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Integrated Channel Assignment and Power Control in Cellular Networks using Hill-Climbing Approach

by
Nowsher Ali

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Abstract

Recent year's incredible success and exponential growth of wireless cellular network services have necessitated careful management of radio resources to improve system capacity. Mainly due to the insufficiency of radio spectrum, reuse or sharing of radio frequency must be considered. In practical, the sharing of radio frequency introduces interferences among users, which in turn limit the system capacity. On the other hand, control of transmitter power can suppress co-channel interference, adjacent channel interference and limits the consumption of power. Thus channel assignment and power control are two effective means in wireless cellular networks and they are highly correlated to each other. Most of the existing papers have focused on optimizing the assignment of channels assuming that the allocation of transmitter power is known and fixed or vice-versa. In this thesis, we study the integration of channel assignment and power control simultaneously to increase the network capacity and throughput. We have proposed a new channel assignment approach, called HCA-PC (Hybrid Channel Assignment + Power Control) using dynamic reuse distance concept to optimize the channel assignment. We develop a Hill-climbing approach with random restart strategy, using an efficient problem representation and a fitness function that optimizes channel assignment and power control in the cellular network.

The efficient use of available channels and transmitter power has been shown to improve the system capacity. The role of power control is to assign least interfered channel (LIC) to a call so that the signal quality is maintained and interference level is minimized as well as the battery life increases. We have attained better performance with respect to call blocking probability as well as faster running time than a previous approach.

Dedication

This work is dedicated to my parents and paternal uncles.

Acknowledgements

First of all, I would like to thanks my co-supervisor Dr. Arunita Jaekel and Dr. Alioune Ngom for their suggestions, ideas and support during the development of this thesis.

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Chapter 1

Introduction

The worldwide communication and network structure has experienced an explosive growth due to the tremendous demand and evolution of the internet, with availability of various network applications as well as the availability of cheaper hardware. In this context, the wireless cellular network is more popular technique in the era of multimedia communication due to the advancement of cellular technologies. Cellular networks are becoming more popular because of their hardware improvements including availability, portability, low-power, ease of access to telephone and data networks caused by the quick exploitation of network infrastructure. To fulfill this upward trend cellular networks are becoming more diverse in service, better market price, and better performance in service.

1.1 Objective of Cellular Networks

The objective of a cellular network system is to provide communication service to anyone, anywhere, anytime and to maintain QoS regardless of the interference and user motion. As radio spectrum and power is scarce in a cellular network, efficient reuse of radio spectrum and power control is needed to increase the network capacity and battery life. Reuse of radio frequency further increases the co-channel interference which in turn reduces the carrier-to-interference ratio (CIR). Therefore, the integration of radio-frequency assignment and power control is a complicated issue.

1.2 Cellular System Architecture

Traditional mobile services were structured similar to the television broadcasting: one very powerful transmitter, located at the highest spot in an area, would broadcast in a radius of up to fifty kilometers [37]. The cellular concept structured the mobile telephone networks in a different way. Instead of using a very powerful transmitter, more low-power transmitters were placed throughout the coverage area. For example, by dividing a metropolitan area into one hundred different areas (cells) with low-power transmitters using 12 channels each, system capacity could be theoretically increased from 12 channels using one powerful transmitter to 12 hundred channels using one hundred low-power transmitters.

