The analog cellular systems are referred to as first generation systems, which represented a breakthrough in personal wireless communications. The most popular second generation cellular standard is Global System for Mobile Communications (GSM), which has now been adopted by many countries around the world. GSM was deployed in late 1992. It can provide better voice quality and significant capacity improvements as compared to the analog cellular systems [3]. Much research effort is now being spent on third generation cellular systems which will allow for multimedia communications as well as Internet access.

Cellular communication systems are constantly being required to support more users at a better Quality of Service (QoS). The capacity and the QoS of a system are often limited by its allocated radio spectrum which is a scarce resource. One approach is to devise channel assignment schemes which allow more efficient use of the spectrum. A good channel assignment scheme increases the number of channel reuses while keeping the amount of co-channel interference to a minimum. Improved channel assignment schemes can yield capacity enhancements in all three generations of cellular systems.

1.1 Motivation and Objectives

In most existing channel assignment schemes [4]-[13], a base station assigns channels to new calls using only its local information, i.e., the desired and interference signal powers received on each channel. In order to provide high quality service, an efficient channel assignment scheme should result in low call dropping probability. If neighboring base stations are allowed to exchange their local information, a channel assignment which minimizes the undesirable effect to all on-going calls can be carried out.

This thesis has two objectives. The first one is to examine the effectiveness of the Snapshot Analysis, which is an existing approach to evaluate the performances of channel assignment schemes. A new approach is proposed to serve as a bridge between the Snapshot Analysis and the traditional performance analysis. The second objective is to develop a new Distributed Dynamic Channel Assignment (DDCA) scheme and to compare its performance with those of established schemes.

1.2 Outline of the Thesis

In Chapter 2, the basic concepts of a cellular system and several existing channel assignment schemes are described. In Chapter 3, the Snapshot Analysis is reviewed and a new approach to performance analysis, the Slot Viewpoint Analysis, is proposed. In Chapter 4, the proposed DDCA scheme is described and its blocking and dropping probabilities are compared with those of some previously studied schemes. The required number of intra-cell reassignments for each scheme is studied in Chapter 5, together with the trade-off between the performance and the information available at each base station. The main findings and a list of topics for further study are given in Chapter 6.

Chapter 2 Background

This chapter provides a review of the basic principles of a cellular system. Concepts such as cellular layout model, multiple access, frequency reuse, and channel assignment are described. Also included in this chapter is a review of Interference Adaptation Dynamic Channel Assignment (IA-DCA) schemes.

2.1 Cellular Radio System

The base station (BS) and mobile station (MS) are two major components of a cellular system. An MS refers to the subscriber unit carried by a user. Over the service area (the geographical region over which cellular service is offered), MS's communicate with an infrastructure of BS's; each BS serves several MS's simultaneously since it is equipped with a number of transceivers, which enables radio signals to be sent and received on different channels. The area where MS's are connected to a particular BS is called a cell. All BS's are connected to a mobile switching center (MSC). The MSC works as an interface to the public switched telephone network (PSTN), so that mobile users can communicate with other users who are on the wired network. Figure 2.1 shows the infrastructure of a cellular system.

In setting up a communication link between an MS and a BS, a voice channel has to be assigned so that both ends of the link are able to receive with an acceptable signal level. Algorithms, which select channels to be assigned during call initialization, are known as channel assignment schemes. Control channels are introduced to facilitate the channel assignment. One of the main functions of the control channels is to provide a means for signal measurements for both MS and BS.

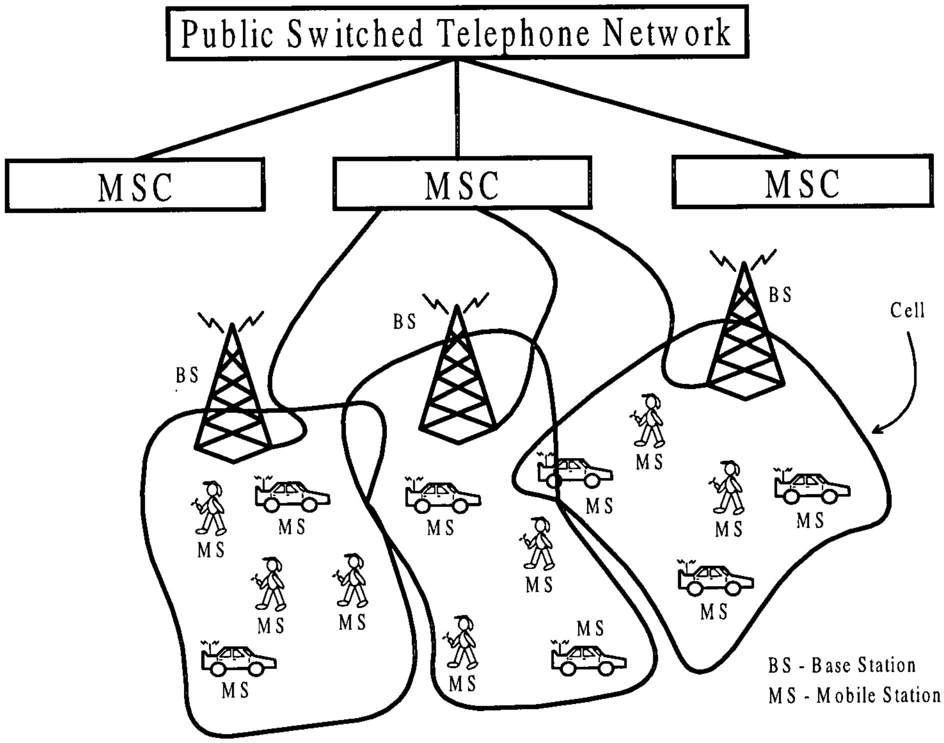


Figure 2.1: Infrastructure of a Cellular System.

When an MS wishes to originate a call, it first sends a call initiation request to the BS with the strongest signal strength. The initiation request, together with the identity of the MS, is sent to the BS via the control channels. The BS receives this information and sends it to the MSC. After making the connection with the called party, the MSC instructs the BS to perform channel assignment and to alert the MS by providing the ringing tone. The situation is similar for a mobile-terminating call; however, due to the mobility of MS's, the called MS has to be paged [2].

2.1.1 Cellular Layout Model

As described in the previous section, a cellular system consists of cells which cover all of its service coverage area. In practice, the shape of a cell is irregular and is determined by the propagation loss of the transmission power from that corresponding BS. For the sake of simplifying the planning and analysis, each cell is often assumed, to have identical shape and size. Both one-dimensional and two-dimensional models can be used to represent the system.

When a number of BS's are installed on highways and along streets with tall buildings which act as shields against interference on either side [6], the BS's can be modelled as a one-dimensional subsystem. One BS is placed in each cell as shown in Figure 2.2 and the BS's are assumed to be equally separated along a straight line. Omni-directional antennas at each BS provide radio coverage on both sides of the cell.

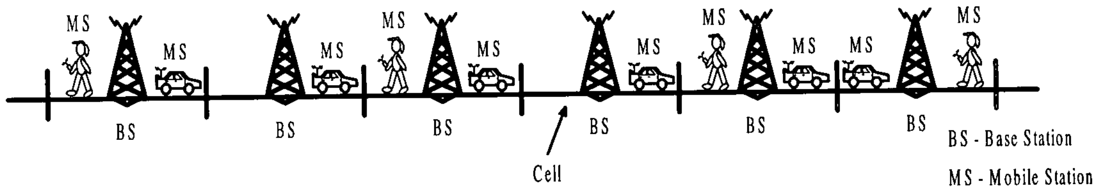


Figure 2.2: One-dimensional Model of a Cellular System.

Two-dimensional models are more often used to represent a cellular system. By extending the one-dimensional model, the cell shape in two dimensions can be represented by a square [5,7]. However, uniform hexagonal cells are commonly used in the literature [4,8-15]. The hexagonal representation is chosen because hexagons can approximate circles more closely and they can be tessellated without leaving gaps between adjacent cells. Moreover, a number of cells (typically 3, 4, 7, 9 or 11) can easily be grouped into a cluster, which is a feature of Fixed Channel Assignment (FCA). When channel fading and power control are not considered, an MS always requests a channel from the closest BS which gives the strongest signal strength. Besides, the choice of using a particular channel would also depend on the interference power received at both terminals (MS or BS). When an MS, with an on-going call, crosses the cell boundary, another BS might have to serve the same call. This is accomplished using an inter-cell handoff procedure. Figure 2.3 shows a cellular system represented by a two-dimensional hexagonal model.

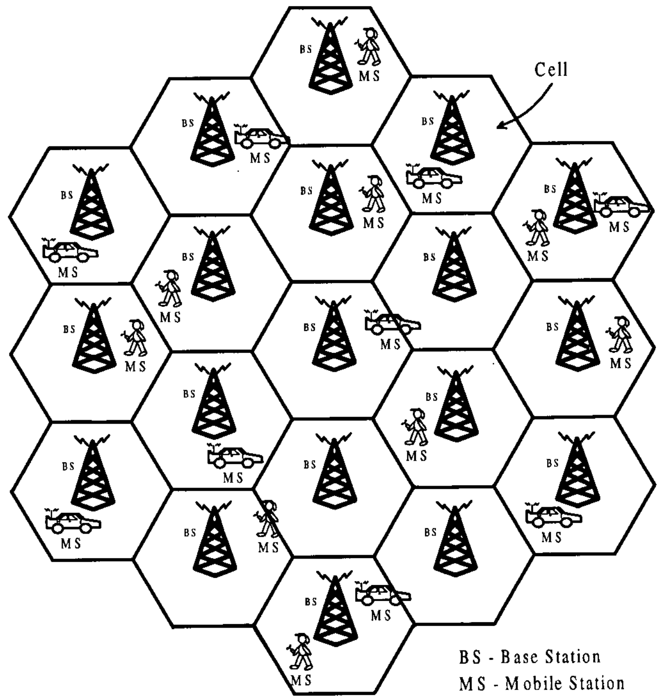


Figure 2.3: Two-dimensional Model of a Cellular System.

2.1.2 Multiple Access

The incorporation of multiple access techniques in cellular systems allows for more efficient use of the limited radio spectrum [16]. Multiple access techniques enable the spectrum to be shared by several MS's. In the AMPS first generation cellular system, the spectrum is divided into a number of channels, each one capable of carrying one voice call. This technique is known as Frequency Division Multiple Access (FDMA). In the Time Division Multiple Access (TDMA) technique, an MS time shares its assigned frequency channel with a number of other MS's. Most second generation systems, e.g. GSM, employ a hybrid version of FDMA and TDMA. There is a third technique, called Code Division Multiple Access (CDMA) in which a specific code is assigned to each MS in order to communicate with its BS. Signals for different terminals (MS or BS) are transmitted simultaneously in the same frequency band but only the designated terminal will be able to decode its signal. Discussions in this thesis will be limited to systems using FDMA, TDMA or a hybrid of the two.

2.1.3 Frequency Reuse

The radio spectrum is divided into a number of channels, either as frequency bands (FDMA) or as time slots (TDMA). The number of channels available to a system depends on the bandwidth of the system, the modulation scheme, and the data rate. Theoretically, the maximum number of active MS's one BS with omni-directional antennas can serve is equal to the number of channels available in a cell. By installing a BS in each cell, the same channel can be used simultaneously in different cells provided that the cells are sufficiently far apart. As frequency reuse greatly enhances spectrum efficiency and system capacity, it is regarded as the core concept of the cellular system [1].

MS's using the same channel will cause interference to one another. This kind of interference, due to the common use of the same channel, is referred to as co-channel interference. Although frequency reuse enables several MS's to use the same channel at the same time, each MS will suffer from different amounts of link quality deterioration. The quality of a communication link is commonly measured by the ratio of the desired signal power to the interference signal power. It is often assumed that the system is interference limited, which means that the interference signal power is much greater than the noise (thermal noise) power and the latter is neglected. In the analysis, a minimum signal-to-interference ratio (SIR) value is used to indicate an acceptable quality of a link. If the ratio of the distance to the interferers to the distance from an MS to its BS is large, the SIR is likely to be above the minimum SIR threshold.

When calculating the SIR for a communication link, the desired signal power and the co-channel interference power received by both MS and BS have to be considered. The SIR measured at the MS due to the co-channel interference from other BS's using the same channel is known as the downlink SIR. On the other hand, the SIR measured at the BS due to the co-channel interference from other MS's using the same channel is known as the uplink SIR. Downlink and uplink co-channel interference are illustrated in Figure 2.4. The system is said to be balanced if the downlink SIR is equal to the uplink SIR. In practice, the system is seldom balanced due to the scattering of MS's.

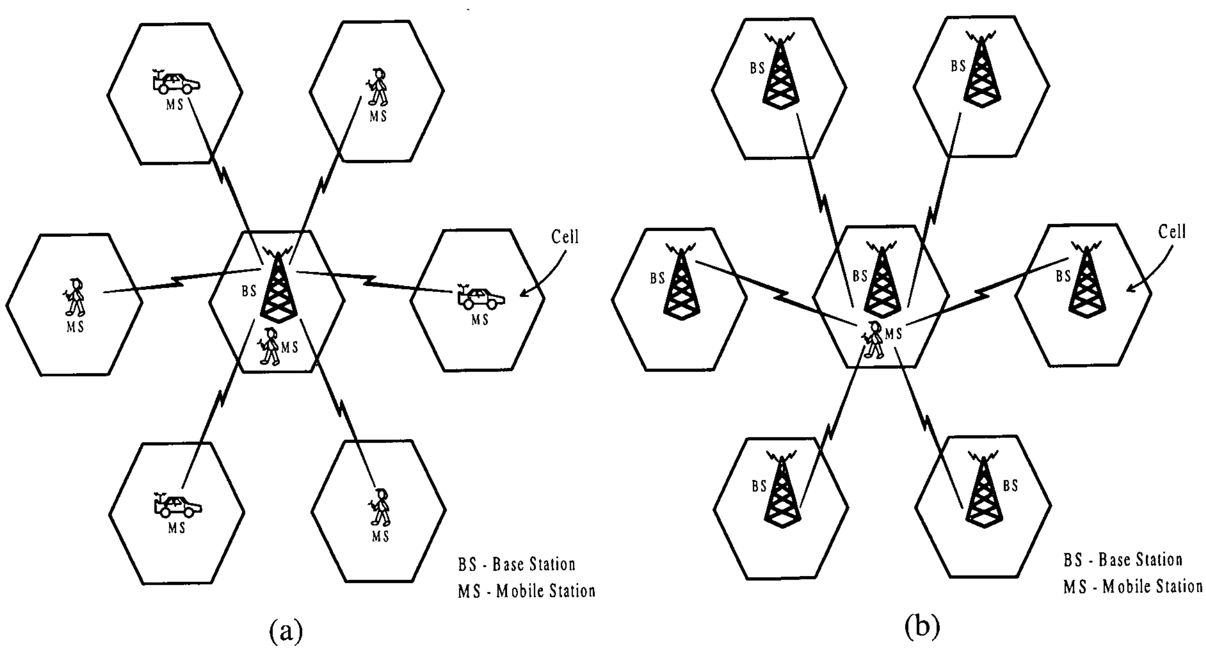


Figure 2.4: Co-channel Interference from Interferers. (a) Receiving at the BS, (b) Receiving at the MS.

2.1.4 Channel Assignment

A channel assignment scheme controls the use of channels so as to maintain acceptable SIR's on all assigned links. In cell-based analysis, channels can be reused at a distance greater than the minimum reuse distance [1]. There is a trade-off between link quality and reuse distance. A smaller reuse distance leads to higher capacity, but worse link quality.

Channel assignment schemes can be classified as Fixed Channel Assignment (FCA) or Dynamic Channel Assignment (DCA). In FCA, the set of channels available to the system is divided into subsets of nominal channels. Each BS is allocated one subset and can assign only channels from that subset to calls. To maintain an acceptable SIR for each user, BS's, with the same subset of nominal channels, have to be a sufficient distance apart. FCA provides good capacity performance only when the cellular system is characterized by a predictable, time-invariant call arrival pattern and a known propagation environment. However, when the call arrival pattern changes rapidly with time, FCA is inefficient because the set of channels which can be used in a cell is fixed. A new call arriving in a cell may have to be blocked even though there are many idle channels in adjacent cells.

Due to the shortcomings of FCA, many different DCA schemes have been proposed. In DCA, each BS is capable of using any channel, provided that the SIR's of the new calls are acceptable. DCA schemes can be classified as [12]: traffic adaptation (TA), location adaptation (LA) and interference adaptation (IA). TA-DCA schemes [17] are capable of adapting to traffic variations and they increase the capacity through a more flexible use of the channels available. The number of channels assigned to each cell depends on the number of calls in progress in that cell. In LA-DCA schemes [17], an MS, which is close to its BS (with high desired signal power received), can use a channel with shorter reuse distance because it can tolerate higher interference power. The most straightforward application of this concept is to divide cells into subcells. Each type of subcells has its own reuse distance and consequently a different reuse pattern. In IA-DCA, channels are assigned according to real-time measurements of (desired and interference) signal powers. Since an assignment decision is based on signal strength measurements, it is expected that, with proper adaptation, IA-DCA can achieve higher capacity gains than the other two types [6,12-13].

In IA-DCA, an established link must have an SIR above the minimum SIR threshold. There are two reasons why a call cannot be served by the system: (1) There is no channel that offers an SIR greater than the call setup threshold during call initialization. (2) A new channel assignment causes the SIR of an on-going call to drop below the minimum SIR threshold. The former situation leads to a blocked call while the latter results in a dropped call.

All DCA schemes discussed in this thesis are of the IA type. The next section contains a review of several well-known IA-DCA schemes.

2.2 Review of Interference Adaptation Dynamic Channel Assignment Schemes

In IA-DCA, channel assignment schemes can further be classified as centralized or distributed [17]. For centralized IA-DCA, a central controller at the MSC has to get all the signal strength measurements from the MS's and BS's before selecting a channel for each communication link. Since the central controller knows how the new assignment is going to affect all on-going calls in the system, the capacity gains obtainable with centralized IA-DCA schemes are quite significant [5,10].

A drawback of the centralized schemes is that a lot of information has to be passed from BS's to the central controller. The average delay in channel assignment is long especially when the traffic load is high [17]. As a result, Distributed DCA (DDCA) schemes, without high centralization overhead, have been proposed. Channel assignment in DDCA is carried out by each BS independently without the need for a central controller. A BS has to monitor a set of idle channels from time to time and make assignment decisions. There are two types of DDCA: Fully decentralized and partially decentralized. In fully decentralized DCA schemes, a BS assigns channels using only the local information (the desired and interference signal powers received on each channel). There is no communication among BS's in the system. In partially decentralized DCA schemes, each BS exchanges its local information with neighboring BS's to assist in the channel assignment procedure. Distributed schemes generally have less delay than centralized schemes in making channel assignment decisions. Moreover, they simplify system implementation as adding new BS's is easier when the system has no central controller. One disadvantage of DDCA schemes is that each BS has no or limited knowledge about its interferers [7]. New calls arriving to the system can cause excessive co-channel interference on other on-going links. A common objective of all DDCA schemes is to minimize co-channel interference, but without using a central controller.

2.2.1 MAXMIN

MAXMIN is a centralized IA-DCA scheme proposed by Goodman et al. [6]. When a call arrives, the central controller assigns a channel that maximizes the minimum of the SIR's of all other calls that are currently being served by the system. In other words, this scheme tries to minimize the number of dropped calls in the future by maximizing the SIR of the call with the poorest SIR after the current assignment.

Consider downlink transmission where BS **B** has to assign a channel to serve MS **A**. MS **A** first measures the signal strength received from BS **B** and the interference power on each traffic channel. Channels with SIR's above the call setup threshold form the set of candidate channels. MS **A** then sends the list of the candidate channels to BS **B** which passes this information to the central controller. The central controller requests each BS which has MS's using any of the channels on the list to communicate back the predicted SIR's on such channels assuming that BS **B** uses the channel. After getting all the predicted SIR's from the BS's, the central controller determines the minimum predicted SIR value for each candidate channel. It then instructs BS **B** to assign the new call to the channel with the maximum of the minimum SIR values. For uplink transmission, BS **B** has to provide the location of MS **A** to the central controller.

In mathematical terms, an MS **A** that requires service is assigned a channel c which gives

$$\underset{c \in C}{Max} \quad \underset{i \in S}{Min} \quad \{\gamma_i\} \tag{2.1}$$

where C is the set of channels that are idle at **A**'s BS, γ_i is the SIR of MS i at its BS and the set S includes all MS's that are ready in service plus the MS that requests service.

2.2.2 Autonomous Reuse Partitioning

Autonomous Reuse Partitioning (ARP) [9] is also known as First Available (FA) [4]. Channel assignments are made in an autonomous fashion. When a new call arrives, channel searches are performed in some order, say decreasing, starting with the highest-order channel. The first idle channel which has an SIR above the call setup threshold is assigned. This results in higher-order channels being reused at shorter distances. These channels thus usually have stronger signal strengths. The frequency reuse pattern will be similar to that in reuse partitioning. ARP achieves the effect of 'reuse partitioning' without frequency planning. Figure 2.5 shows different reuse regions in ARP.

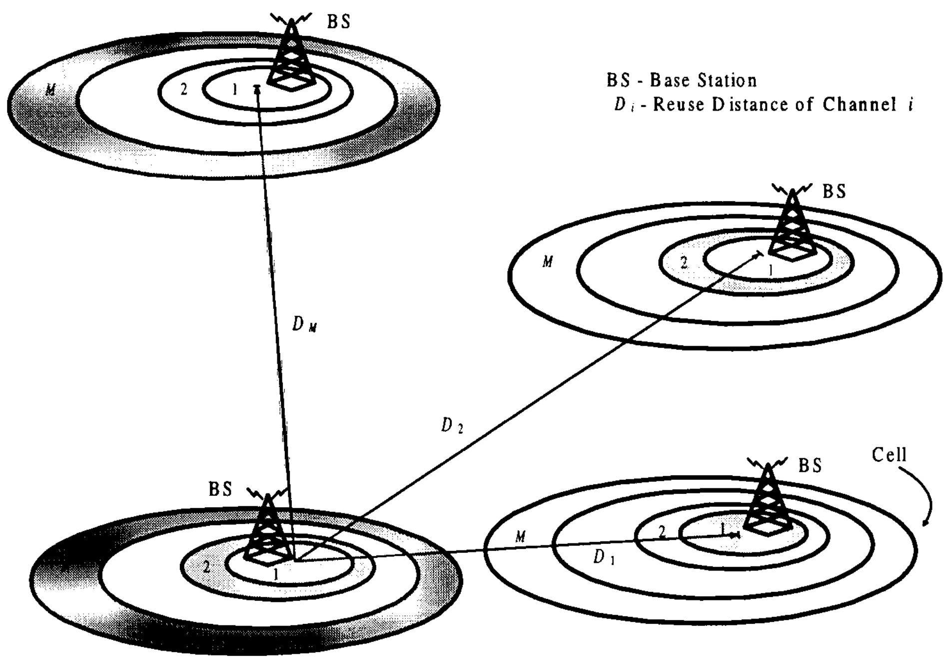


Figure 2.5: Geographical Illustration of Different Reuse Regions.