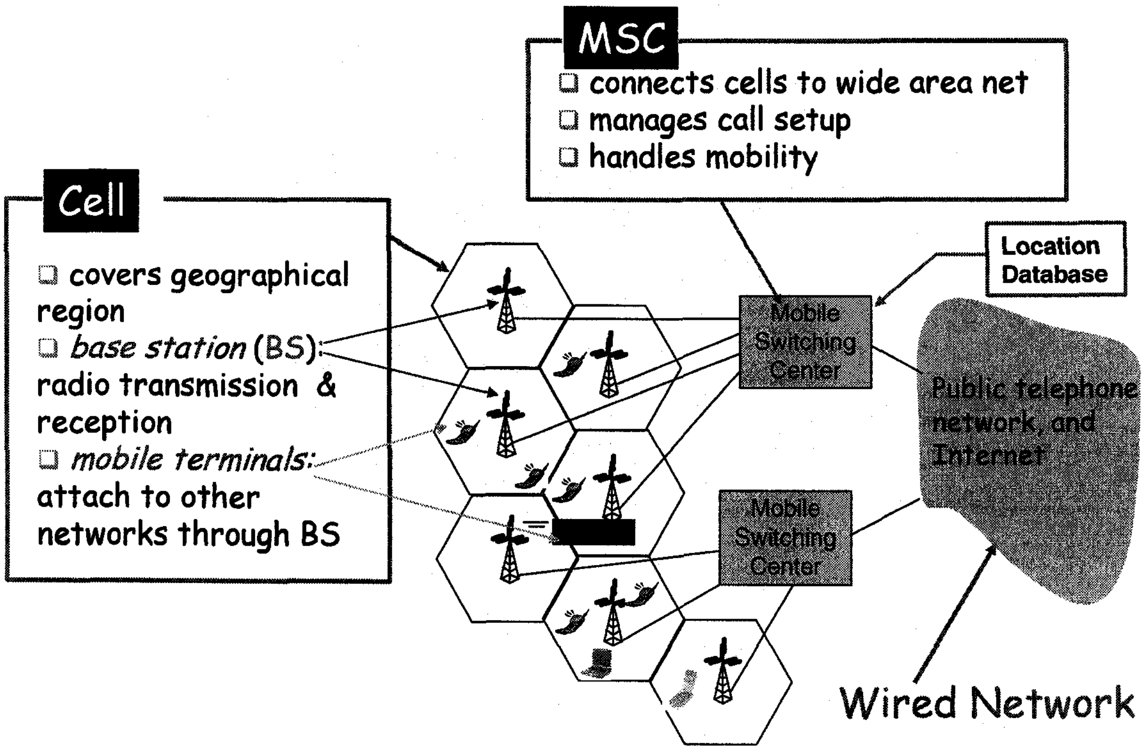


Figure 1.1: A typical Cellular Network System Architecture

In a cellular network, a service area is divided into sub-areas called cells. A cell is the basic geographic unit of a cellular system and represented as a hexagon shape. Each cell size varies depending on the landscape, natural territory, and man-made structures; the true shape of cells is not a perfect hexagon. Each cell has a more powerful entity called base station and a number of mobile terminals (e.g. mobile phones) as shown in figure 1.1. The base station is equipped with radio transmission and reception equipment to serve a cell. Mobile terminals are connected to other networks in the system through the base station in the cell where the terminal is located. A group of base stations are connected to a Mobile Switching Center (MSC), which is also the interface between wireless communication networks and other wired or wireless public service telephone networks (PSTN) as shown in figure 1.1. Although a base station is fixed, it is responsible for coordinating communication between the mobile terminal and the rest of the information network. The MSC controls calls, tracks billing information, and cellular subscribers. The PSTN is made up of local networks, the exchange area networks, and the long-haul networks that interconnect telephones and other communication devices on a worldwide basis. This network is more suitable for the geographical area where mobile terminals are spread uniformly and infrastructure exists or availability of infrastructure is possible easily.

1.3 Channel Management & Channel Assignment

Channel management is simply a proper management of the frequencies in the development of a better inter-communication plan in presently-available highly crowded electromagnetic bandwidth. If proper steps are not taken during the planning stage, the frequency selection might create interference among nodes, which in turn decreases the network capacity and throughput [15].

In a cellular network, the channel-assignment is a mechanism that assigns channels to cells or mobile terminals in order to establish a communication between a mobile terminal and a base station [41]. A channel consists of a pair of frequencies: one is for the transmission from the base station to the mobile terminal i.e. the down link and another for the transmission in reverse direction i.e. the uplink. Channel assignment is a fundamental task of resource management whose proper utilization could increase the fidelity, capacity, throughput, and quality of service (QoS) in cellular networks in such a way that efficient frequency utilization is possible as well as the elimination of frequency interferences.

As compared to the exponential growth of mobile terminals, the availability of channels or frequency spectrum is very limited. This requires a method to share these channels for efficient assignment and proper management of channel resources. The more channels are shared, the better. The major penalty of sharing channels is the unwanted (co-channel) interference generated during the sharing process. Different sharing (multiple accesses) techniques have different impacts on a network.

1.4 Interference

The transmission carried over between mobile terminals in a wireless cellular network interferes with neighboring links, significantly reducing the capacity of the networks. Interference is the summation of received signal power at a receiver from other cells or third party transmitters sharing the same channel or radio frequencies.