2.2.3 Maximum SIR

Maximum SIR (MSIR) [15] is also called Minimum Interference (MI) [6] or Least Interference (LI) [10]. It has been incorporated into the Cordless Telephone 2 (CT-2) and Digital European Cordless Telecommunications (DECT) systems. For downlink transmission, suppose that BS **B** has to serve a new call for MS **A**. MS **A** measures the signal strength received from BS **B** and the interference power on each idle channel, so that the SIR's of all idle channels can be calculated. If there are several channels whose SIR's exceed the call setup threshold, the channel with the highest SIR (minimum interference) is assigned to the new call. For uplink transmission, BS **B** measures the interference power so as to calculate the SIR of each idle channel. The channel with the highest SIR is assigned to serve MS **A**.

2.2.4 Channel Segregation

Channel Segregation (CS), proposed by Furuya and Akaiwa [11], is a priority-based algorithm, which prioritizes channels according to how successful they have been used in the past. Priority values are assigned to each channel at every BS. The priority value of a channel increases with each successful assignment of the channel, and decreases when the channel cannot be assigned. When a new call is initiated, the associated BS scans all idle channels in the order of their priorities. The highest-priority channel's SIR is measured and if it is above the call setup threshold, the channel is used to serve the call. If the SIR is below the call setup threshold, the channel cannot be used and the next highest-priority channel is scanned for accessibility. The call has to be blocked if there is no channel with an SIR greater than the call setup threshold.

Since the channels are ranked according to their previous successful uses, the highest-priority channel are the ones that have the best interference situation in their respective cells. The updating of the channel priority is as follows

- When channel i is assigned to a new call at time instant t, the priority function $p(i, t)$ is increased using

$$p(i, t) = \frac{p(i, t-1)n(i) + 1}{n(i) + 1} \tag{2.2}$$

- When channel i cannot be used by the BS after the SIR measurement at time instant t, the priority function $p(i, t)$ is decreased using

$$p(i, t) = \frac{p(i, t-1)n(i)}{n(i)+1} \tag{2.3}$$

where $n(i)$ is the number of times channel i has being considered for use by the BS.

As the value of $n(i)$ becomes large, the priority function $p(i, t)$ may become less sensitive to changing traffic conditions. In such a case, the priority function will not serve its purpose. In [18], a new set of priority updating equations is proposed in order to alter the rate of convergence. The updating of the channel priority is as follows

- The priority $p(i, t)$ of channel i is initialized by

$$p(i, 0) = M - i \tag{2.4}$$

where M is the total number of channels, numbered from 1 to M. Before any channel assignment is carried out, channel number one has the highest priority, and channel number M has the lowest priority

- When channel i is assigned to a new call, the priority function $p(i, t)$ is increased using

$$p(i, t) = p(i, t-1) + M \tag{2.5}$$

- When channel i cannot be used by the BS after the SIR measurement, the priority function $p(i, t)$ is decreased using

$$p(i, t) = p(i, t-1) - M. \tag{2.6}$$

The new set of priority updating equations ensures that, if a channel cannot be used for call setup, it is assigned the lowest priority so that it will not be tested again before other idle channels have had a chance to be tested. Each priority value $p(i, t)$ is kept in the interval [-M, +M]

by the addition or subtraction of M as necessary.

2.2.5 Minimum Cost

In [15], a cost function is used to select a channel to serve a new call. Such a scheme is known as Minimum Cost (MC), where by a channel with the lowest cost is assigned, provided that its SIR is above the call setup threshold. Although channel usages in neighboring cells have to be updated among BS's, MC is regarded as distributed because channel assignment decisions are made locally.

In Figure 2.6, when a new call is served in cell x, it will interfere with on-going calls in neighboring cells using the same channel. The cost of admitting such a call into the system to all other on-going calls depends on a number of factors: the assigned channel c, the distance between two interfering BS's D_i, the cell radius R, the number of co-channel users n, the location of a co-channel user (r_i, θ_i), and the transmitted power of each user P_i. Thus the cost function Q is given by

$$Q = f(D_i, R, c, r_i, \theta_i, P_i), \qquad i \in n. \tag{2.7}$$

In [15], the average co-channel interference to type 3 cells ($D_3/R = 2\sqrt{3}$) and to type 2 cells ($D_2/R = 3$) due to the new assignment in cell x are calculated. The average interference to type 2 cells is approximately twice as much as that in type 3 cells when shadow fading is ignored. The cost to the co-channel users in type 2 cells is then taken to be twice the cost to the co-channel users in type 3 cells.

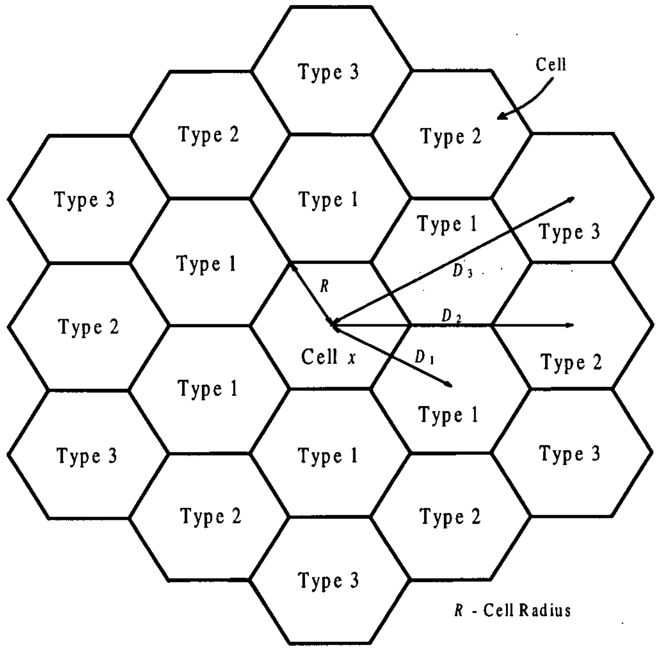


Figure 2.6: Two-tier Neighboring Cells around Cell x.

Let $\Lambda(x)$ denote the set of idle channels in cell x and $U(y)$ denote the occupied channel set in interfering cell y. $I_1(x)$ is defined as the set of the first tier interfering cells of cell x, $I_{22}(x)$ as the set of the second tier type 2 interfering cells of cell x, and $I_{23}(x)$ as the set of the second tier type 3 interfering cells of cell x. The cost to the interfering cell $y \in \{I_1(x), I_{22}(x), I_{23}(x)\}$, due to assigning channel c in cell x is defined as

$$Q_x(y, c) = \begin{cases} 0, & c \notin U(y) \\ k, & c \in U(y) \text{ and } y \in I_1(x) \\ 2, & c \in U(y) \text{ and } y \in I_{22}(x) \\ 1, & c \in U(y) \text{ and } y \in I_{23}(x). \end{cases} \tag{2.8}$$

The cost k of assigning a channel which interferes with on-going calls in the first tier of the neighboring cells is chosen to be 13 [15]. This value is large enough to avoid assigning a channel which is currently used in $I_1(x)$. The overall cost to cell x's two-tier neighboring cells for channel c is

$$Q_x(c) = \sum_{y \in \{I_1(x), I_{22}(x), I_{23}(x)\}} Q_x(y, c) \tag{2.9}$$

When a channel is assigned or released in BS **B**, all of the BS's in **B**'s two-tier neighboring cells are informed. When a new call arrives at cell x, the associated BS has to start calculating the overall cost for each channel c in $\Lambda(x)$. Afterwards, channels are scanned for use in increasing order of cost. If the SIR of the lowest-cost channel is above the call setup threshold, the channel is assigned to serve the call; otherwise, the next lowest-cost channel is checked. The call will be blocked if there is no channel with SIR greater than the call setup threshold.

Chapter 3 Validation of Snapshot Analysis

In this chapter an approach to performance analysis, known as the Snapshot Analysis [19], which has been used to study channel allocation problems in cellular systems is investigated. It was used in [6] to examine the capacity improvements of several DDCA schemes over FCA in a one-dimensional system. In [20], the Snapshot Analysis was used to show that the DDCA schemes can yield higher system capacity when used in conjunction with power control. However, there is no previous work that explains how the Snapshot Analysis can be related to the traditional analysis. In order to show the effectiveness of the Snapshot Analysis and its relationship to the traditional analysis, the Slot Viewpoint Analysis is proposed.

Two traditional ways to evaluate the performances of different channel assignment schemes are recalled, followed by a detailed description of the Snapshot Analysis. The Slot Viewpoint Analysis with simulation results are presented. The Slot Viewpoint Analysis can serve as a bridge between the Snapshot Analysis and the traditional analysis.

3.1 Traditional Analysis

There are two common ways to evaluate the performances of channel assignment schemes, namely, analytical treatment and computer simulation. Both approaches have their own merits and each one helps to verify the results obtained by the other.

3.1.1 Analytical Treatment

In the analytical approach, queueing theory is used to model the call arrival scenario. A 'Queue' is used to describe the behaviour of a cellular system in which calls arrive and depart with certain probability distributions. There are many queueing scenarios which allow different channel assignment schemes to be analyzed. Most queues can be described using the standard queue descriptor [21]

$$A/B/m/K/M \tag{3.1}$$

where A describes the interarrival time distribution and B describes the service time distribution. Both A and B can be replaced by one of the following symbols to denote a particular distribution: $\boldsymbol{M}$ (exponential), $\boldsymbol{D}$ (deterministic), and $\boldsymbol{G}$ (general). The term m denotes the number of servers and K specifies the maximum number of customers which can be present in the system. The term M is used to describe the size of the customer population. If the value of either K or M is not specified, it is assumed to be infinite.

The Erlang B formula, described as a ***M/M/m/m*** queue, is widely used to estimate the probability of call blocking in telephone systems. This formula is also known as 'blocked call cleared' because when the number of calls exceeds the number of lines available, blocking occurs and the excess calls are lost. The Erlang B formula for the probability of call blocking is [2]

$$P_b = \frac{\left(\frac{\lambda}{\mu}\right)^m}{m! \sum_{n=0}^{m} \left(\frac{\lambda}{\mu}\right)^n \frac{1}{n!}} \tag{3.2}$$

where λ is the mean call arrival rate, $\frac{1}{\mu}$ is the mean call duration and m is the number of channels available. The Erlang B formula can be used to analyze the performance of cell-based FCA when there is no channel fading.

Analytical treatments of DCA schemes are more complicated. In contrast to FCA, there is no fixed relationship between channels and cells in DCA. In DCA, modelling the channel usage conditions in any cell is not easy and various assumptions have to be made. Bounds on the performance of DCA schemes have been obtained in [22,23].

3.1.2 Computer Simulation

Due to the difficulties in applying analytical techniques in the study of complicated channel assignment algorithms, computer simulations are often used. Simulation techniques can provide a better understanding of the effectiveness of an assignment scheme in a more realistic setting.

Most computer simulations are of the 'Monte Carlo' type, in which the performance over a large number of trials is assessed and the statistical performance is determined. The arrival of calls is commonly assumed to be a Poisson process and the call durations are assumed to be independent and exponentially distributed. Figure 3.1 shows a typical simulation flowchart.

3.2 Snapshot Analysis

The Snapshot Analysis derives its name from its way of analyzing the channel assignment problem. The cellular system is studied at one randomly chosen point in time. The system frozen at that time instant is referred to as a 'snapshot'. In a snapshot, MS's are waiting to be served by their BS's using the channel assignment scheme under investigation. The Snapshot Analysis is based on the assumption that the channel assignment algorithm is infinitely fast, so that each MS in the snapshot would have been considered by the assignment algorithm.

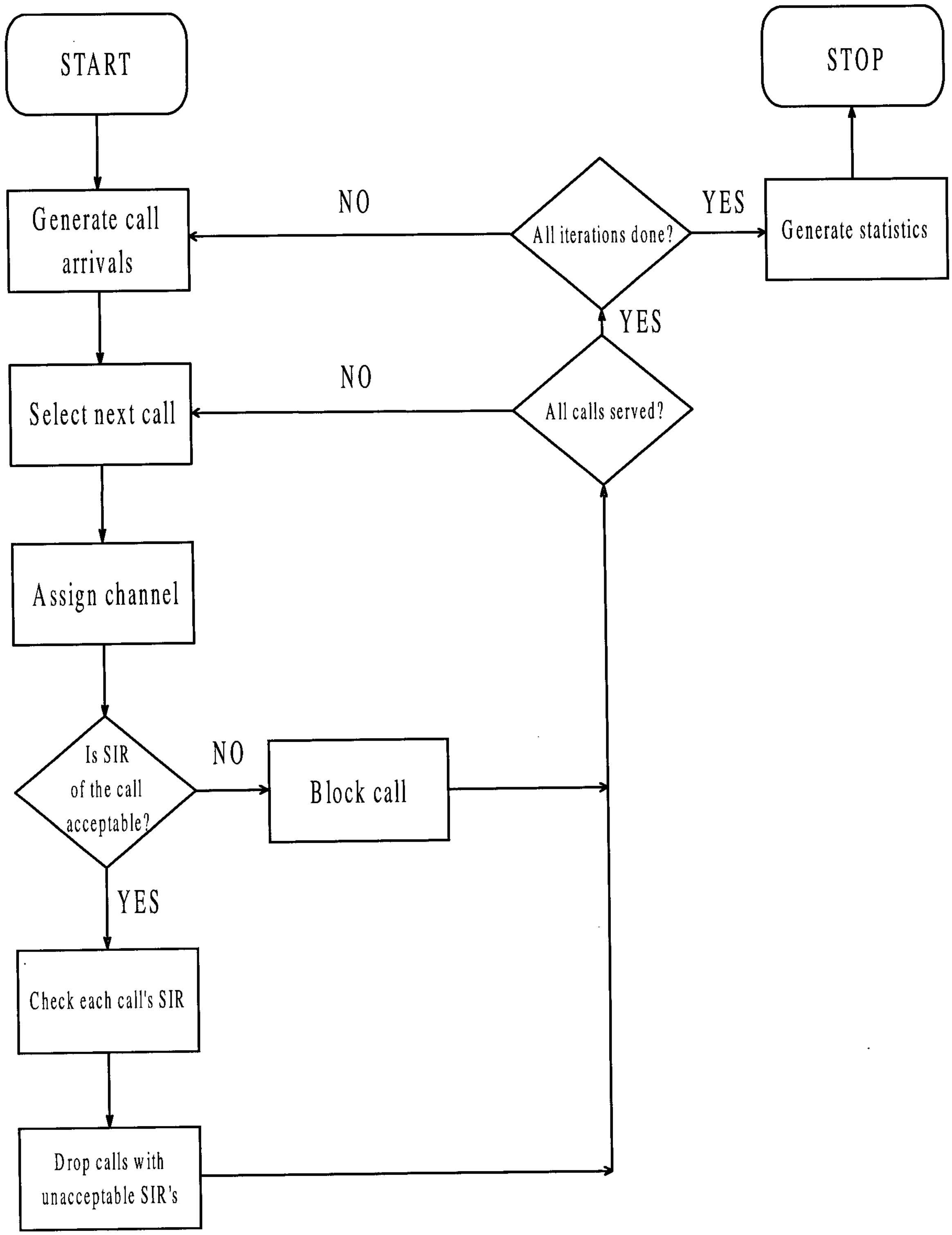


Figure 3.1: Simulation Flowchart.

There are two reasons why an MS is not assigned a channel at the end of the analysis: (1) There is no channel that offers an SIR greater than the call setup threshold due to severe co-channel interference. (2) A new channel assignment causes the SIR of an assigned channel to fall below the minimum SIR threshold. Both situations are referred to as service denials. Generally, a number of snapshots are taken, so that simulation results are averaged over all the snapshots. Two randomly chosen snapshots along the time-line are shown in Figure 3.2.

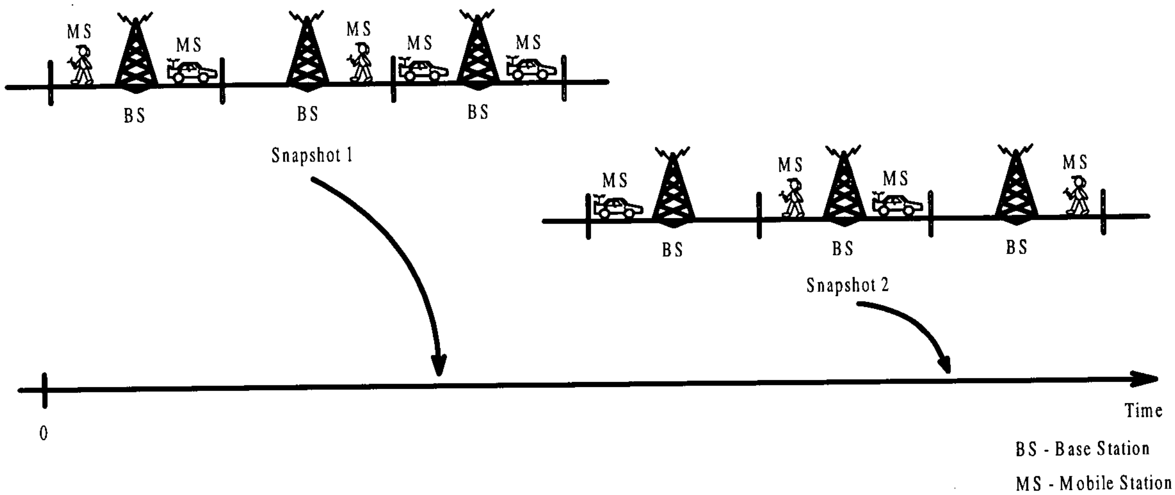


Figure 3.2: Snapshots Taken from a Simulation Time-line.

One disadvantage of the snapshot approach is that it does not distinguish between MS's with different types of requests, such as on-going calls and new calls. Furthermore, as the system is studied at one time instant, the Snapshot Analysis is not able to consider any time correlation properties of the traffic, i.e., the call arrival and call duration statistics. Only the spatial distribution of MS's in a snapshot is being investigated with different channel assignment strategies. The performance is evaluated by counting the number of MS's the channel assignment scheme cannot accommodate (service denial).

3.2.1 Simulation Model and Performance Measures

The simulation model used in this chapter is based on the one described in [6].

- The simulated layout is a one-dimensional cellular system, which consists of 80 cells. In order to avoid edge effects (cells close to the edge of the system, which have fewer interfering cells on one side, generally have a lower service denial probability than inner cells), simulation results are taken from the inner 50 cells. Each BS is located at the center of a cell, and serves MS's that are within the cell boundaries. It is assumed that there is no channel fading and an MS always requests a channel from its closest BS (to receive the strongest signal strength). The call is blocked if this BS has no available channel.

- Distance between any two adjacent MS's is independent and exponentially distributed with a mean of $1/\lambda_c$ length units. In other words, the number of MS's in a cell of unit length is a Poisson distributed variable with an expected value λ_c (mean traffic per cell). Furthermore, MS's are uniformly distributed in the system.

- There is a total of ten (non-interfering) channels in the system. Thermal noise is negligible.

- Only uplink (MS to BS) transmissions are considered.

- The propagation loss is assumed to be a monotonic function of distance from an MS. The propagation loss exponent, α, is chosen to be four.

- All transmissions are of equal power. No power control is incorporated into the assignment schemes.

- Movements of an MS during a call are assumed to be negligible when compared to the cell size, i.e., all MS's are stationary.

- The SIR γ_i of MS i at its BS is given by

$$\gamma_i = \frac{d_i^{-\alpha}}{\sum_{j \in I} d_j^{-\alpha}} \tag{3.3}$$

  where d_k is the distance of MS k from the BS of MS i. The set I contains all the interfering MS's of MS i. In [6], FCA was used as a reference to compare with DCA. It is assumed that the frequency reuse factor N is 2, so that channels can be reused at every other BS. The worst SIR γ_{worst} an MS suffers in a one-dimensional system is given by

$$\gamma_{worst} = \frac{1}{2\sum_{l=1}^{\infty}(2Nl-1)^{-\alpha}} \tag{3.4}$$

  and for $\alpha = 4$, the minimum SIR threshold for a call to stay in the system is chosen to be 15.89 dB.

Performance of a channel assignment scheme is evaluated as a function of the mean number of MS's per cell per channel, λ. Two different performance measures, the probability of service denial, P_{sd} [6] and the probability of assignment failure, P_a [20], have been proposed:

$$P_{sd} = E\left[\frac{\text{Number of mobiles denied service in a snapshot}}{\text{Number of mobiles that need service in a snapshot}}\right] \tag{3.5}$$

$$P_a = \frac{\sum_{l=1}^{k} \text{Number of mobiles denied service in snapshot } l}{\sum_{l=1}^{k} \text{Number of mobiles that need service in snapshot } l} \tag{3.6}$$

where k is the number of snapshots evaluated in the simulation. The above two expressions can be rewritten as

$$P_{sd} = \frac{1}{k}\sum_{l=1}^{k} \frac{N_{d,l}}{N_l} \tag{3.7}$$

$$P_a = \frac{\sum_{l=1}^{k} N_{d,l}}{\sum_{l=1}^{k} N_l} \tag{3.8}$$

where $N_{d,l}$ is the number of MS's denied service in snapshot l and N_l is the number of MS's that need service in snapshot l. If $N_l = N$, i.e., equal number of MS's in each snapshot, the two expressions are identical. As the average number of MS's in each snapshot increases, the difference between P_{sd} and P_a decreases. P_a will be used as the performance measure in this chapter.

3.2.2 Application to Minimum Interference Schemes

The Minimum Interference (MI) channel assignment schemes were examined using the Snapshot Analysis in [6]. A channel with the least interference (highest SIR) is assigned during the call setup. In the Snapshot Analysis, the order in which MS's are assigned channels greatly affects the efficiency of channel reuse. Since MS's are not distinguished by their arrival order, two different channel assignment schemes are examined.

- In the Random Minimum Interference (RMI) scheme, the order of service is random. For example, the order of assignments can be identical to the order in which calls were generated in a snapshot.
- In the Sequential Minimum Interference (SMI) scheme, an MS is assigned a channel according to its physical position in the one-dimensional cell structure. The order of assignments is that an MS is served only after all MS's that are to the left of it have had a chance to be served. Such a scheme would require coordination among BS's.

Figure 3.3 shows the performances of RMI and SMI evaluated using the Snapshot Analysis. It can be seen that SMI performs better than RMI. In SMI, since channels are assigned from the left-most MS to the right-most MS, a nice channel reuse pattern can be obtained, i.e., the assigned channels tend to go from the lowest-ordered to the highest and then the same pattern repeats again. Given that there are ten channels in the system, the same channel is very likely to be assigned to every tenth MS starting from the left. Channels are reused at the maximum distance possible so that SMI has a better performance than RMI.