One can define interference as the amount of noise power that is not intended for a node but is sensed due channel sharing. Usually the interfering transmitter is distant, and in theory its signals should not arrive at the receiving site. Unfortunately coverage areas by transmitting nodes cannot be exactly defined. If the interference level in a network increases then the call between a mobile terminal and a base station could be blocked or dropped, because in this situation the carrier-to-interference ratio (CIR) or carrier-to-interference plus noise ratio (CINR) falls below the threshold value. Interference levels are considered for transmission in such a way that a least interference channel (LIC) is selected by measuring the interference level at all the channels provided the interference level is below the interference threshold.

The CIR or CINR measures the received signal quality at a receiver in cellular networks. The ratio of the received signal power received from a transmitter in the cell where it is located to the unwanted remaining power at the receiver is called carrier-to-interference ratio (CIR) or carrier-to-interference-and-noise ratio (CINR). Usually a threshold value of CIR is determined to figure out the correctness of the wanted signal at a receiver. Lower CIR at a receiver indicates the higher error rate and low utility in a network. But higher CIR value indicates the higher throughput and high utility in a network.

1.5 Power Control

In order to establish a communication in a cellular network power must be assigned to a transmitter or a receiver. It is important that a radio receiver receive a power level that is high enough for its proper function but not so high as to disturb other receivers. If the transmitted power is very high then the battery will be drained off quickly, which in turn reduce the battery life tremendously. High transmission power also increases interference with other users, which in turn reduces the system capacity. Furthermore, decay of battery life due to the higher transmission power also affects the network lifetime.

In a cellular network, the carrier-to-interference ratio (CIR) or carrier-to-interference plus noise ratio (CINR) is the main feature of determining the signal quality [41]. Here carrier represents the signal power received by a receiver from the transmitter in the cell where it is located and interference is the cumulative effect of signal powers received from transmitters using the same channel in all other cells in the network. The signal quality and the level of interference in the wireless network depend upon the transmitter power. The objective of power control is to assign proper level of power to each transmitter so that the signal quality is maintained and the interference is minimized.

In literature several techniques and algorithms have been used to manage the transmitted power of base station and mobile terminals. Power control is needed for the forward link (base station to mobile terminals) as well as for the reverse link (mobile terminal to base station). The efficient management of power-control is needed in cellular networks, because of its influence on the battery life of the communication devices and on the capacity of the networks.

Channel sharing allows the efficient use of the available channels but the reuse of channels also increases the interference levels that limit the efficiency. On the other hand power control suppresses the adjacent channel interference, the co-channel interference, and minimizes the consumption of power. Thus the problem of channel assignment is highly correlated to power control. When a call arrives and a channel is assigned without considering the CIR level, it may cause the CIR of an ongoing call to drop below the required threshold value, thereby causing forced termination of ongoing calls. But it is found in literature that the users tend to prefer of call blocking of new calls to dropping of ongoing calls. Thus the energy savings and the efficient use of network resources are the two components that make power-control one of the most active research topics for the researchers in wireless communication.

The power control algorithms can be classified as centralized and decentralized and discrete or continuous. A centralized power control includes a central controller that maintains information about all the radio links in the system and it decides control actions for all users. On the other hand, a distributed controller only controls the power of one single transmitter based on local information in the network. In power control algorithm with continuous power level, the power levels are assigned from a continuous range whereas in case of discrete power level, the power levels are assigned form a discrete set [41].

The above discussion helps to motivate the researchers that the adjustment of transmitted power is extremely important due to the following reasons:

- The transmitted power of a mobile node determines the network topology.
- The communication terminals in cellular networks are usually energy constrained.
- Transmitting high power could degrade other communication systems or networks.
- Transmitting of higher power is unnecessary if the receiver is close to the transmitter.

1.6 Integrated Channel-Assignment and Power-Control

Channel-assignment and power-control are two effective means to improve the capacity of wireless networks. By integrating these two, we can further increase the network capacity and throughput [32]. This is the main focus of this thesis, which is focuses on the integration of channel-assignment and power-control. We investigate how power-control can be combined with channel-assignment to maximize the network capacity and network throughput.