Since the Snapshot Analysis is the main focus of this chapter, only RMI will be considered hereafter.

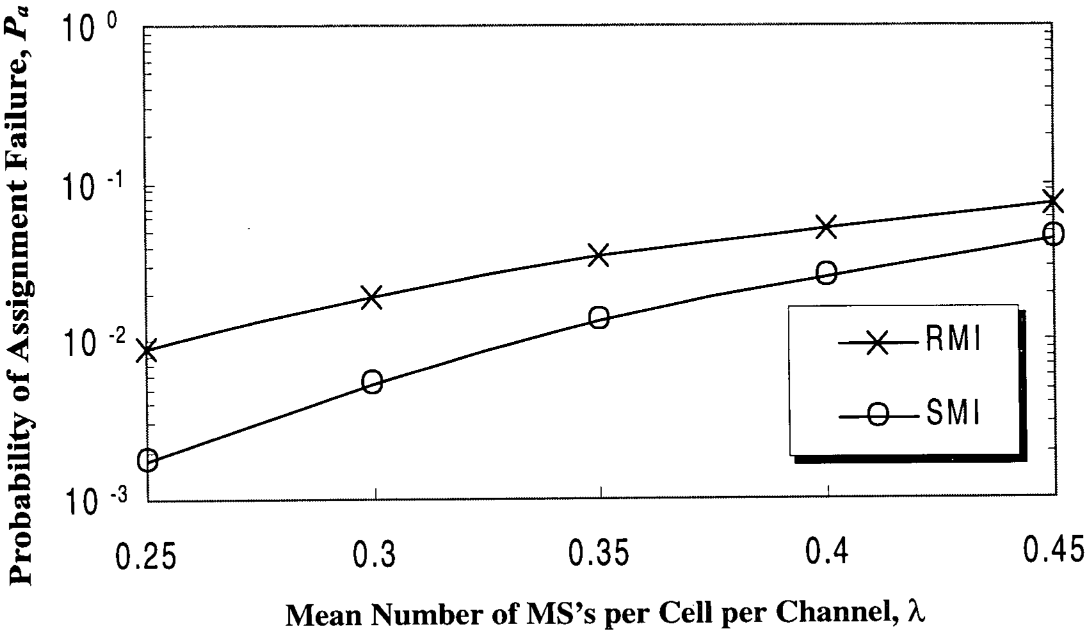


Figure 3.3: RMI and SMI Evaluated Using Snapshot Analysis.

3.3 Slot Viewpoint Analysis

In order to study how the Snapshot Analysis can be applied in a practical system, the Slot Viewpoint Analysis, which introduces the slot concept, is proposed. The Slot Viewpoint Analysis serves as a bridge between the Snapshot Analysis and traditional analysis.

In Slot Viewpoint Analysis, the simulation time-line, as illustrated in Figure 3.4, is divided into a number of 'slots' with equal size. Unlike traditional analysis of a cellular system, call requests in the system are not served immediately. Channel assignment is only carried out at the end of each slot and the number of service denials is recorded after each assignment. At the end of the simulation, recorded results from all slots are used to calculate the probability of assignment failure, P_a, as

$$P_a = \frac{\sum_{l=1}^{k} \text{Number of mobiles denied service in slot } l}{\sum_{l=1}^{k} \text{Number of mobiles that need service in slot } l}. \quad (3.9)$$

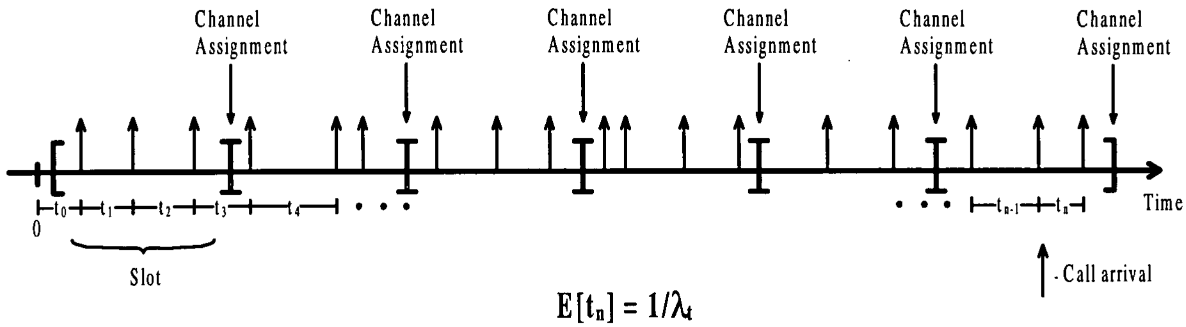


Figure 3.4: Slot Viewpoint Approach.

It is assumed that the channel assignment at the end of each slot is carried out infinitely fast, i.e., no later than the arrival time of the first call request in the next slot. If the length of a slot is long, a call request may have to wait for a long time before a channel is assigned. In such a case, the Slot Viewpoint Analysis is only applicable to call requests involving non real-time applications, such as email, voice mail or data. The Slot Viewpoint Analysis can be used to approximate both the Snapshot and the traditional analysis by varying the size of the slots.

For a situation in which the slot size is big enough, such that all MS's in the current slot have finished using the channels long before the channel assignment in the next slot, the Slot Viewpoint Analysis will produce similar results to the Snapshot Analysis. For example, the slot size can be set to ten times the mean call duration (assumed to be two minutes) to avoid any carry over of MS's to the next slot. Channel assignment applied to all MS's in a slot now becomes the same as in a snapshot.

In comparing the probability, P_a, of assignment failure from the Slot Viewpoint and the Snapshot Analysis, P_a is plotted as a function of the mean number of call requests per slot/ snapshot. This is because call requests in the snapshot approach are generated in terms of space, while in the Slot Viewpoint, call requests are generated according to time as illustrated in Figure 3.5, where λ_t is the mean arrival rate.

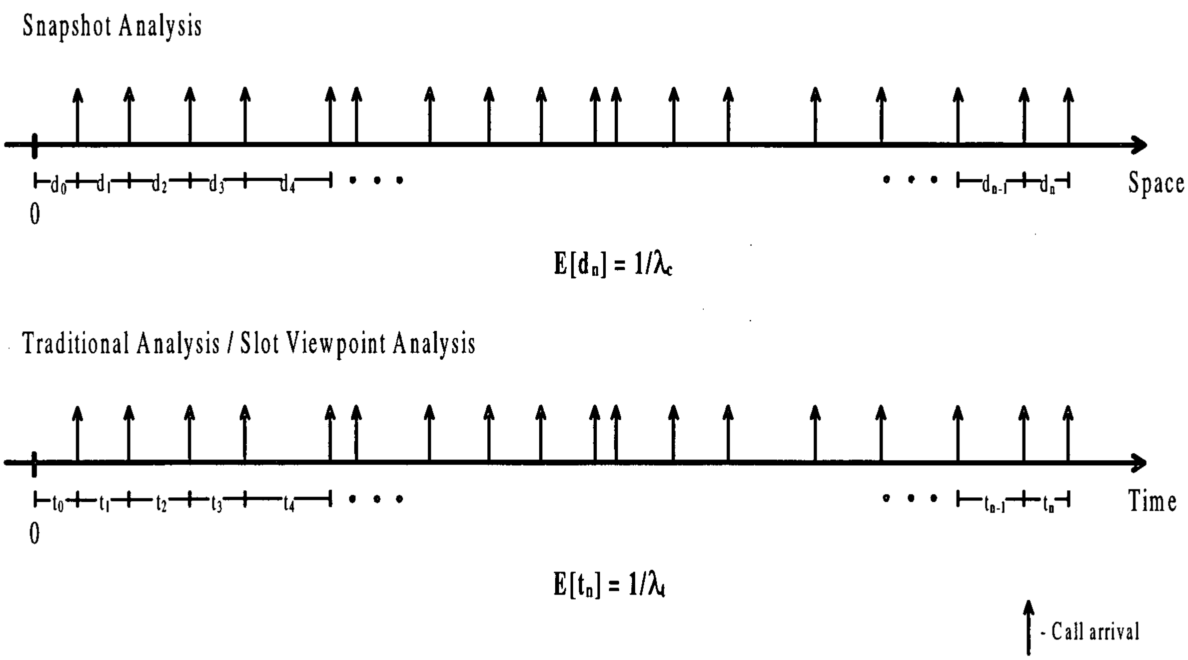


Figure 3.5: Two Different Ways of Generating Call Requests.

In Slot Viewpoint Analysis, with the length s of a slot, the average number of call requests per slot is $\lambda_t s$. In Snapshot Analysis, since simulation results are taken from the inner 50 cells, the average number of calls in a snapshot is $50\lambda_c$. Figure 3.6 shows the performance of RMI evaluated using both the Snapshot and the Slot Viewpoint Analysis.

Different slot sizes are used in the Slot Viewpoint Analysis while keeping the same average number of calls per slot ($\lambda_t s$) by varying the mean arrival rate (λ_t). In the Slot Viewpoint Analysis, if the ratio of the slot size to the mean call duration is greater than ten, there is no difference in performance using either approach. However, if this ratio is less than ten, say 5 or 2.5 as shown in Figure 3.6, on-going calls are held over to the next slot, which results in poorer performance for the Slot Viewpoint compared to the Snapshot Analysis.

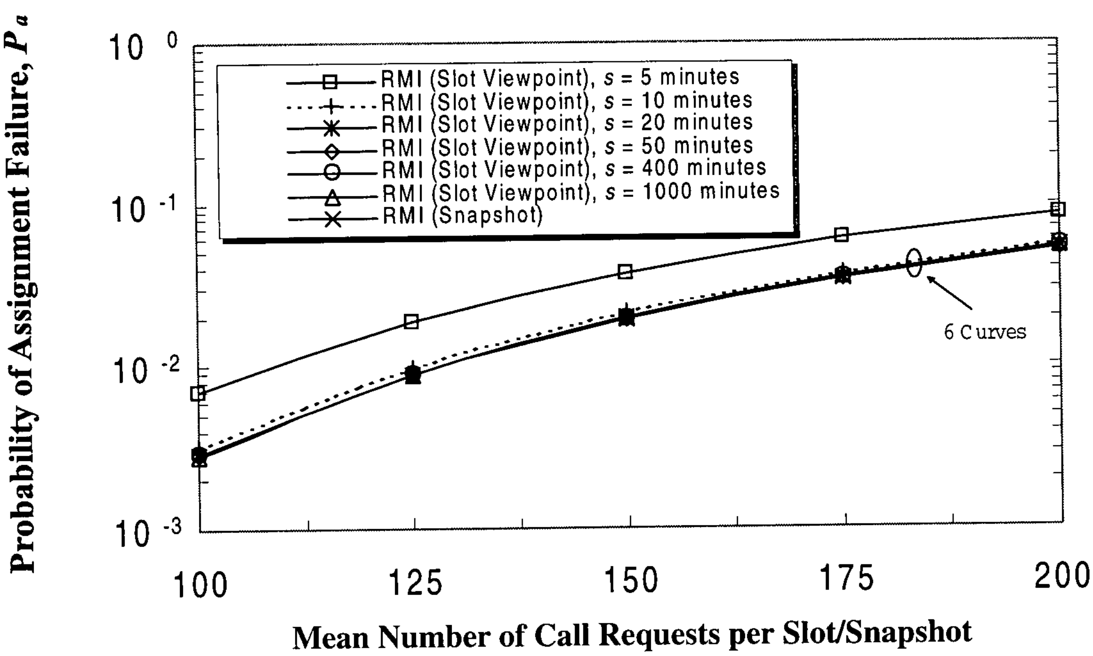


Figure 3.6: RMI Evaluated by Snapshot Analysis and Slot Viewpoint Analysis.

As the slot size decreases to zero, the Slot Viewpoint Analysis approaches traditional analysis. A call is served before the next call arrival.

Another performance measure has to be introduced because it is now necessary to consider calls which are dropped when a new channel assignment causes their SIR's to fall below the minimum threshold. The unsuccessful call probability, P_{us}, is given by

$$P_{us} = \frac{\text{Number of calls blocked + Number of calls dropped}}{\text{Total number of calls}}. \tag{3.10}$$

The mean call duration is assumed to be two minutes and the slot size s, is set to be 0.125 minutes. The unsuccessful call probability is a function of the offered traffic load (Erlangs/cell). Figure 3.7 shows the performance of RMI obtained using traditional analysis and the Slot Viewpoint Analysis. It can be seen that the two methods yield nearly identical performances. The Slot Viewpoint Analysis helps to clarify the relationship between the Snapshot Analysis and the traditional analysis.

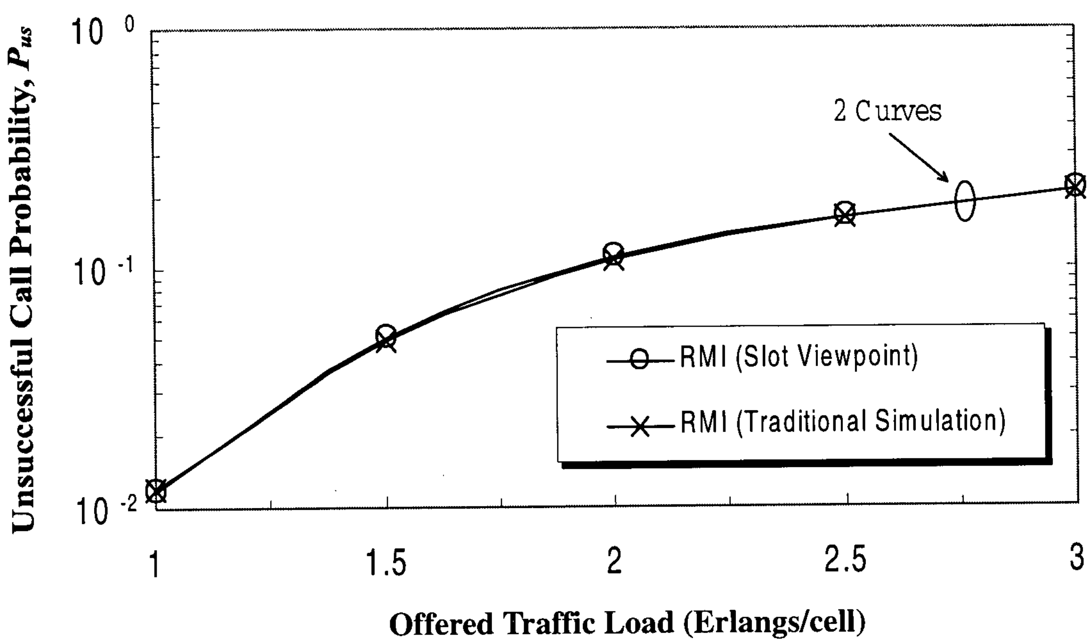


Figure 3.7: RMI Evaluated by Traditional Analysis and Slot Viewpoint Analysis.

In traditional analysis, the performance of a channel assignment scheme is usually plotted as a function of the mean arrival rate, λ_t. As λ_t increases, the unsuccessful call probability increases to one. On the other hand, in the Snapshot Analysis, the performance of a channel assignment scheme is usually plotted as a function of the mean number of call requests in a snapshot. The probability, P_a, of assignment failure depends on both λ_c and the number of cells. This makes the Snapshot Analysis incompatible with traditional analysis. The Slot Viewpoint Analysis introduces the slot concept: By varying the slot size s, different performances can be observed. It can be seen that the Snapshot Analysis and the traditional analysis represent two extreme cases, which can be bridged by the Slot Viewpoint Analysis.

The Snapshot Analysis cannot be used to approximate the results obtained by a traditional analysis, but it can indicate how effectively a channel is being reused in different channel assignment schemes. The Snapshot Analysis can be used to evaluate channel assignment schemes in a relative, but not an absolute, sense.

3.4 Summary

Two traditional analysis methods, the analytical approach and the computer simulation were reviewed. The Snapshot Analysis results for the Minimum Interference (MI) schemes were presented. The proposed approach to performance analysis, the Slot Viewpoint Analysis, can be used to unify the Snapshot Analysis and traditional analysis. It was argued why the Snapshot Analysis cannot replace a traditional analysis.

Chapter 4 Proposed Dynamic Channel Assignment Scheme

Distributed DCA schemes avoid the need for communicating a lot of information between the BS's and a central controller. However, a drawback is that each BS has no knowledge of MS's served by other BS's. New calls admitted to the system may cause excessive interference to existing co-channel links. With some interference information from its neighboring cells, the BS at a host cell (the cell in which a channel needs to be assigned) may be able to reduce the deterioration of the SIR's of MS's served by other BS's. This idea forms the basis of the proposed IA-DCA scheme, distributed MAXMIN with interference information (DMAXMIN_WI). Although it requires information exchanges among BS's, DMAXMIN_WI is distributed (or partially decentralized) because each BS is responsible for making individual channel assignment decisions.

A centralized MAXMIN scheme was developed in [6] to compare with the performances of various DDCA schemes. A central controller assigns a channel that maximizes the minimum of the SIR's of all existing calls that are being served by the system. DMAXMIN_WI is a new IA-DCA scheme, which employs this same channel assignment algorithm, but without using a central controller.

4.1 SIR Estimation

Consider a cellular system, with m BS's, serving n, $n < m$, calls on channel c. The link gain between BS i and MS j is denoted by g_{ij}. Assume that MS i is served by BS i and that the link gains are given by

$$g_{ij} = d_{ij}^{-\alpha} L_{ij} \tag{4.1}$$

where d_{ij} is the distance between BS i and MS j, α is the propagation loss exponent, and L_{ij} is the shadow fading factor which is lognormally distributed. The transmitted power, $P_{BS,c,k}$, on channel c from BS k is P_{BS} or 0 depending on whether BS k is using channel c or not. The downlink (BS to MS) received SIR, $\gamma_{down,c,k}$, on channel c at a currently served MS k is given by

$$\gamma_{down,c,k} = \frac{P_{BS} g_{kk}}{\sum_{l=1, l \neq k}^{m} P_{BS,c,l} g_{lk}}, \quad k = 1,\ldots,n. \tag{4.2}$$

The transmitted power, $P_{MS,c,k}$, on channel c from MS k is P_{MS} or 0 depending on whether MS k is using channel c or not. The uplink (MS to BS) received SIR, $\gamma_{up,c,k}$, on channel c at a currently serving BS k is given by

$$\gamma_{up,c,k} = \frac{P_{MS} g_{kk}}{\sum_{l=1, l \neq k}^{n} P_{MS,c,l} g_{kl}}, \quad k = 1,\ldots,m. \tag{4.3}$$

Each MS (BS) is capable of measuring the signal strength of its host BS (MS) via the control channels as well as the interference power on each channel in real-time so that it can determine the SIR on each channel. This is a reasonable assumption if the channels do not change rapidly with time.

4.2 DMAXMIN_WI Algorithm

In DMAXMIN_WI, interference information has to be sent from the interfering cell BS's to the host cell BS to assist in the channel assignment task. Consider the cellular layout shown in

Figure 4.1. Suppose that the BS in cell 21 has to assign a channel to a new call for MS **A**.

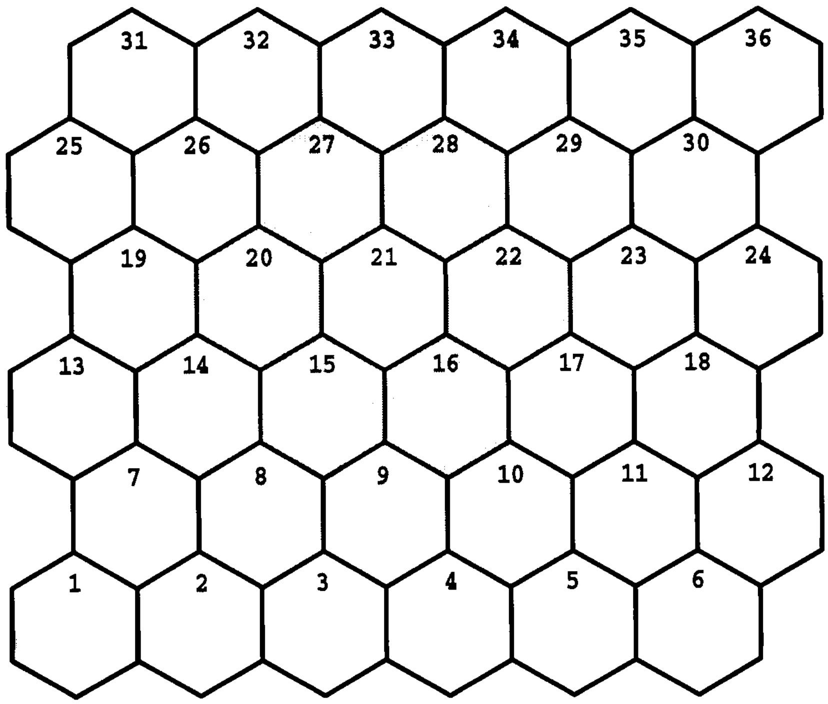


Figure 4.1: Cellular Layout with 36 Hexagonal Cells. The Shaded Cells are the Two-tier Interfering Neighbors of Cell 21.

For downlink channel assignment, MS **A** first measures the signal strength from its host BS **B**. After measuring the interfering power on each channel, MS **A** is able to obtain a set of candidate channels with SIR's above the call setup threshold. It then sends a list of the candidate channels to BS **B** which passes this information to its neighboring cells.

Each neighboring BS requests each of its MS's using one of the channels on the list to communicate back its predicted SIR assuming that BS **B** uses its channel. The predicted SIR, $\gamma_{pred,\, down,\, c,\, k}$, of an MS k using channel c can be calculated using

$$\gamma_{pred,\,down,\,c,\,k} = \frac{P_{BS}g_{kk}}{P_{BS}d_{hk}^{-\alpha} + \sum_{l=1,\,l\neq k}^{m} P_{BS,\,c,\,l}\,g_{lk}}, \quad k = 1,\ldots,n \tag{4.4}$$

where d_{hk} is the distance from the host BS **B** to MS k. It is assumed that each BS knows the locations of all other BS's in the service area. The calculation in (4.4) is just an estimate when shadow fading is present. After getting all the predicted SIR's from its MS's, each neighboring BS sends these values (the interference information) to BS **B**. After receiving the interference information from its neighboring cells, BS **B** determines the minimum predicted SIR value for each candidate channel. It then assigns the new call to the channel with the maximum of the minimum SIR values.

For uplink channel assignment, BS **B** has to inform its neighboring cells of the location of MS **A**. This location information could be obtained using the Global Positioning System (GPS). The predicted SIR, $\gamma_{pred,\,up,\,c,\,k}$, of a neighboring BS k using channel c can be calculated using

$$\gamma_{pred,\,up,\,c,\,k} = \frac{P_{MS}g_{kk}}{P_{MS}d_{kA}^{-\alpha} + \sum_{l=1,\,l\neq k}^{n} P_{MS,\,c,\,l}\,g_{kl}}, \quad k = 1,\ldots,m \tag{4.5}$$

where d_{kA} is the distance from BS k to MS **A**. The uplink channel is determined using the same algorithm once BS **B** receives the interference information from its neighboring cells. There is an alternative approach for the uplink channel assignment: If shadow fading is assumed to be highly correlated among different channels, each interfering BS of BS **B** might be able to measure the path loss from MS **A** while MS **A** is transmitting an access request to the network. One advantage is that the interference information will contain more accurate prediction of SIR's, which enhances the performance of the channel assignment algorithm. A disadvantage of such an approach is the possibility of 'collision' among several MS requests, which may prevent the interfering BS's from measuring the path loss.

4.3 Simulation Model and Performance Measures

The performance of DMAXMIN_WI is compared with those of existing channel assignment schemes using computer simulation. The simulation model used includes the cellular layout, the signal power propagation, the call arrival and call duration statistics. Several performance measures are defined to investigate the characteristics of different channel assignment schemes.

4.3.1 Cellular System Layout

In the computer simulation, a cellular layout with 36 hexagonal cells, as shown in Figure 4.1, is used. The layout is constructed in a way such that each of the six rows contains six hexagonal cells [13,14]. Each BS is located at the center of a cell and uses omni-directional antennas. In order to avoid edge effects (cells close to the edge of the system, which have fewer interfering cells, generally experience less co-channel interference than the inner cells), the layout is 'wrapped around' to form a torus [13,15], such that each cell is surrounded by 35 interfering cells. Simulation results are taken from all 36 cells.

For FCA, however, the 'wrap-around' method cannot generally be used due to the shape of the reuse cluster. Instead, the same cellular layout with no wrap-around is used. Cells close to the edge of the layout tend to receive less interference from their neighboring cells, which yields optimistic results. Therefore, results are obtained only from the central four cells which have a complete set of two-tier interfering cells (a total of 18 interfering cells) [14].

4.3.2 Call Arrival and Call Duration Models

In traditional performance analysis, the call arrivals are usually assumed to follow a Poisson distribution and are uniformly distributed over the service area. Two different call arrival models with non-uniform traffic distribution, as illustrated in Figure 4.6, are also used for completeness of the comparison. The call duration is assumed to be exponentially distributed. The offered traffic load, ρ (Erlangs/cell), is defined as

$$\rho = \frac{\lambda}{\mu} \tag{4.6}$$

where λ is the mean call arrival rate per cell and $\frac{1}{\mu}$ is the mean call duration.

4.3.3 Shadow Fading

In practice, the link gain, g_{ij} in (4.1), is difficult to predict due to the presence of fading. Fading can be classified as long-term shadow fading and short-term Rayleigh fading [1]. Shadow fading is mainly caused by terrain configuration and the man-built environment between the BS and the MS. The Rayleigh fading is the result of multipath reflections of a transmitted wave by local scatters surrounding a receiver. Rayleigh fading is usually considered as a wave interference phenomenon rather than a path loss effect. Only shadow fading is considered in the simulation.

The lognormally distributed, shadow fading factor in (4.1), L_{ij}, is given by [5]

$$L_{ij} = 10^{\frac{\sigma Z}{10}} \tag{4.7}$$

where $Z \sim N(0,1)$ is a zero mean, unit variance Gaussian random variable and σ is the standard deviation for shadow fading. The random variable Z can be generated using the Box-Muller method from two random variables, U_1 and U_2, uniformly distributed in [0,1], using one of the following [25]

$$Z = \sqrt{-2\ln U_1}\cos(2\pi U_2) \tag{4.8}$$

or

$$Z = \sqrt{-2\ln U_1}\sin(2\pi U_2). \tag{4.9}$$

As a result, L_{ij}, a lognormally distributed random variable with zero mean value and standard deviation σ (in dB) is given by

$$L_{ij(dB)} = 10\log_{10}L_{ij} = \sigma Z \sim N(0, \sigma^2) \tag{4.10}$$

$$L_{ij} = 10^{\frac{L_{ij(dB)}}{10}} = 10^{\frac{\sigma Z}{10}}. \tag{4.11}$$

4.3.4 Performance Measures

Carefully selected performance measures have to be used to evaluate the effectiveness of a channel assignment scheme. Blocking probability as a function of offered traffic load is often used in telephony networks. Since call drops occur more frequently with the measurement-based DDCA schemes than the cell-based channel assignment schemes [17], dropping probability has to be considered at the same time. The unsuccessful call probability [15] was introduced to account for the aggregate effect of both call blocking and dropping. For most users, a dropped call is usually considered to be more annoying than a blocked call; the Grade of Service (GOS) allows different weights to be assigned to dropped and blocked calls. The definitions of the four performance measures are given below:

(1) Blocking probability, P_b, is the probability that a new call is not assigned a channel and is given by

$$P_b = \frac{\text{Number of new calls blocked}}{\text{Total number of calls generated}}. \tag{4.12}$$

(2) Dropping probability, P_d, is the probability that a non-blocked call is not assigned another channel when the SIR on its current channel falls below the minimum SIR threshold. This means that the call is dropped, i.e. prematurely terminated by the serving BS. P_d is given by

$$P_d = \frac{\text{Number of reassignment failures}}{\text{Total number of non-blocked calls}}. \tag{4.13}$$

(3) Unsuccessful call probability, P_u, is the probability that a call is either blocked or dropped and is given by

$$\begin{aligned} P_u &= \frac{\text{Number of blocked or dropped calls}}{\text{Total number of calls generated}} \\ &= P_b + P_d(1 - P_b). \end{aligned} \tag{4.14}$$

(4) Grade of service (GOS) is defined as [24]

$$GOS = (1 - \alpha)P_b + \alpha P_d \tag{4.15}$$

where $\alpha \in [0,1]$ is the GOS parameter that determines the relative importance of P_b and P_d.

4.3.5 Assumptions

The simulation model is based on the following assumptions:

- There is a total of 70 (non-interfering) channels in the system. Thermal noise is negligible.
- Call arrivals follow a Poisson distribution and are uniformly distributed over the service area. The call duration is exponentially distributed, with a mean of two minutes.
- The propagation loss exponent, α, is chosen to be 3.5 and the standard deviation for shadow fading is 6 dB.
- An MS chooses as its host the BS with the strongest received signal strength. The movement of an MS during a call is negligible compared to the cell size.
- All BS (MS) transmissions are of equal power. No power control is incorporated into the assignment schemes.
- The minimum SIR threshold for a call to yield an acceptable quality is 10 dB. When the SIR falls below 10 dB during the call, a maximum of five intra-cell reassignments per call is allowed. After five reassignments, a call is dropped if its SIR is still below the minimum SIR threshold. The same algorithm, as for call setup, is used for reassignment. It is assumed that the reassignments are carried out fast enough, so that reassignments occur only between two successive call arrivals.

- The call setup SIR threshold is a parameter which has a substantial effect on the performance. For DMAXMIN_WI, a new call is blocked if no channel with an SIR greater than 12 dB can be found. ARP with different call setup thresholds (16 dB, 19 dB, 22 dB, and 25 dB) was simulated to illustrate the effect of changing this parameter. In FCA, a call is admitted if its SIR is above 10 dB. Blocked calls are removed from the system.

- In DMAXMIN_WI, interference information is obtained only from the two-tier neighboring cells around the host cell because co-channel users in these cells are the most likely to be affected by the new assignment in the host cell.

- For FCA, a cluster size of seven is chosen so that a set of ten nominal channels is available in each cell. In FCA, a search for an acceptable channel from the nominal set which proceeds in a sequential manner from the same starting point yields a poor performance. This is because BS's which share the same set of nominal channels will tend to use the first few channels from the set more often, causing unnecessary call drops. In the simulation, each BS starts its channel search with a randomly selected channel.

4.4 Simulation Results and Discussions

The comparison between DMAXMIN_WI and other channel assignment schemes is performed for uniform as well as non-uniform traffic distributions. Both downlink and uplink transmissions are considered.

4.4.1 Uniform Traffic Distribution

The blocking probabilities with FCA, ARP and DMAXMIN_WI are shown in Figure 4.2. An approximation to the blocking probability, P_b, of FCA, using the Erlang B formula, is also shown. The Erlang B formula approximates P_b of a cell-based FCA closely as all channels in the nominal set are free to be assigned while they are idle. It is shown in [1] that for a cell-based FCA with an N-cell reuse pattern and a propagation loss exponent α, the worst SIR γ_{worst} of an on-going call can be approximated by

$$\gamma_{worst} = 10\log\frac{(3N)^{\alpha/2}}{6}. \tag{4.16}$$

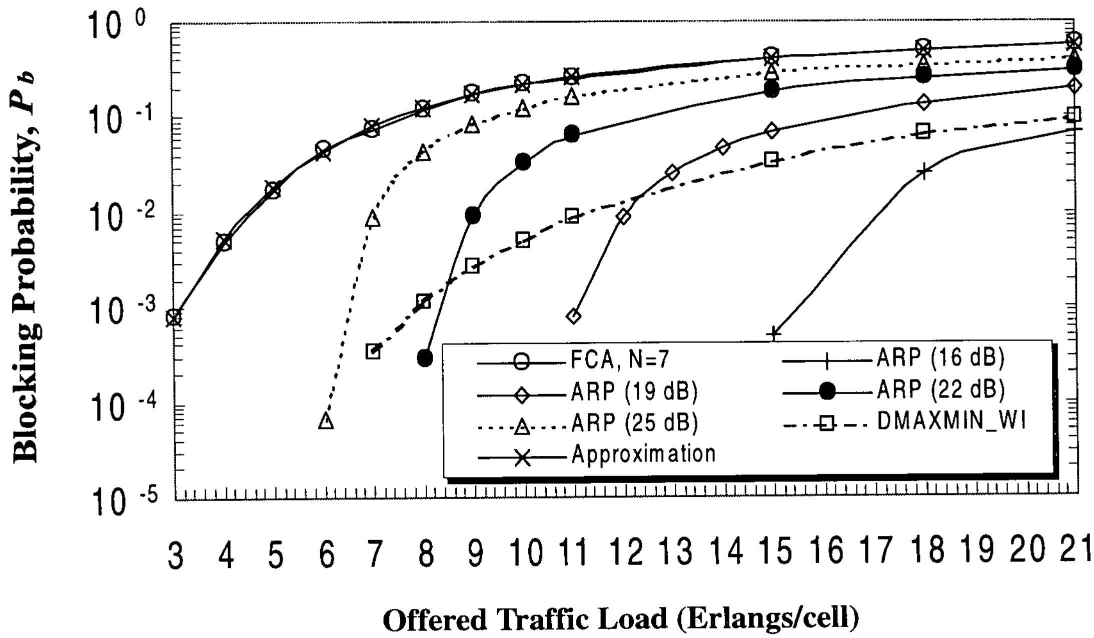
For $N = 7$ and $\alpha = 3.5$, the approximated SIR is 15.36 dB, which is about 5 dB higher than the minimum SIR threshold (10 dB) used in the simulation; this explains the close agreement between P_b for the Erlang B approximation and that of the measurement-based FCA.

Consider the downlink transmission as shown in Figure 4.2a. For $P_b = 10^{-2}$, the carried traffic for FCA, ARP (25 dB, 22 dB, 19 dB, 16 dB) and DMAXMIN_WI are 4.5, 7, 9, 12.1, 17.2, and 11.4 Erlangs respectively. The traffic handling capacities of ARP (16 dB) and DMAXMIN_WI are 3.8 times and 2.5 times as high as that of FCA. For DMAXMIN_WI, the call setup threshold is 2 dB above the minimum threshold; if the call setup threshold is too high, interference information would be used inefficiently as most calls are blocked.

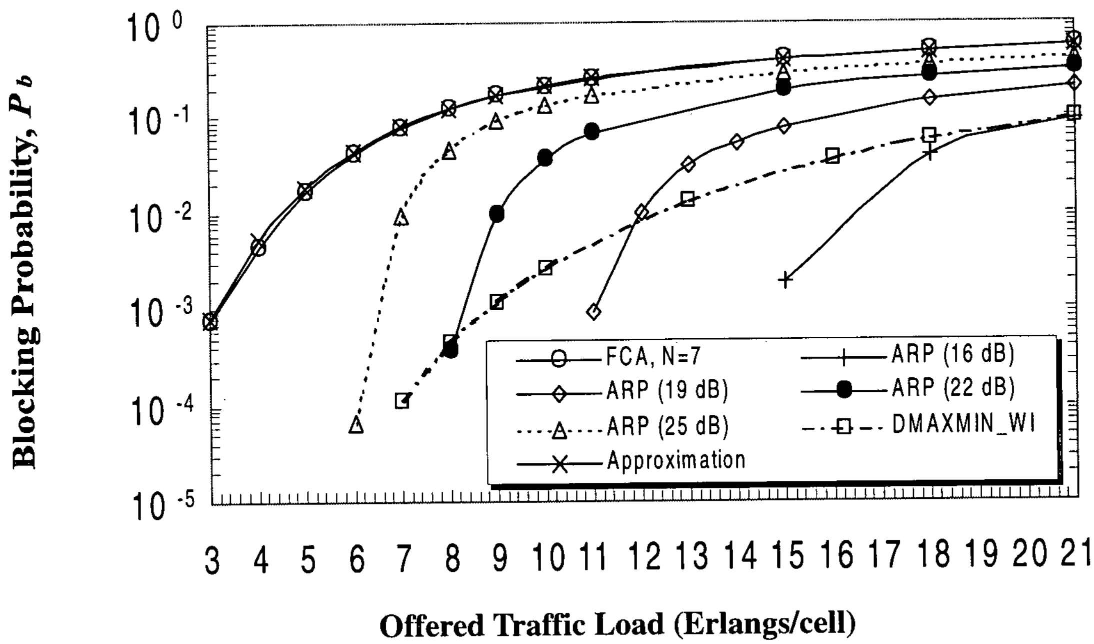
In Figure 4.2b, similar results can be observed in the uplink transmission. For $P_b = 10^{-2}$, the carried traffic for FCA, ARP (25 dB, 22 dB, 19 dB, 16dB) and DMAXMIN_WI are 4.6, 7, 9, 12, 16.5, and 12.4 Erlangs respectively. DMAXMIN_WI supports 2.7 times the traffic of FCA. In

DCA, each BS has potential access to seven times more channels than in FCA; this explains the much lower P_b when the carried traffic is low.

ARP with call setup threshold equal to 16 dB gives the lowest P_b, followed by 19 dB, 22 dB, and 25 dB. At a traffic load of 21 Erlangs, the blocking probabilities are 7%, 20%, 31%, and 41% for ARP 16dB, 19 dB, 22 dB, and 25 dB respectively in the downlink transmission. DMAXMIN_WI performs better than ARP 19 dB under the uniform traffic distribution when the offered traffic load is above 12 Erlangs. Similar observations hold for the uplink transmission. For DMAXMIN_WI, the uplink transmission tends to have better P_b than the downlink transmission at low traffic loads. At a traffic load of 7 Erlangs, P_b for the downlink channel is three times that for the uplink.



(a)



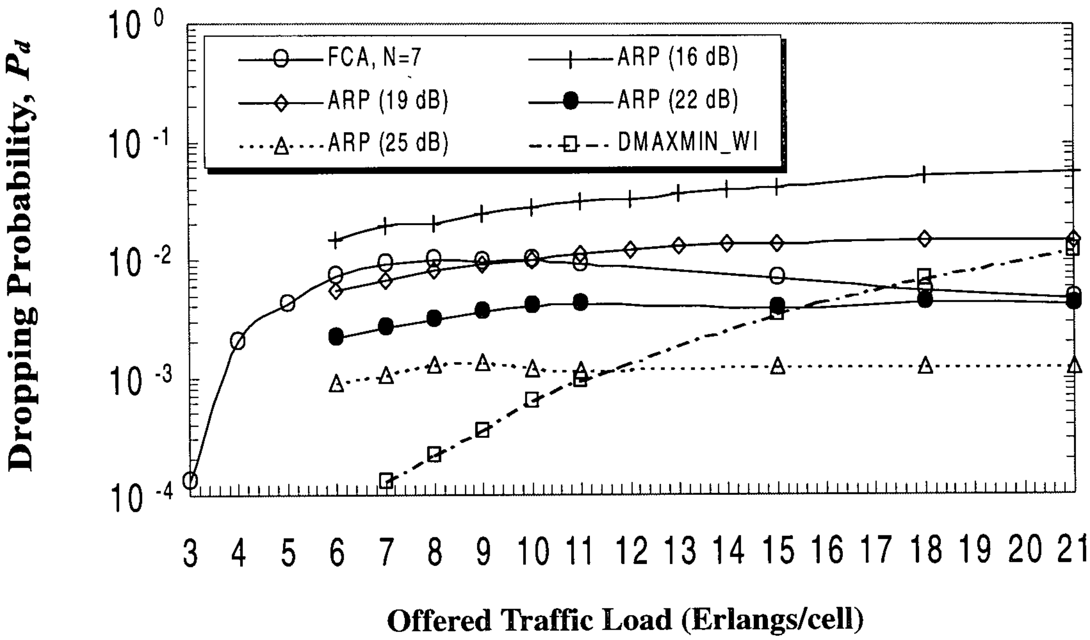
(b)

Figure 4.2: Call Blocking Probability, P_b, with Uniform Traffic Distribution. (a) Downlink Transmission, (b) Uplink Transmission.

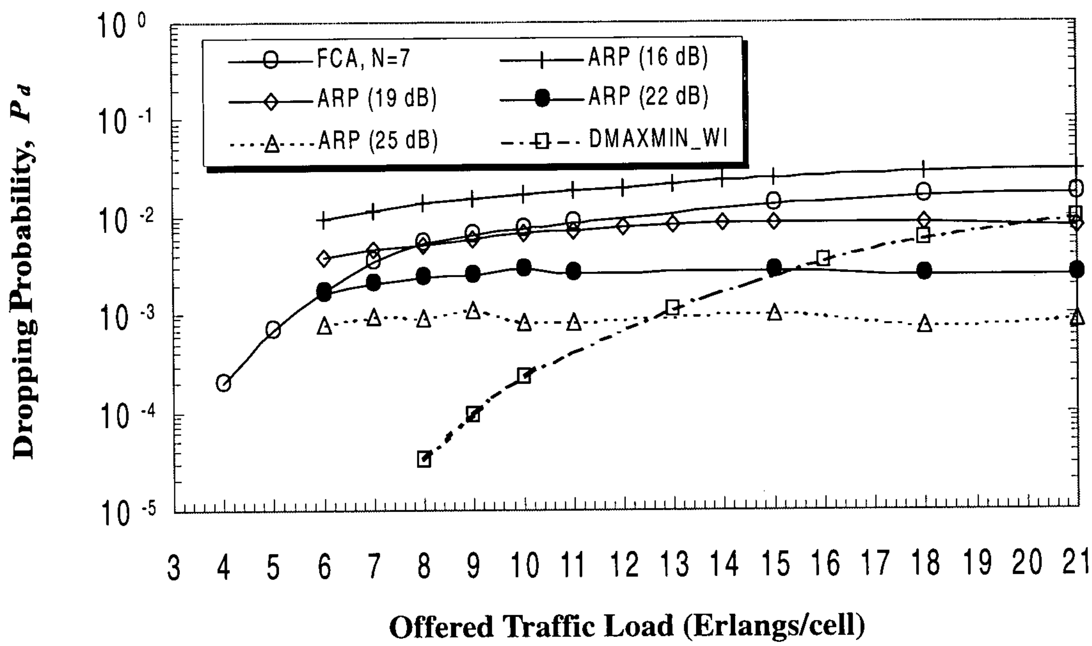
The dropping probabilities for the three channel assignment schemes are shown in Figure 4.3. For downlink transmission, at a traffic load of 8 Erlangs, the dropping probabilities are 0.9%, 2%, 1%, 0.3%, 0.1% and 0.02% for FCA, ARP (16 dB, 19 dB, 22 dB, 25 dB), and DMAXMIN_WI respectively. For uplink transmission, at the same traffic load, the corresponding dropping probabilities are 0.5%, 1.4%, 0.5%, 0.2%, 0.09%, 0.003%.

The probability, P_d, of dropping for FCA is the highest for a traffic load of about 7 Erlangs. This is because when the traffic load increases further, almost all nominal channels in each BS are used and P_b is high. An admitted new call will tend to have a strong signal strength which results in a lower P_d. With interference information, DMAXMIN_WI is able to assign a channel so as to minimize the interference to the co-channel users located in the two-tier neighboring cells. Co-channel users are less likely to be dropped in the future as the poorest SIR after the current assignment is maximized.

Although P_b for ARP (16 dB) is lower than that for DMAXMIN_WI even at high traffic loads, its P_d is even worse than that for FCA. At high traffic loads, P_d for DMAXMIN_WI increases rapidly due to the low call setup threshold (12 dB). A newly admitted call can result in the dropping of several existing calls.



(a)



(b)

Figure 4.3: Call Dropping Probability, P_d, with Uniform Traffic Distribution. (a) Downlink Transmission, (b) Uplink Transmission.

Generally, there is a trade-off between the goals of achieving a low P_b and a low P_d. ARP with a low call setup threshold admits more new calls into the system (i.e. a lower P_b); however, those calls can cause excessive interference to co-channel users which results in a high P_d. In order to investigate the combined effect of both blocking and dropping probabilities, the unsuccessful call probability, P_u, is plotted in Figure 4.4. At $P_u = 10^{-2}$, the traffic loads supported by FCA, ARP (25 dB, 22 dB, 19 dB) and DMAXMIN_WI are 4.4, 7, 8.8, 10.8, and 11 Erlangs respectively for downlink transmission. The traffic handling capacity of DMAXMIN_WI is 2.5 times as high as that of FCA. For traffic loads below 15 Erlangs, ARP (16 dB) has virtually no call blocking. Its P_u, which is the same as its P_d, is always worse than the P_u of DMAXMIN_WI. If the call setup threshold of ARP is set lower than 16 dB, more calls are admitted to the system even at high traffic loads. It is expected that the increase in P_d will result in an P_u which is even worse than that of ARP (16 dB). Higher call setup thresholds (19 dB, 22 dB, 25dB) lead to higher P_u because of the higher P_b values. For uplink transmission, at $P_u = 10^{-2}$, the traffic loads supported by FCA, ARP (25 dB, 22 dB, 19 dB, 16 dB) and DMAXMIN_WI are 4.5, 7, 8.9, 11.3, 6.5, and 12.4 Erlangs respectively.