1.7 Motivation

The capacity of a cellular system can be described as the number of available channels, or the number of users that the system can support. Channel-assignment and power-control are two effective means to improve the capacity of wireless networks. By integrating these two, we can further increase the network capacity and its throughput. Power control (PC) has been studied extensively incorporated with channel assignment to reduce call blocking and call dropping in cellular networks [13], [29], [44], [46]. The role of power control in cellular network is primarily to reduce multiple access interference and to mitigate the near far effect [15] so that the better network capacity is achievable. Thus, the aim of power control is to achieve energy efficient communication, i.e. assign transmit powers to different transmitters in such a way that QoS constraints like throughput, delay, battery life, CINR etc. are met by expending minimum possible power. Thus channel assignment with the integration of power control is a key issue in cellular networks, because it can help prolong battery life, improve network capacity by mitigating interference and maintain link QoS by adapting to mobility.

1.8 Problem Statement

In this thesis, we deal with the problem of finding an optimal assignment of channels in wireless cellular networks. We propose a new HCA strategy called HCA-LIC (Hybrid Channel Assignment with Least Interfered Channel) strategy using dynamic reuse distance concept [32]. This new HCA strategy has been implemented using a Hill-climbing approach to integrate the problem of channel assignment with power control. The channels are assigned using a HCA scheme [41] based on the level of interference measured on each of the free channels immediately prior to the commencement of the call. The channels are measured in sequential basis and the least interfered channel (LIC) is selected for the new call provided the interference level is below a set interference threshold. When a channel is assigned to a new call and the communication is established, it might affect on other ongoing calls already on the channel. If the interference level of any ongoing call rises above the interference threshold, the specific ongoing call will be terminated. To avoid the termination of ongoing calls, we consider the reassignment of channels to the ongoing calls if it is necessary. We have modeled a fitness function or energy function in our approach using dynamic channel assignment scheme and centralized power control on reuse distance concept. The minimization of this energy function gives the optimal channel assignment and power control.

In this thesis, we develop a Hill-climbing approach which optimizes channel assignment and power control using our new problem representation as well as an appropriate fitness function. The channels are assigned to the host cell for transmission which has the least interference level as well as the interference level is below a set interference threshold. The channel usage information of neighboring cells is obtained from a *CxF* allocation matrix, *A* → [a_{ij}], where each element a_{ij} in the matrix is one or zero such that [41]

$$aij = \begin{cases} 1 & \textit{if channel j is assigned to cell i} \\ 0 & \textit{otherwise} \end{cases}$$

and *C* is the total number of cells in the system and *F* is the total number of channels available to the system. The allocation matrix is updated every time a channel is assigned and released in the network.

1.9 Contributions

An overview of our contributions in this thesis can be summarized as follows:

1. **Integration of HCA and PC**

   We have combined channel assignment and power control into a single optimization problem, by determining an appropriate objective function that allow to minimize call blocking probability as well as to increase battery life.

2. **Development of a Hill-Climbing Approach for HCA-PC Solution**

   We have implemented a simple hill-climbing method for the solution of the problem discussed above.

1.10 Structure of the Thesis

This thesis investigates the integration of channel-assignment and power-control in wireless cellular networks. In chapter-2, we discuss a number existing techniques for channel-assignments and power-control with a brief outline of how they influence the wireless cellular networks. As well, the integration of channel-assignment and power-control with their combining effect on cellular networks over their individual effect is discussed. We also review the ES and HC approaches.

In chapter-3, we define our HCA scheme with dynamic reuse distance concept, features of our HC algorithm, and define our method for combining the problem of finding an optimal channel assignment with power control. Chapter-4 describes the basic assumptions of the cellular model used in the simulation; the various assumptions used in the simulation model, some of the implementation details, and also present our results.

Finally, in chapter-5, the main conclusion is presented, as well as possible directions for future work that is still open is described.

Chapter 2

Literature Review

Channel–assignment, power control, and the integration of channel–assignment & power control for cellular networks have been investigated by researchers from various perspectives. A brief survey and the review of some important existing issues that are relevant to our problem have been discussed in the following section. Though this survey is by no means extensive, it provides an insight into some of the key ways of formulating the channel assignment and power control problem.

2.1 Channel Assignment

In literature, the channel assignment problem has been shown to be NP-hard problem [41]. The researchers are highly motivated about the reuse of channels, efficient frequency utilization, as well as the elimination of frequency interferences. In order to assign channels properly and efficiently in wireless cellular networks different researchers have used different channel-assignment schemes to solve channel-assignment problem based on fixed or dynamic reuse distance concept.