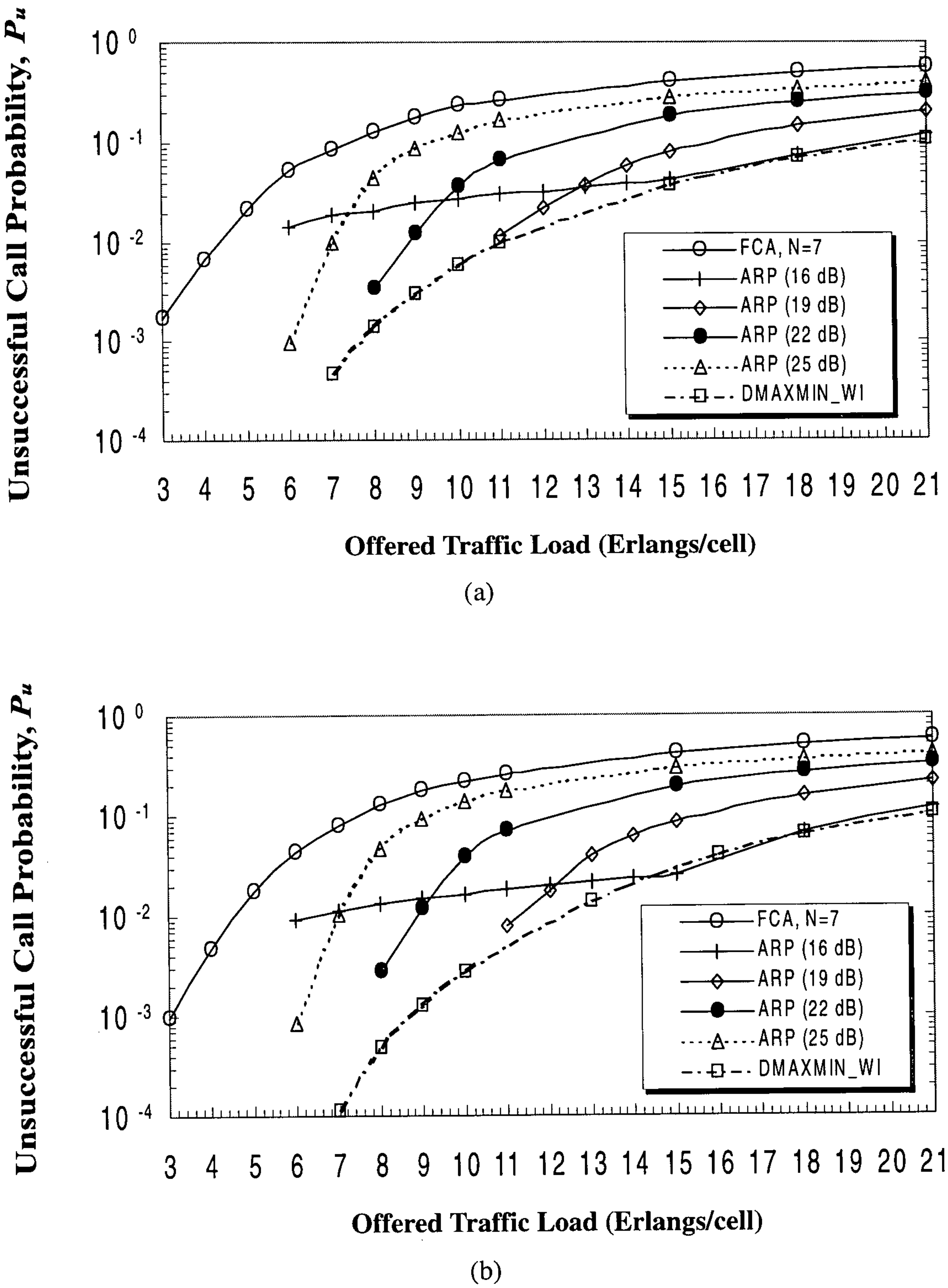
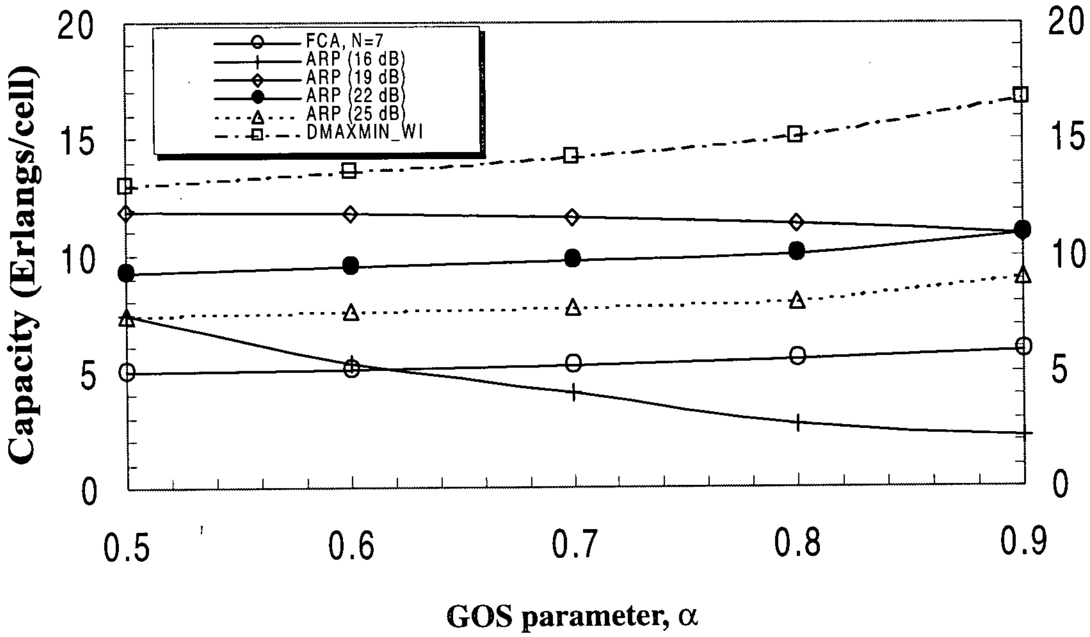
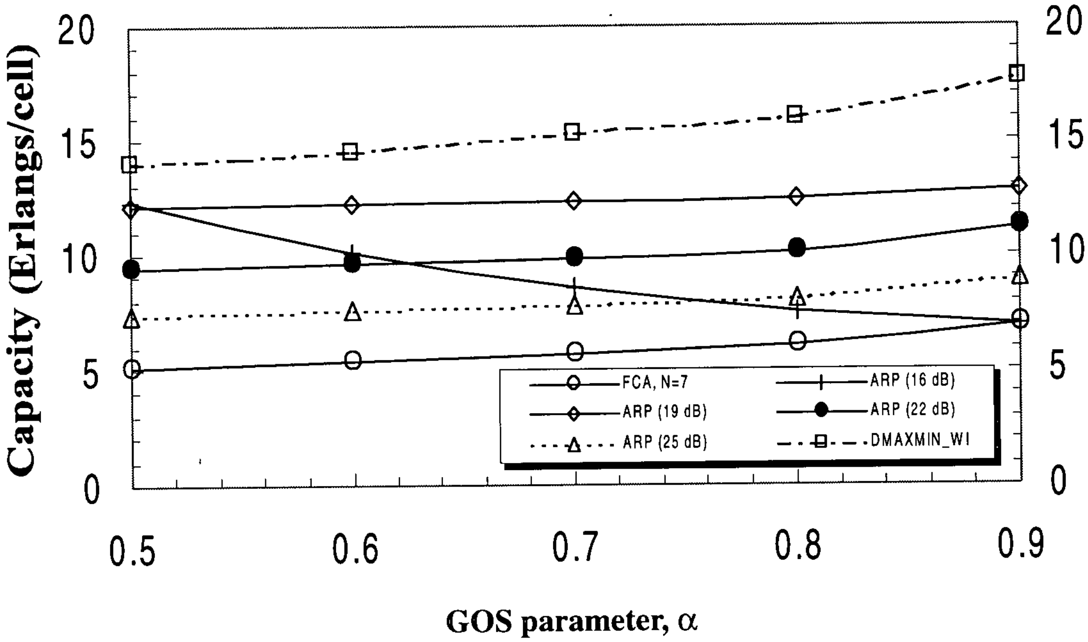


Figure 4.4: Unsuccessful Call Probability, P_u, with Uniform Traffic Distribution. (a) Downlink Transmission, (b) Uplink Transmission.



(a)



(b)

Figure 4.5: Capacity of Different Assignment Schemes at GOS = 10^{-2}, with Uniform Traffic Distribution. (a) Downlink Transmission, (b) Uplink Transmission.

Figure 4.5 shows the capacities of the three schemes at GOS = 10^{-2}. The range of α is chosen such that GOS always weighs a dropped call more than a blocked call. For the range of α values shown, DMAXMIN_WI yields the highest capacity, while FCA and ARP (16 dB) support the lowest. Capacity supported by ARP (16 dB) decreases rapidly with α because its P_d is relatively high when compared to other assignment schemes. For $\alpha = 0.9$, the capacity improvements for DMAXMIN_WI over ARP (25 dB, 22 dB, 19 dB, 16 dB) and FCA are about 85%, 50%, 50%, 650%, 200% (downlink transmission) and 100%, 60%, 40%, 150%, 150% (uplink transmission) respectively. The proposed DMAXMIN_WI scheme thus provides a substantial performance improvement over the other two assignment schemes for uniform traffic distribution.

4.4.2 Non-uniform Traffic Distribution

Over the service area of a cellular system, some places, such as the urban areas, generally have a higher demand for cellular services. In such a case, the traffic distribution may be non-uniform. Since DMAXMIN_WI has the best overall performance under a uniform traffic distribution, it is of interest to study how well it performs under non-uniform traffic distributions.

Two traffic distribution patterns **A** and **B** are used to examine the performance of DMAXMIN_WI. Figure 4.6 shows the two scenarios where the number in each cell represents the Poisson call arrival rate (calls/hour). The two traffic distribution patterns are subsets of the non-uniform traffic distribution for 49-cell patterns used in [26,27]. Since a different model is used in this thesis, the call arrival rates are set to be three times the values used in [26,27].

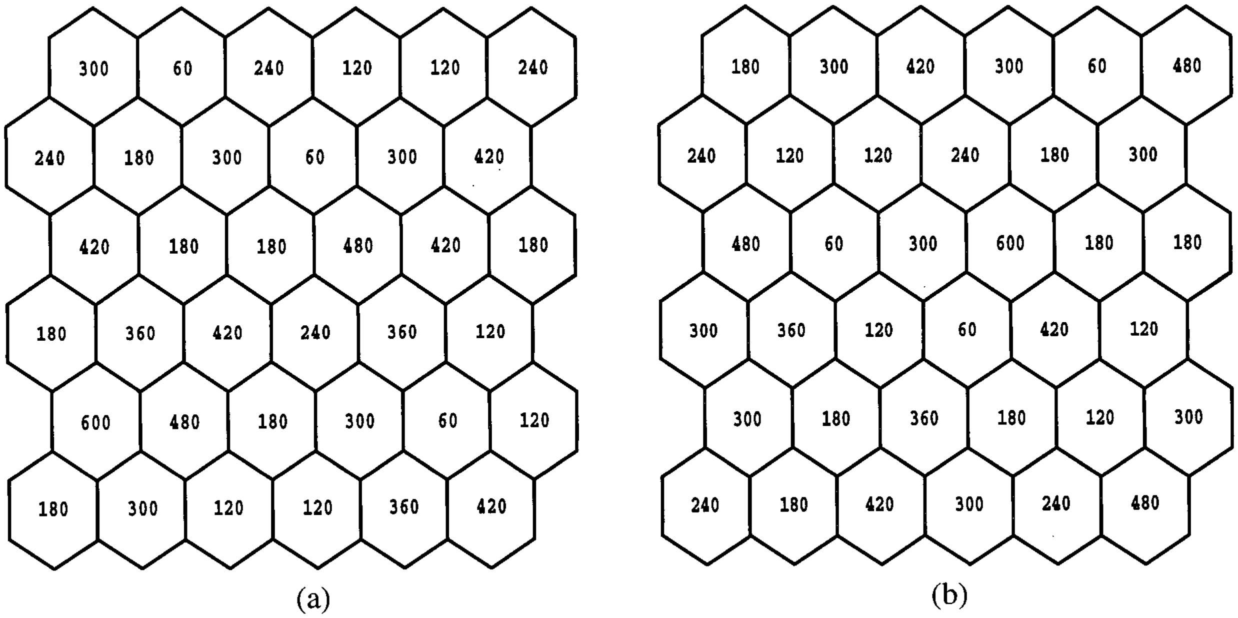
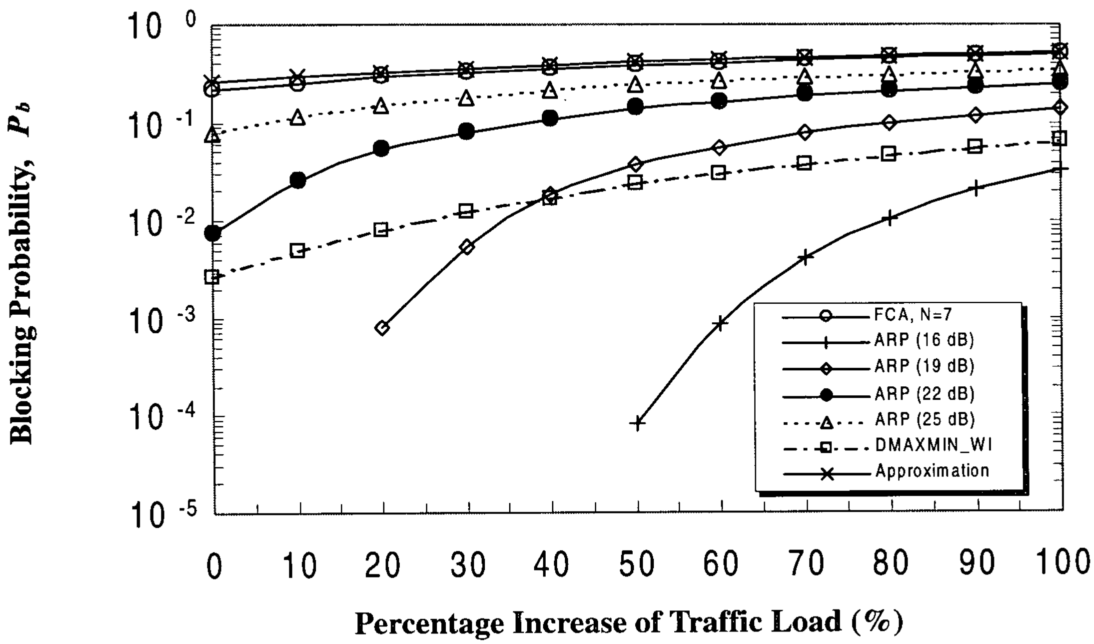
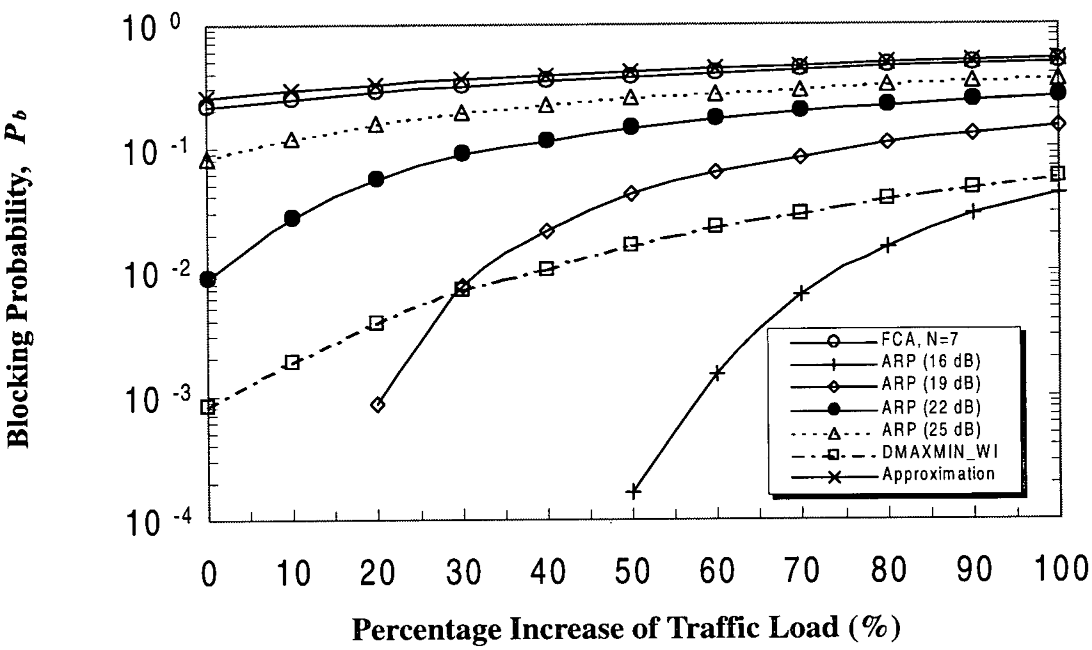


Figure 4.6: Non-uniform Traffic Distribution (calls/hour). (a) Traffic Distribution Pattern **A**, (b) Traffic Distribution Pattern **B**.

The call arrival rates range from 60 to 600 calls/hour. For pattern **A**, the total call arrival rate is 9360 calls/hour. With a mean call duration of two minutes, the corresponding traffic load to the whole system is 312 Erlangs. This traffic load is referred to as the base load for **A**. For pattern **B**, the total call arrival rate is 9420 calls/hour, which represents a base load of 314 Erlangs. The performance of DMAXMIN_WI and the other channel assignment schemes are simulated by increasing the traffic load from 0 to 100 percent over the base load. Figures 4.7 to 4.9 show the call blocking, call dropping and unsuccessful call probabilities of the three channel assignment schemes with traffic pattern **A**.

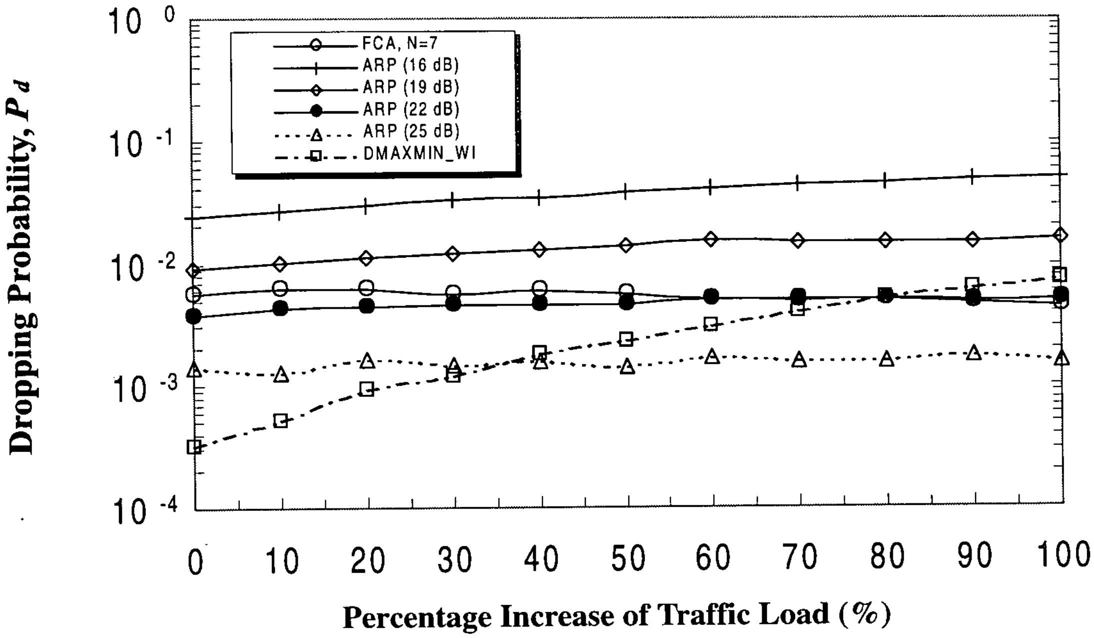


(a)

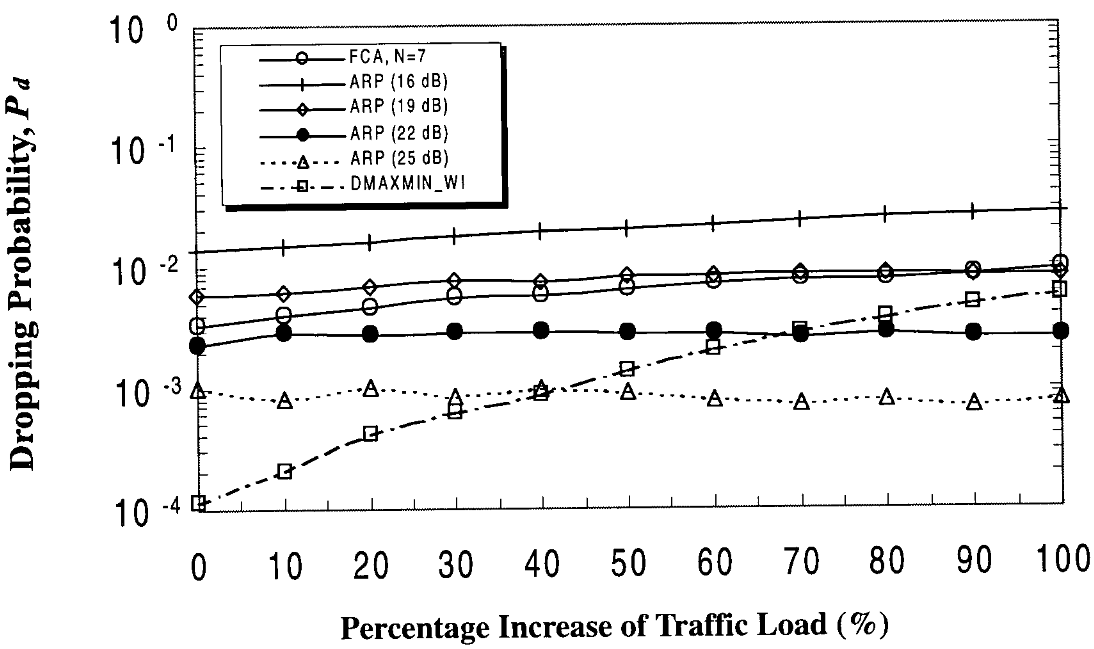


(b)

Figure 4.7: Call Blocking Probability, P_b, with Traffic Distribution Pattern **A**. (a) Downlink Transmission, (b) Uplink Transmission.

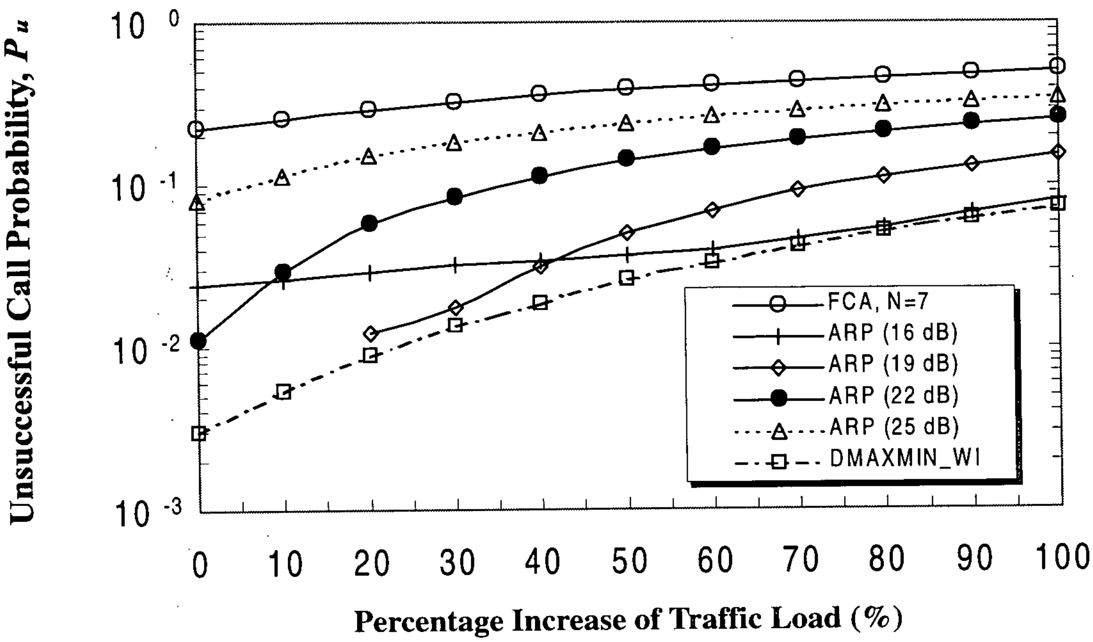


(a)

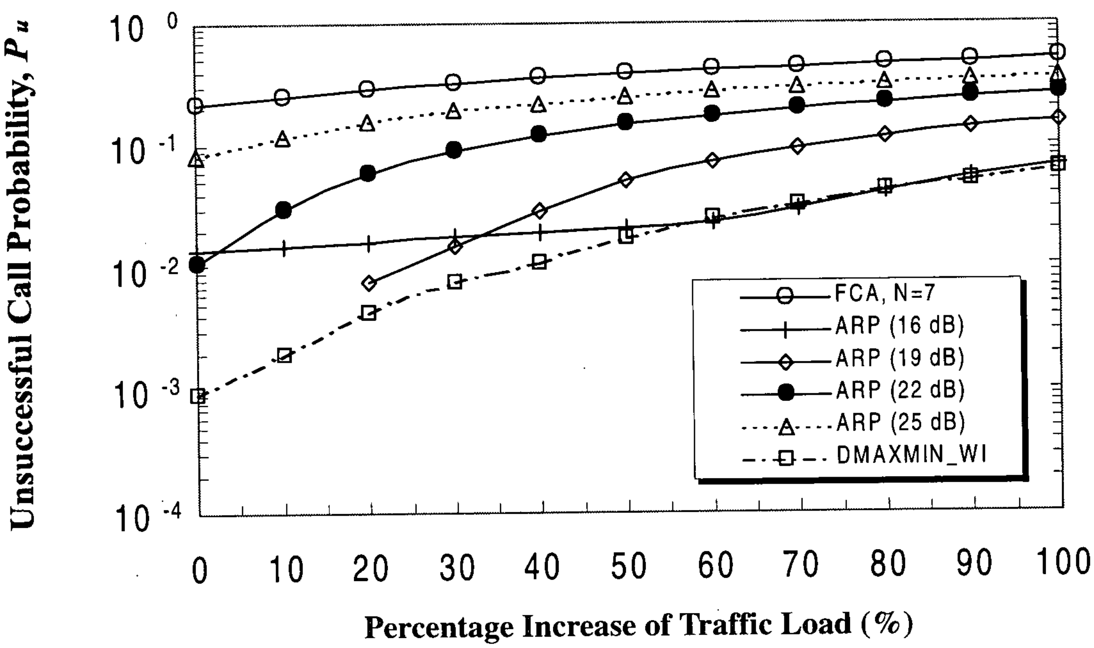


(b)

Figure 4.8: Call Dropping Probability, P_d, with Traffic Distribution Pattern **A**. (a) Downlink Transmission, (b) Uplink Transmission.



(a)



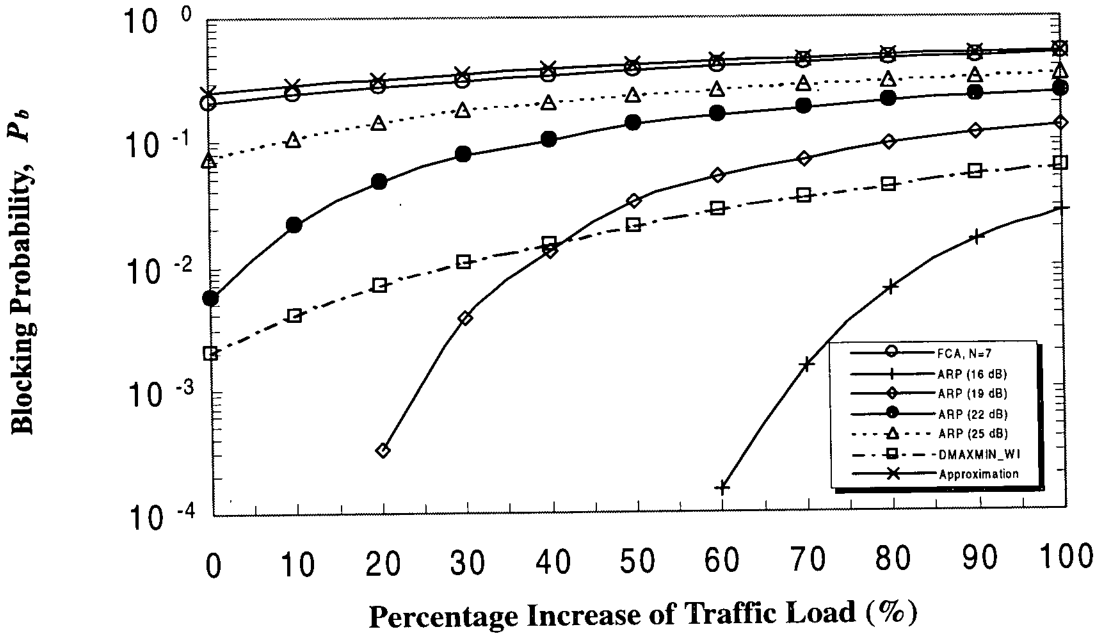
(b)

Figure 4.9: Unsuccessful Call Probability, P_u, with Traffic Distribution Pattern **A**. (a) Downlink Transmission, (b) Uplink Transmission.

In Figure 4.7, the call blocking probability P_b for a cell-based FCA is approximated by using the Erlang B formula. The overall call blocking probability of the system is a weighted-average of the call blocking probability in each cell; this approximation is used to compare with the simulation results for the measurement-based FCA as shown. For both downlink and uplink transmissions, the FCA simulation results are slightly better than the approximate curves at low traffic loads because the approximation assumes blocking probabilities from all cells are statistically independent. The relative performances of the channel assignment schemes with non-uniform traffic distribution are similar to those with uniform traffic distribution: The results show that at high traffic loads (> 40% increase of the base load), ARP (16 dB) gives the lowest P_b, followed by DMAXMIN_WI, ARP (19 dB, 22 dB, 25 dB) and the FCA schemes. In Figure 4.7a, when the traffic is 100% over the base load, the blocking probabilities are 7%, 3%, 14%, 25%, 35% and 50% for DMAXMIN_WI, ARP (16 dB, 19 dB, 22 dB, 25 dB) and the FCA schemes respectively.

The dropping probabilities for the three channel assignment schemes are plotted in Figure 4.8. ARP (16 dB) performs the worst because of its relatively low call setup threshold. ARP with call setup threshold less than 16 dB is expected to have even worse P_d. It can be seen that a lower P_d (ARP 25 dB) will result in a higher P_b. For traffic less than 40% of the base load, DMAXMIN_WI outperforms both ARP and FCA in terms of P_d.

Figure 4.9 shows that DMAXMIN_WI has the lowest unsuccessful call probability. Under heavy traffic conditions (> 60% of the base load), 16 dB is the best call setup threshold for ARP as shown.



(a)

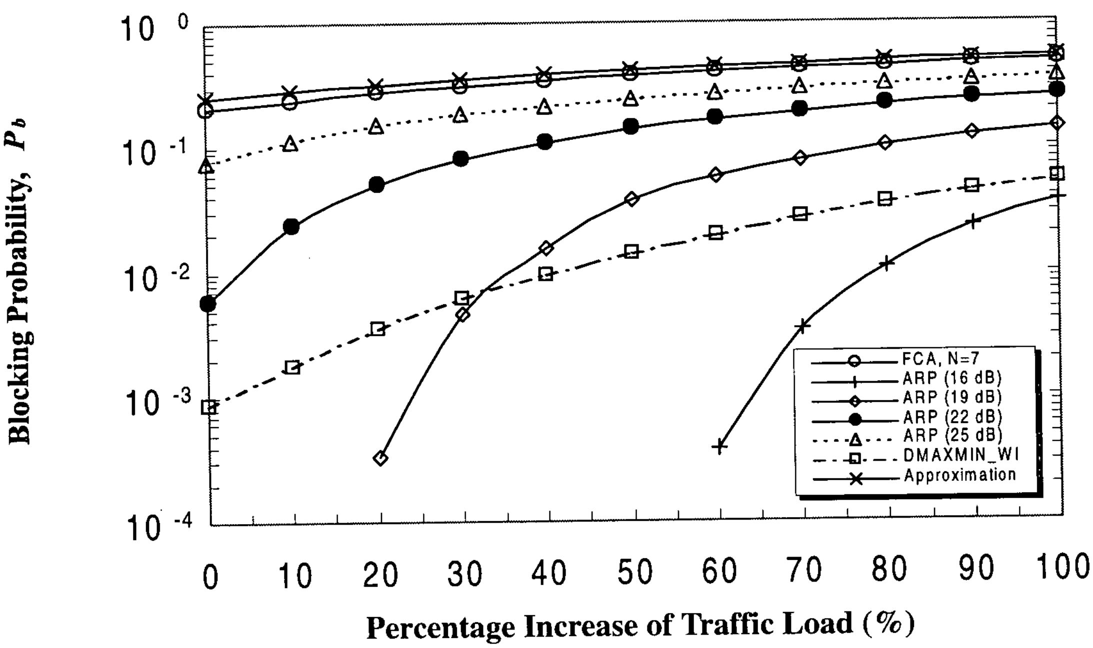


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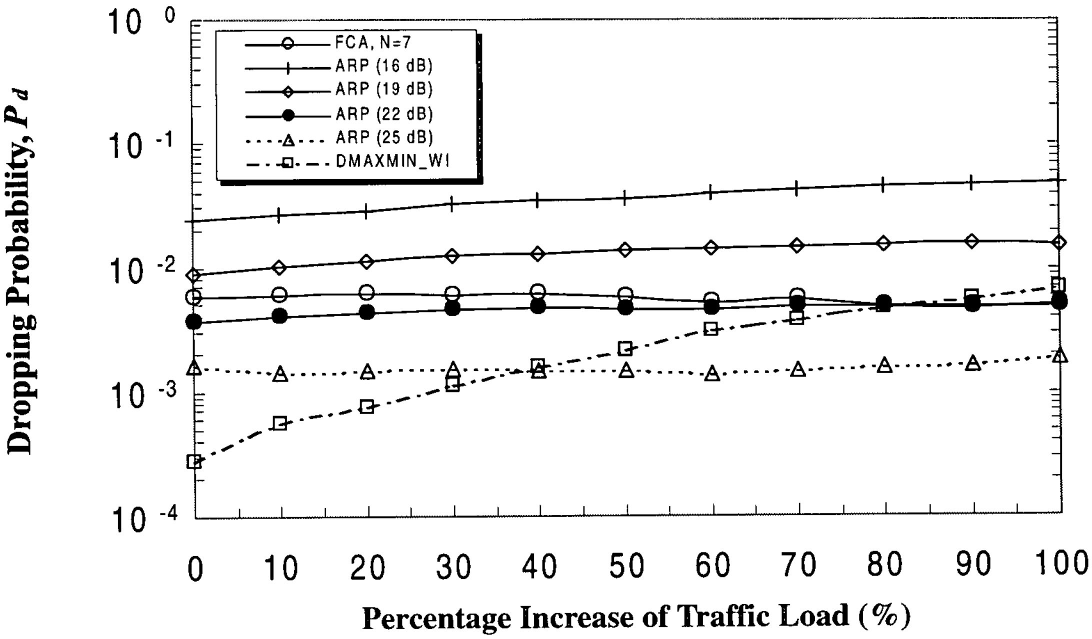
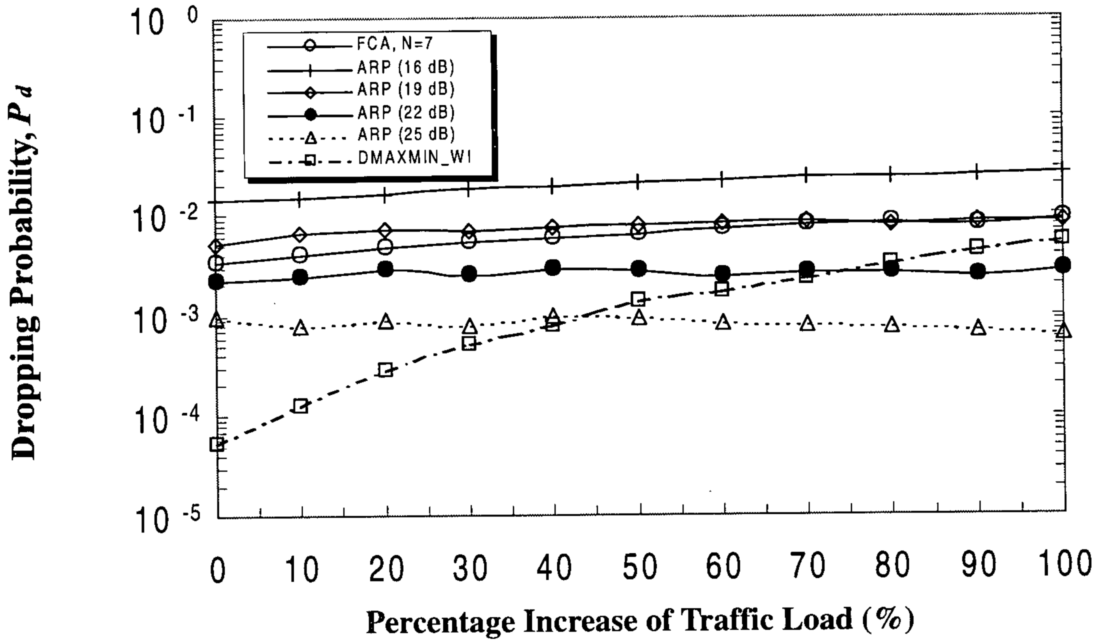
Figure 4.10: Call Blocking Probability, P_b, with Traffic Distribution Pattern **B**. (a) Downlink Transmission, (b) Uplink Transmission.

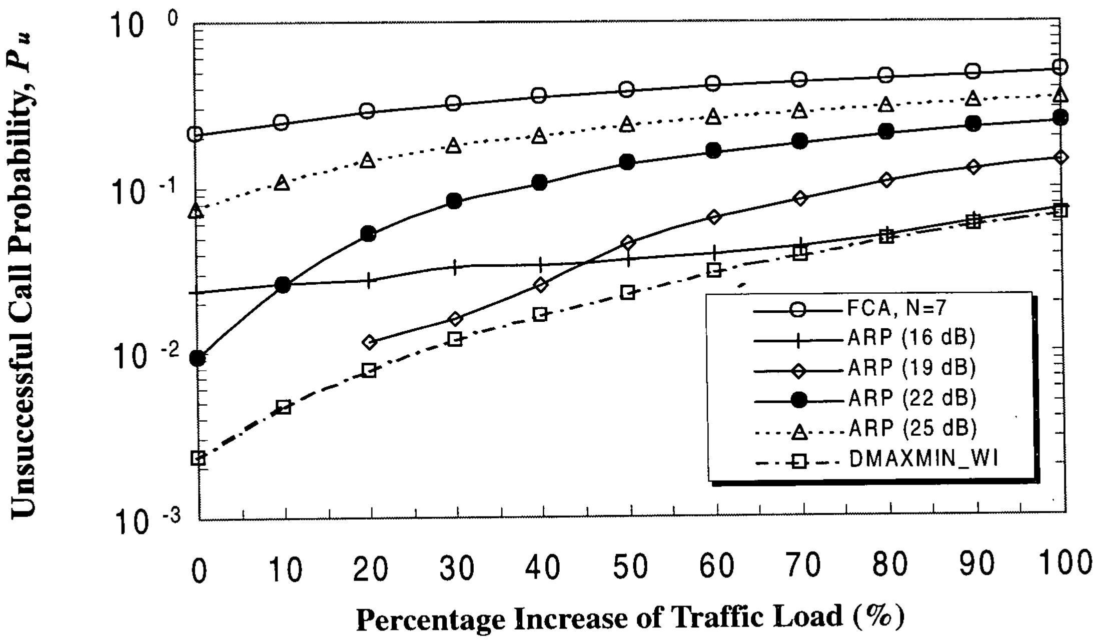


(a)

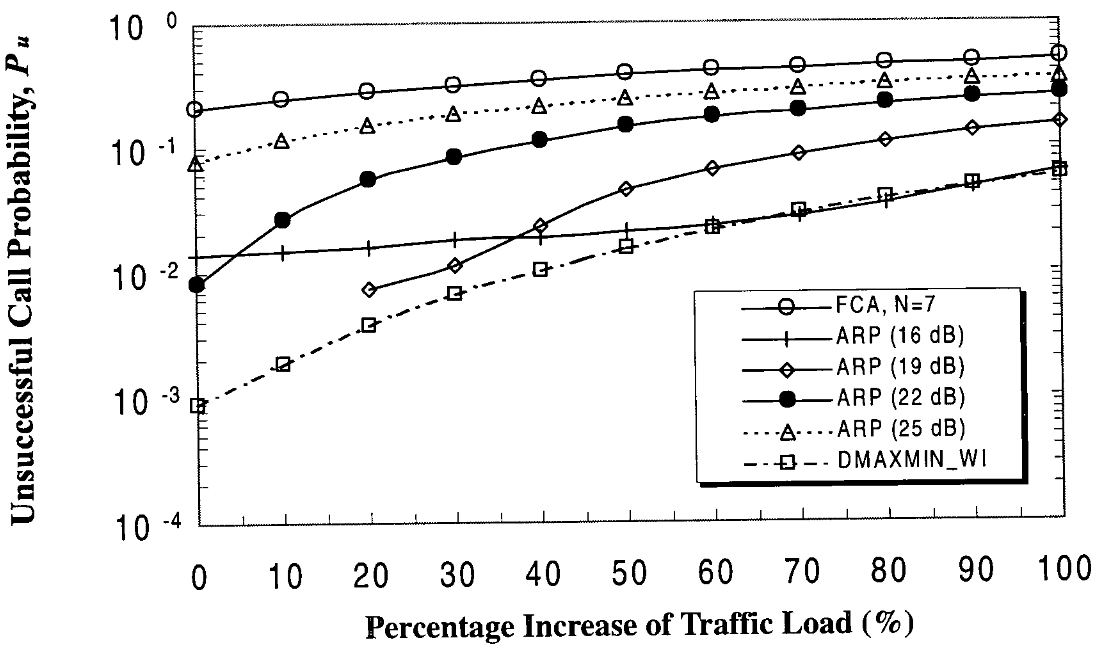


(b)

Figure 4.11: Call Dropping Probability, P_d, with Traffic Distribution Pattern **B**. (a) Downlink Transmission, (b) Uplink Transmission.



(a)



(b)

Figure 4.12: Unsuccessful Call Probability, P_u, with Traffic Distribution Pattern **B**. (a) Downlink Transmission, (b) Uplink Transmission.

Figures 4.10 to 4.12 show the call blocking, call dropping and unsuccessful call probabilities of the three channel assignment schemes with traffic pattern **B**. DMAXMIN_WI performs better than all other schemes except ARP (16 dB) in terms of P_b. However, ARP (16 dB) has a higher unsuccessful call probability than DMAXMIN_WI. Hence, the proposed DMAXMIN_WI scheme has the best overall performance when compared with the other channel assignment schemes for both uniform and non-uniform traffic distributions.

4.5 Summary

A new dynamic channel assignment scheme, distributed MAXMIN with interference information (DMAXMIN_WI), was presented. The proposed scheme can be applied to both downlink and uplink transmissions. With interference information from neighboring BS's, a BS is capable of assigning a channel to a new call, which causes the least impact on on-going calls using the same channel. Computer simulation was used to compare the performances of the proposed scheme and other previously studied channel assignment schemes. Blocking and dropping probabilities, unsuccessful call probability, and grade of service were investigated. DMAXMIN_WI was shown to outperform conventional FCA as well as ARP for both uniform and non-uniform traffic distributions.

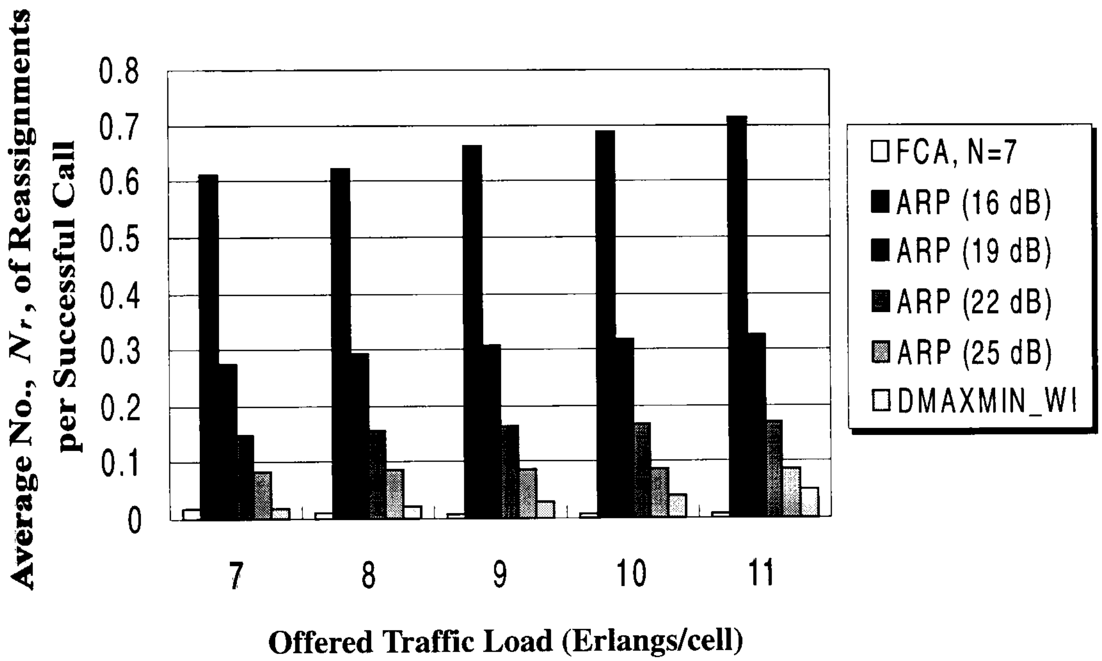
Chapter 5 Further Investigations of the Proposed Channel Assignment Scheme

The proposed channel assignment scheme, distributed MAXMIN with interference information (DMAXMIN_WI), has a better call blocking and dropping performance than the other channel assignment schemes (FCA and ARP) as shown in Chapter 4. In this chapter, a number of other issues related to DMAXMIN_WI are investigated:

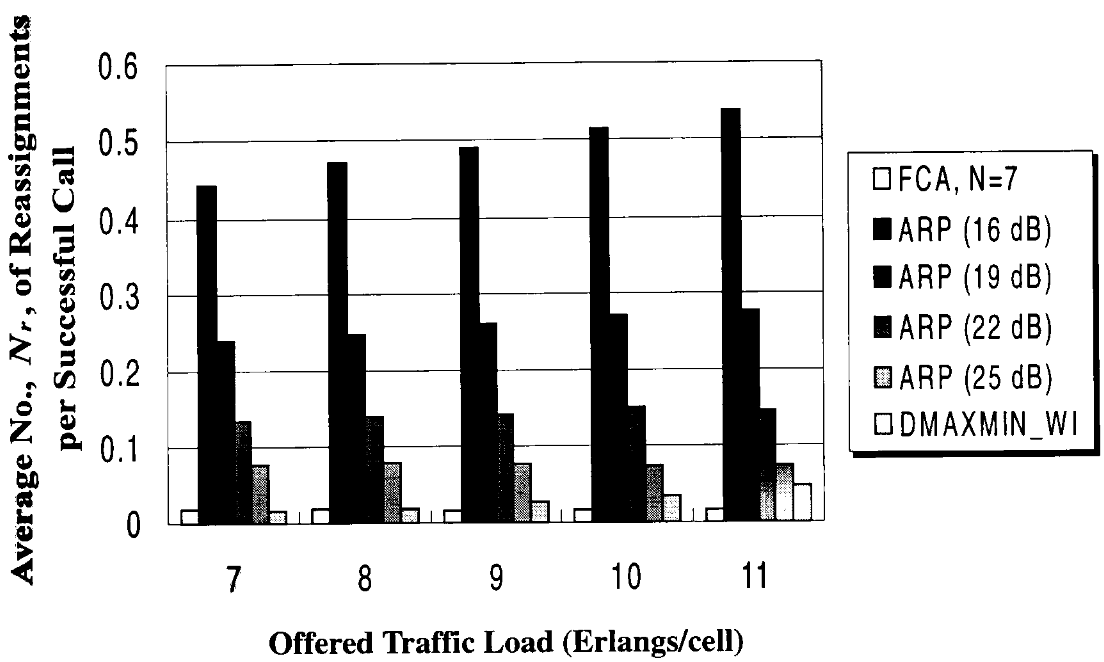
- What is the average number of intra-cell reassignments required for each successful call (i.e. a call which is not blocked and terminates normally)? What is an appropriate value for the maximum number of intra-cell reassignments allowed for each call?
- How do the blocking and dropping probabilities experienced by an MS change with its distance from the center of the cell it is located in?
- In DMAXMIN_WI, interference information is assumed to be from the two-tier neighboring cells around the host cell. How does the available interference information affect the overall performance? How is the performance of DMAXMIN_WI different from that of the centralized MAXMIN scheme?

5.1 Intra-cell Reassignment

The average number, N_r, of intra-cell reassignments per successful call at five different offered traffic loads is plotted in Figure 5.1.



(a)



(b)

Figure 5.1: Average No., N_r, of Intra-cell Reassignments per Successful Call with Uniform Traffic Distribution. (a) Downlink Transmission, (b) Uplink Transmission.

ARP generally requires more intra-cell reassignments than DMAXMIN_WI. ARP (16 dB) has the highest N_r since a lower call setup threshold allows more calls into the system. With interference information, DMAXMIN_WI can reduce the number of intra-cell reassignments significantly. For both uplink and downlink transmissions, FCA requires the least number of intra-cell reassignments. In FCA, the chosen reuse factor N ensures that the same channel can be reused at a certain distance. Co-channel interference is therefore less severe in a system using FCA than one using DCA, which results in fewer intra-cell reassignments. As the traffic load increases, N_r for FCA decreases. This is because when the system is heavily loaded, almost all nominal channels in each BS are used and an admitted call tends to have a strong signal strength.

A maximum of five intra-cell reassignments per call is assumed in Chapter 4. This parameter may have a substantial effect on the performance of any channel assignment scheme. Figures 5.2 to 5.4 show the performance of DMAXMIN_WI with different maximum number, M_r (1, 5, 10), of intra-cell reassignments allowed.

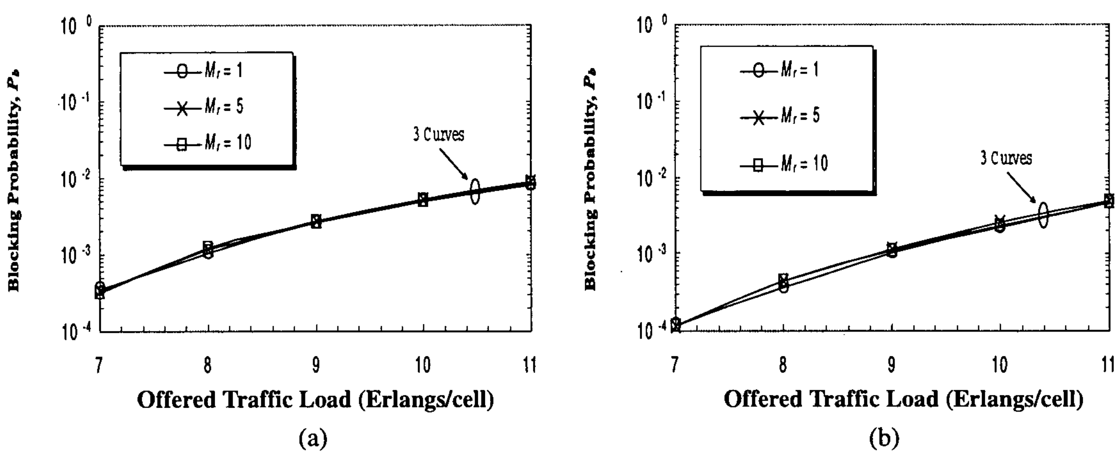


Figure 5.2: Call Blocking Probability, P_b, of DMAXMIN_WI with Various Values of M_r. (a) Downlink Transmission, (b) Uplink Transmission.

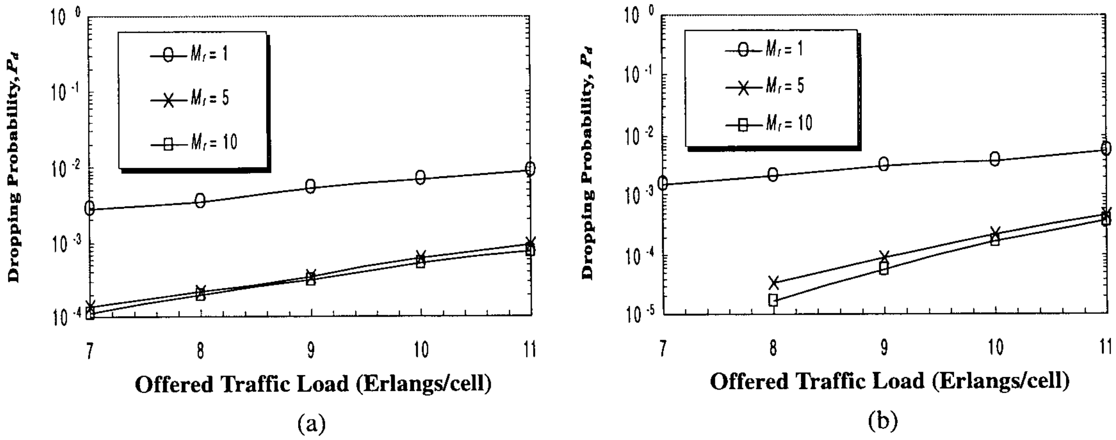


Figure 5.3: Call Dropping Probability, P_d, of DMAXMIN_WI with Various Values of M_r. (a) Downlink Transmission, (b) Uplink Transmission.

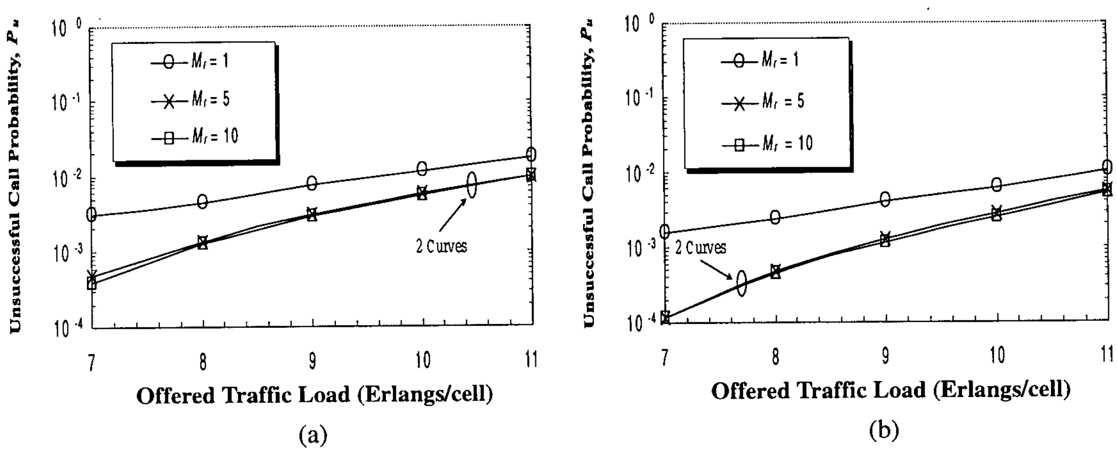


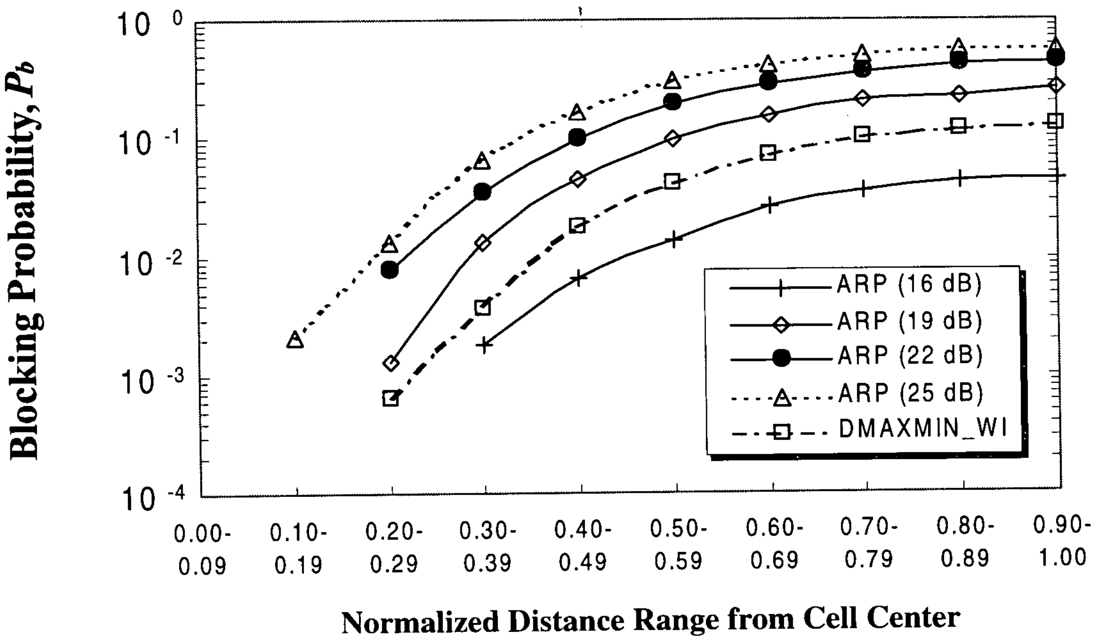
Figure 5.4: Unsuccessful Call Probability, P_u, of DMAXMIN_WI with Various Values of M_r. (a) Downlink Transmission, (b) Uplink Transmission.

The blocking probabilities on both the uplink and downlink do not change much with M_r = 1, 5 and 10. For downlink transmission as shown in Figure 5.3(a), the dropping probabilities decrease with M_r. At a traffic load of 11 Erlangs, the dropping probability of DMAXMIN_WI with M_r = 1, 5, and 10 are 0.9%, 0.09%, 0.08% respectively. A call is very likely to be dropped if it is allowed to switch to another channel only once. It was reported in [7] that an intra-cell reassignment can cause some other on-going calls to drop easily in measurement-based channel assignment schemes. Such successive call droppings can greatly degrade the system performance. By increasing M_r from 1 to 5, the dropping probability is reduced by a factor of ten as shown. Increasing M_r beyond 5 has little effect on performance.

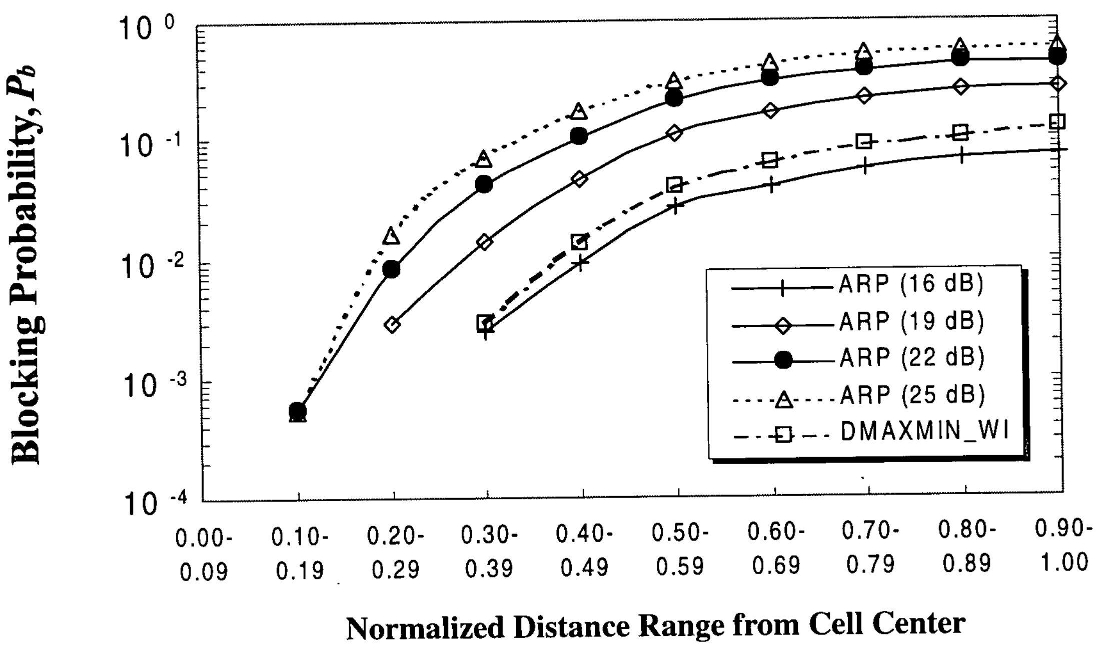
5.2 Call Blocking and Dropping Distributions within a Cell

Figure 5.5 shows call blocking probability as a function of the normalized distance, d_n, from the center of the cell, at an offered load of 18 Erlangs. If we need $P_b < 10^{-2}$ in downlink transmission, then $d_n \leq 0.39$ for DMAXMIN_WI, $d_n \leq 0.19$ for ARP (25 dB), $d_n \leq 0.29$ for ARP (22 dB and 19 dB) and $d_n \leq 0.49$ for ARP (16 dB) users. It can be seen that users close to the cell center are less likely to be blocked because of their higher signal strengths.

The call dropping probability as a function of d_n at the same offered load is shown in Figure 5.6. For $P_d < 10^{-3}$ in downlink transmission, $d_n \leq 0.39$ for DMAXMIN_WI, $d_n \leq 0.29$ for ARP (16 dB and 19 dB), $d_n \leq 0.39$ for ARP (22 dB) and $d_n \leq 0.49$ for ARP (25 dB) users. As ARP (25 dB) admits fewer new calls to the system, MS's suffer less co-channel interference, and hence have a lower P_d.



(a)



(b)

Figure 5.5: Call Blocking Probability, P_b, as a Function of Normalized Distance Range from Cell Center. (a) Downlink Transmission, (b) Uplink Transmission.

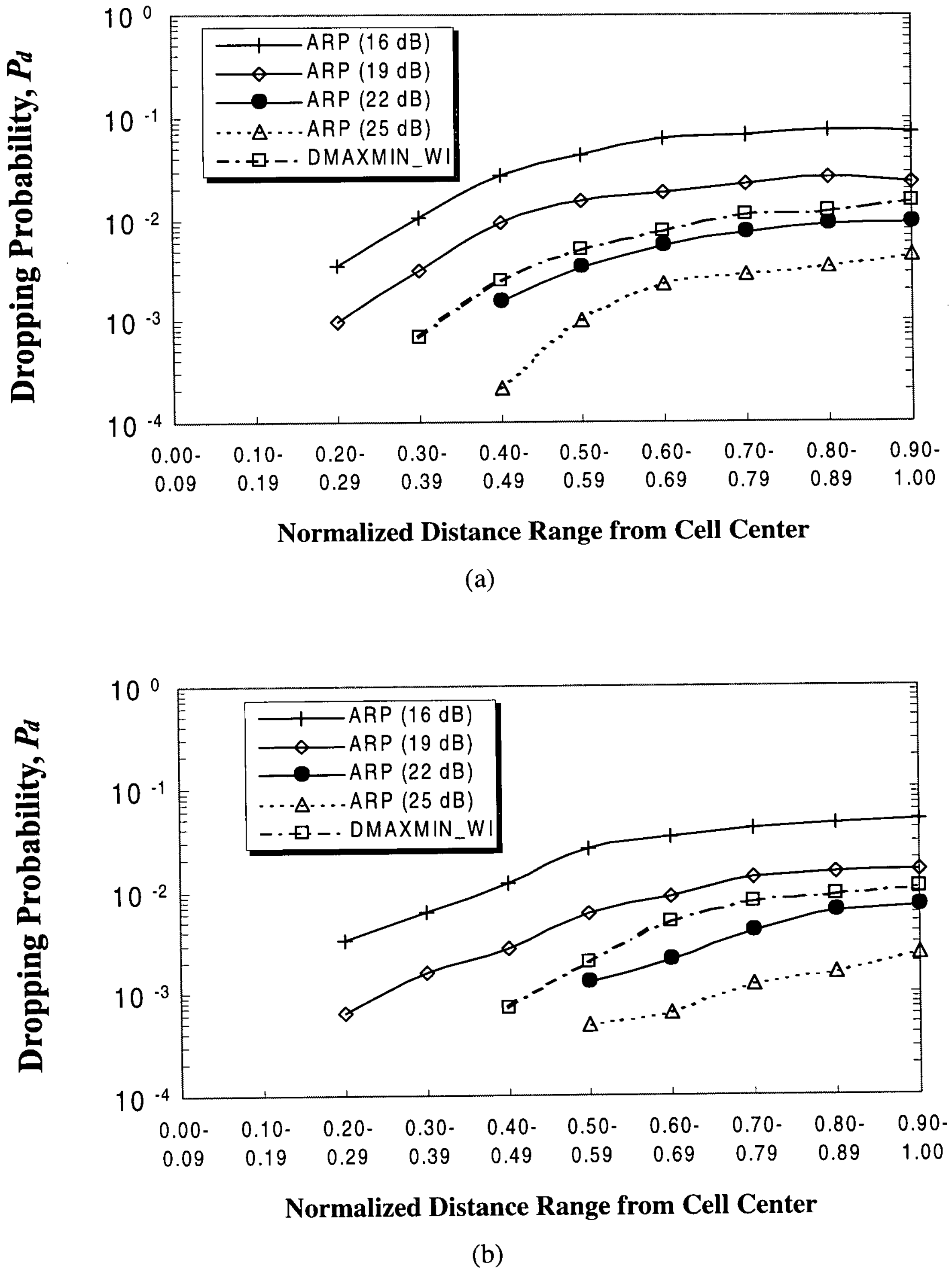


Figure 5.6: Call Dropping Probability, P_d, as a Function of Normalized Distance Range from Cell Center. (a) Downlink Transmission, (b) Uplink Transmission.

5.3 Available Interference Information

In Chapter 4, it was assumed that for DMAXMIN_WI, interference information is only gathered from the two-tier neighboring cells (i.e., a total number of 18 interfering cells) around the host cell. This is because co-channel users in these 18 cells are the most likely to be affected by a new channel assignment in the host cell. In practice, cells in the outer tiers also suffer additional co-channel interference due to the new channel assignment. By obtaining interference information from all the cells in the service area before assigning a channel to a call, DMAXMIN_WI yields the same performance as the centralized MAXMIN scheme. It is of interest to study the capacity improvement of DMAXMIN_WI if more interference information could be obtained by host cells. If interference information is obtained only from the first tier neighboring cells, the performance of DMAXMIN_WI is expected worsen. For convenience, DMAXMIN_WI with first tier interference information is referred to as Scheme **A** and DMAXMIN_WI with two-tier interference information is referred to as Scheme **B** from now on.

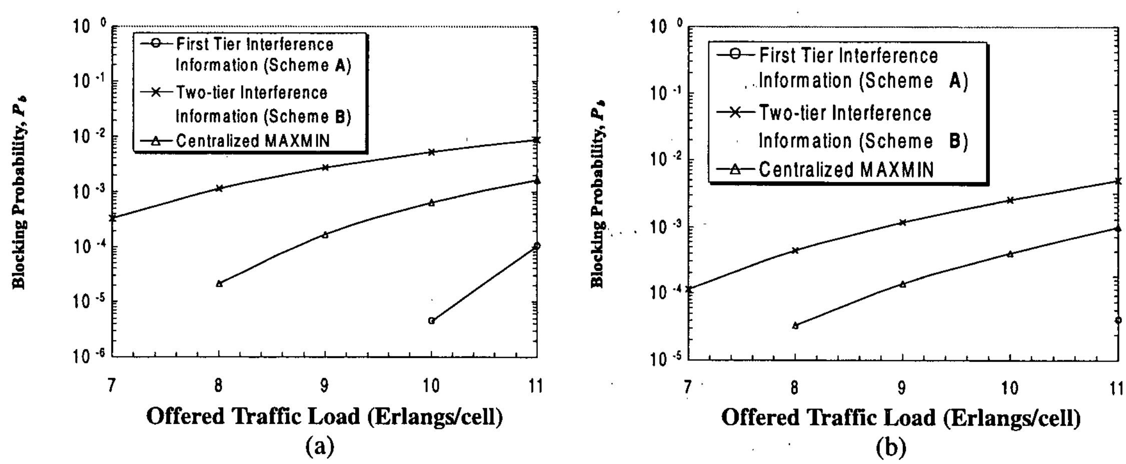


Figure 5.7: Call Blocking Probability, P_b, of DMAXMIN_WI with Different Amount of Interference Information and the Centralized MAXMIN scheme. (a) Downlink Transmission, (b) Uplink Transmission.

As shown in Figure 5.7, Scheme **B** gives the highest blocking probability, followed by the centralized MAXMIN scheme and Scheme **A**. At a traffic load of 11 Erlangs, the downlink blocking probabilities are 0.9%, 0.2%, and 0.01% for Scheme **B**, centralized MAXMIN and Scheme **A** respectively.

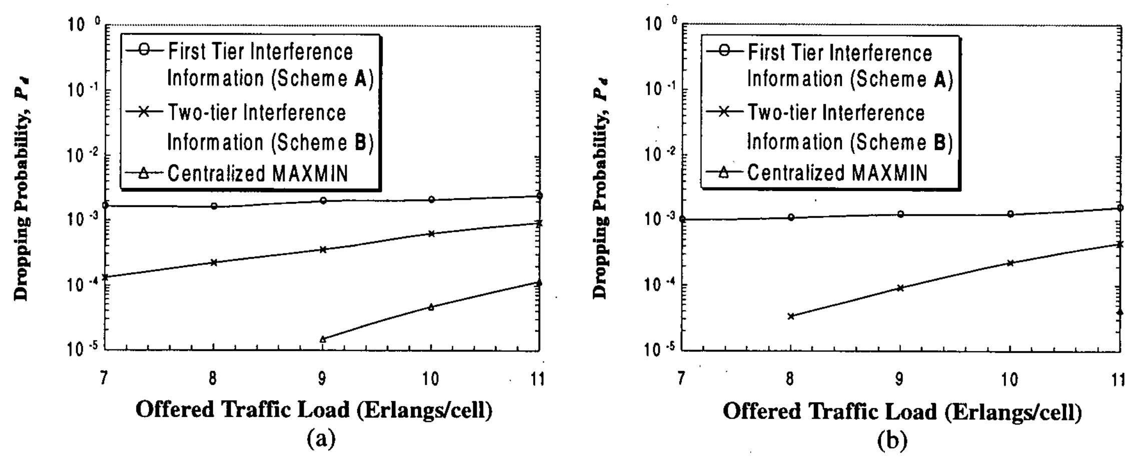


Figure 5.8: Call Dropping Probability, P_d, of DMAXMIN_WI with Different Amount of Interference Information and the Centralized MAXMIN scheme. (a) Downlink Transmission, (b) Uplink Transmission.

The dropping probabilities of the three schemes are plotted in Figure 5.8. The dropping probability of Scheme **A** is much worse than that for Scheme **B** and the centralized MAXMIN scheme. If the host BS obtains interference information only from its first tier neighboring cells, channels which have not been used in the first tier cells are very likely to be assigned. However, the assigned channels may be used heavily in the second tier cells, which results in a high dropping probability. This also explains the low blocking probability of Scheme **A** seen in Figure 5.7. With interference information from all cells, the centralized MAXMIN scheme gives the lowest dropping probability.

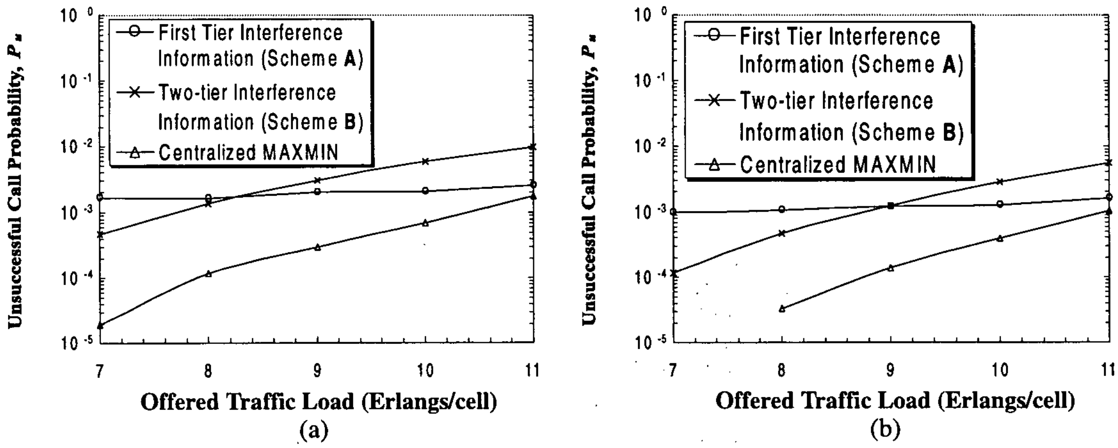


Figure 5.9: Unsuccessful Call Probability, P_u, of DMAXMIN_WI with Different Amount of Interference Information and the Centralized MAXMIN scheme. (a) Downlink Transmission, (b) Uplink Transmission.

Figure 5.9 shows the unsuccessful call probability of the three schemes as a function of offered traffic load. Scheme **A** has a lower unsuccessful call probability than Scheme **B** at high traffic loads because the blocking probability of Scheme **A** is relatively low. The centralized MAXMIN scheme gives the best overall performance. However, its processing complexity increases with the number of cells in the system. Since interference information is only obtained from a pre-determined set of interfering cells in DMAXMIN_WI, the processing complexity is kept constant regardless of the size of the service area.

5.4 Summary

Several issues related to DMAXMIN_WI were examined: The average number of intra-cell reassignments required for each successful call, the call blocking and dropping probabilities as a function of the distance of an MS from the center of its host cell, and the trade-off between performance and interference information available at each BS. It was found that DMAXMIN_WI generally requires fewer intra-cell reassignments than ARP. An MS close to the center of its host cell tends to have a stronger signal strength which reduces the probability of it being blocked or dropped by its BS. The centralized MAXMIN scheme generally outperforms DMAXMIN_WI.

Chapter 6 Conclusion

Distributed dynamic channel assignment (DDCA) schemes for use in a cellular system were studied. In contrast to centralized channel assignment schemes, DDCA schemes allow each BS in the service area to make individual channel assignment decisions without the need for a central controller. Centralized DCA generally has a better performance than distributed DCA, but at the expense of high centralization overhead as reported in previous studies [5,6,12,20]. As a result, distributed DCA schemes are more attractive for implementing future cellular systems due to the simplicity of the channel assignment algorithm in each BS [17]. The main contribution of this thesis is the introduction of a new DDCA scheme.

A new approach to performance analysis, the Slot Viewpoint Analysis, was proposed to unify the traditional analysis and the Snapshot Analysis [19]. Instead of assigning a channel to a new call right after its arrival, calls are grouped into a number of fixed-sized slots in the Slot Viewpoint Analysis. Channel assignments are carried out only at the end of each slot. If the slot size is decreased to zero, the Slot Viewpoint Analysis yields the same results as the traditional analysis; if the ratio of the slot size to the mean call duration is greater than ten, the Slot Viewpoint Analysis yields similar results to the Snapshot Analysis. It was found that the Snapshot Analysis cannot replace traditional analysis, but it can be used to evaluate different channel assignment schemes in a relative sense.

A new DDCA scheme, distributed MAXMIN with interference information (DMAXMIN_WI), was proposed and its performance was compared to two existing channel assignment schemes using computer simulation. DMAXMIN_WI can be classified as a partially decentralized channel assignment scheme because each BS has to communicate with several neighboring BS's to obtain the interference information. With the information, each BS is capable of assigning a channel, so that the poorest SIR after the assignment is maximized. The performances of DMAXMIN_WI, ARP and FCA in both uplink and downlink transmissions were investigated assuming shadow fading. Besides the uniform traffic pattern, two non-uniform traffic patterns were used to study the three channel assignment schemes. DMAXMIN_WI was shown to have lower blocking and dropping probabilities than FCA. It was shown that the call setup threshold has a substantial effect on the performance of ARP. ARP with a low call setup threshold (16 dB) has a lower blocking probability than DMAXMIN_WI, at the expense of a high dropping probability. When performances were evaluated using the unsuccessful call probability, DMAXMIN_WI outperformed FCA as well as ARP for both uniform and non-uniform traffic distributions.

The number of intra-cell reassignments required per successful call for the three channel assignment schemes were compared. For DCA, DMAXMIN_WI requires the least number of reassignments because fewer on-going calls have their SIR's fall below the minimum SIR threshold after a new channel assignment. It was also shown that with a maximum of five intra-cell reassignments per call, the performance of DMAXMIN_WI was similar to that with a maximum of ten intra-cell reassignments per call. The blocking and dropping probabilities experienced by an MS change as a function of its distance from the center of the cell was studied. Calls of an MS close to the cell center are less likely to be blocked or dropped because of their higher signal strengths. DMAXMIN_WI was compared with the centralized MAXMIN scheme to illustrate the trade-off between centralization overhead and performance.

6.1 Future Work

Some other research topics which could be studied in the future are as follows:

- To compare the three channel assignment schemes (DMAXMIN_WI, ARP and FCA) using the Snapshot Analysis and verify their relative performances.
- To study the performance of DMAXMIN_WI in conjunction with different power control algorithms.
- To examine the gain in capacity of DMAXMIN_WI with directional antennas installed at each BS.
- To analyze the performance of DMAXMIN_WI using different mobility models.

Glossary

AMPS	Advanced Mobile Phone System
ARP	Autonomous Reuse Partitioning
BS	Base Station
CDMA	Code Division Multiple Access
CS	Channel Segregation
DCA	Dynamic Channel Assignment
DDCA	Distributed Dynamic Channel Assignment
DECT	Digital European Cordless Telecommunications
DMAXMIN_WI	Distributed MAXMIN with Interference Information
FCA	Fixed Channel Assignment
FDMA	Frequency Division Multiple Access
GOS	Grade of Service
GPS	Global Positioning System
GSM	Global System for Mobile Communications
IA-DCA	Interference Adaptation Dynamic Channel Assignment
LA-DCA	Location Adaptation Dynamic Channel Assignment
MAXMIN	Centralized MAXMIN scheme
MC	Minimum Cost
MS	Mobile Station
MSC	Mobile Switching Center
MSIR	Maximum Signal-to-Interference Ratio
NMT	Nordic Mobile Telephone

PSTN	Public Switched Telephone Network
QoS	Quality of Service
RMI	Random Minimum Interference
SIR	Signal-to-Interference Ratio
SMI	Sequential Minimum Interference
TACS	Total Access Communications System
TA-DCA	Traffic Adaptation Dynamic Channel Assignment
TDMA	Time Division Multiple Access
α	Propagation loss exponent
d_{ij}	Distance between base station i and mobile station j
d_n	Normalized distance from cell center
D_i	Distance between two interfering base stations
γ_i	Signal-to-Interference Ratio of mobile station i
g_{ij}	Link gain between base station i and mobile station j
$I(x)$	Interfering cells of cell x
λ	Mean traffic per cell per channel
λ_c	Mean traffic per cell
λ_t	Mean arrival rate
$\Lambda(x)$	Available channel set of cell x
L_{ij}	Shadow fading factor between base station i and mobile station j
M	Total number of channels
M_r	Maximum number of intra-cell reassignments per call allowed

n	Total number of co-channel users
$n(i)$	Total number of times channel i has been considered for use
N	Frequency reuse factor
N_r	Average number of intra-cell reassignments per successful call
$p(i,t)$	Priority function of channel i at time instant t
P_a	Assignment failure probability
P_b	Call blocking probability
P_d	Call dropping probability
P_i	Transmitted power of mobile station i
P_{sd}	Service denial probability
P_u	Unsuccessful call probability (used in Traditional Analysis)
P_{us}	Unsuccessful call probability (used in Slot Viewpoint Analysis)
Q_x	Overall cost to cell x's two-tier neighboring cells
(r_i,θ_i)	Location of a mobile station
R	Cell radius
σ	Standard deviation for shadow fading
s	Slot length
$U(y)$	Occupied channel set of cell y

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Appendix A. Verification of the Wrap-around Assumption

The wrap-around method is used in [13,15] to avoid edge effects (cells close to the edge in the service area, surrounded by fewer interfering cells, generally experience less co-channel interference than the inner cells). The cellular layout is wrapped around to form a torus, so that each cell is virtually surrounded by 35 interfering cells as described in the simulation model. In the following, the performance of DMAXMIN_WI evaluated using the wrap-around method is compared to that without wrapping around. For convenience, simulation without using the wrap-around method (results averaged over 36 cells/over central 4 cells) is referred to as Simulation **A/B** and simulation using the wrap-around method is referred to as Simulation **C** hereafter.

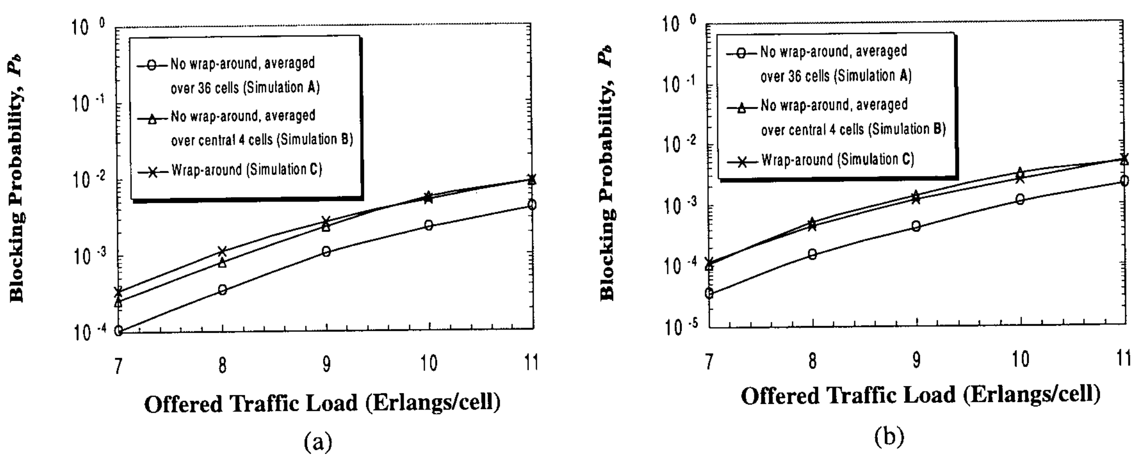

Figure A.1: Call Blocking Probability, P_b, of DMAXMIN_WI with/without the Wrap-around Method. (a) Downlink Transmission, (b) Uplink Transmission.

It can be seen in Figure A.1 that similar call blocking probabilities are obtained from both Simulation **B** and **C**, while Simulation **A** gives the lowest blocking probability. In Simulation **A**, cells close to the edge experience less co-channel interference so that the blocking probabilities in those cells are relatively low. When simulation results are averaged over 36 cells, the performance is optimistic when compared with Simulation **B** in which results are averaged over the central four cells (with two tiers interfering cells). In Simulation **C**, as the layout is wrapped around, each cell is virtually surrounded by 35 interfering cells. That explains the similar blocking probabilities obtained by Simulation **B** and **C**.

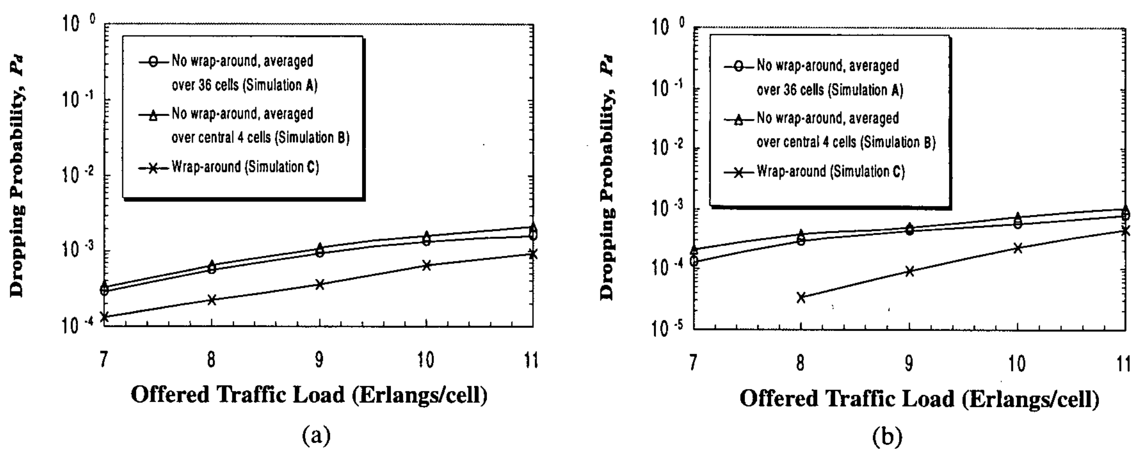

Figure A.2: Call Dropping Probability, P_d, of DMAXMIN_WI with/without the Wrap-around Method. (a) Downlink Transmission, (b) Uplink Transmission.

Figure A.2 shows the call dropping probabilities of the three simulations. Since more new calls are admitted in cells which are close to the edge as in Simulation **A** and **B**, central cells tend to experience higher co-channel interference. It can be seen that both Simulation **A** and **B** give higher dropping probabilities when compared with Simulation **C**. In Simulation **C**, as the layout is wrapped around, there is a mutual interaction among cells which prevents any cell from admitting relatively more new calls than the others. This effect reduces the number of new calls getting into the system, which results in a lower dropping probability.

The unsuccessful call probabilities of the three simulations are plotted in Figure A.3. The general observation is that Simulation **A** gives the lowest unsuccessful call probability due to its low blocking probability and Simulation **B** gives the highest unsuccessful call probability as its dropping probability is relatively high.

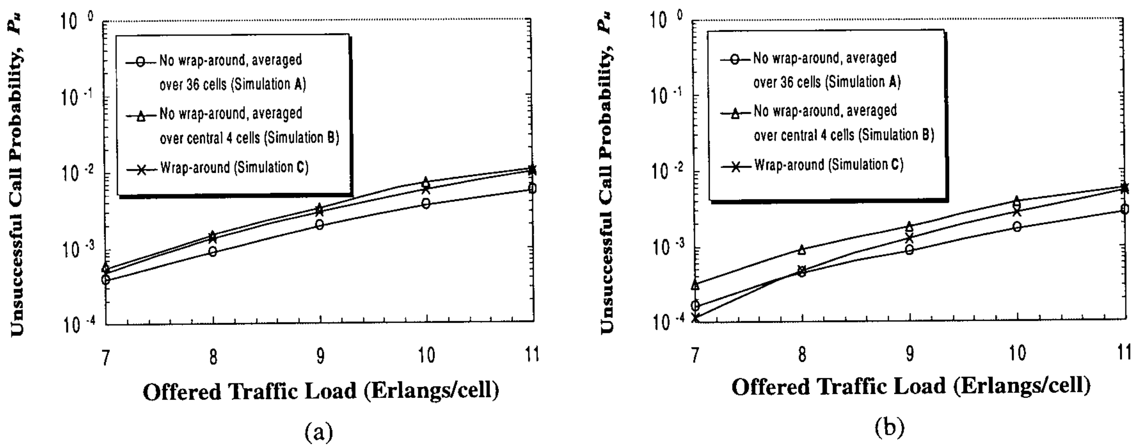

Figure A.3: Unsuccessful Call Probability, P_u, of DMAXMIN_WI with/without the Wrap-around Method. (a) Downlink Transmission, (b) Uplink Transmission.

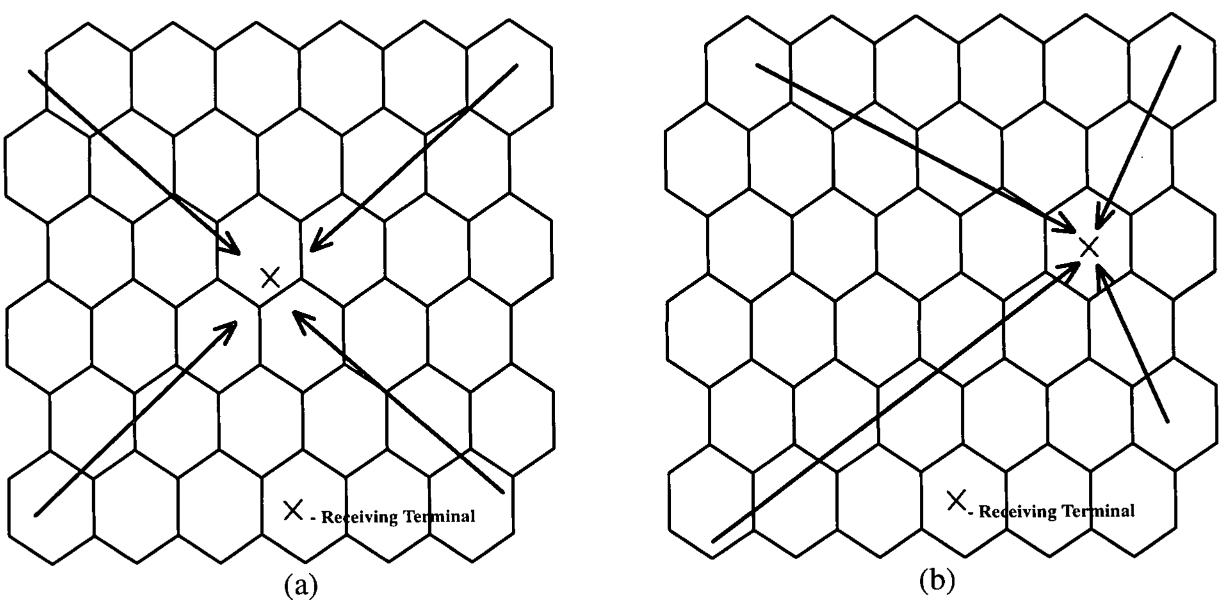

Figure A.4: Different Amount of Co-channel Interference Received at the Receiving Terminal. (a) with Wrap-around Method, (b) without Wrap-around Method.

Figure A.4 illustrates the amount of co-channel interference experienced by a receiving terminal depending whether the wrap-around method is used or not. With wrap-around, the receiving terminal, regardless of its physical location, experiences co-channel interference as if it is located at the center of the service area (Figure A.4a). When no wrap-around is used, the receiving terminal, when it is away from the center (Figure A.4b), experiences less co-channel interference in some directions. That explains the optimistic call blocking performance obtained in Simulation **A**.