2.1.1 Multiple Access (Channel Sharing Methods)

Multiple access schemes are used to allow many simultaneous users to use the same fixed frequency spectrum. In any radio system, the bandwidth which is allocated to it is always limited. For mobile network systems the total bandwidth is typically 50MHz, which is split in half to provide the forward and reverse links of the system. Sharing of the spectrum is required in order increase the user capacity of any wireless network. FDMA, TDMA and CDMA are the three major methods of sharing the available bandwidth to multiple users in wireless system.

2.1.1.1 Frequency Division Multiple Access

In Frequency Division Multiple Access (FDMA), the available bandwidth is subdivided into a number of narrower band channels [23]. Each user is allocated a unique frequency band in which to transmit and receive on. During a call, no other user can use the same frequency bandwidth. Each user is allocated a forward link channel i.e. from the base station to the mobile terminal and a reverse channel i.e. back to the base station, each being a single way link. That means, FDMA allocates a single channel to one user at a time. Although it is easy to implement, FDMA is wasteful of bandwidth: the channel is assigned to a single conversation whether or not somebody is speaking. Figure 1.2 shows the allocation of the available bandwidth into several channels.

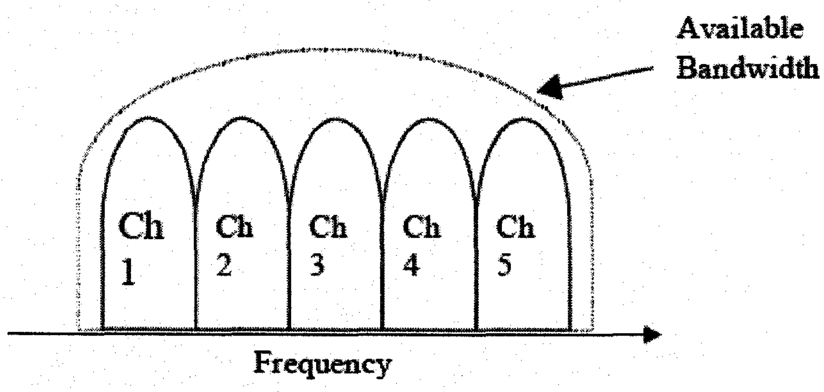


Figure 2.1: FDMA scheme, where the available bandwidth is subdivided into narrower band channels (reproduced from [23])

2.1.1.2 Time Division Multiple Access

In Time Division Multiple Access (TDMA), each frequency channel is divided into a number of time slots which are assigned to multiple users in a round robin fashion in which they can transmit or receive [23]. TDMA is a digital transmission technology that allows a number of users to access a single radio-frequency (RF) channel by allocating unique time slots to each user within each channel. Each caller is assigned a specific time slot for transmission as shown in figure 1.2. Today, TDMA is an available, well-proven technique in commercial operation in many systems.

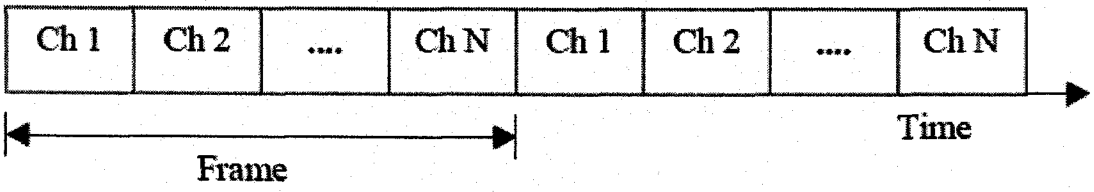


Figure 2.2: TDMA scheme, where each user is allocated a small time slot (reproduced from [23])

2.1.1.3 Code Division Multiple Access

Code Division Multiple Access (CDMA) is a spread spectrum technique that uses neither frequency channels nor time slots [23]. It is more advanced sharing method where codes form the channels and all transmitters "simultaneously" occupy the entire available frequency channels. In wireless networks these basic multiple access schemes are combined with geographical spectrum reuse, where the same radio channel bandwidth is shared among several mobile terminals which are sufficiently remote from each other. Figure 1.4 shows the general use of the spectrum using CDMA.

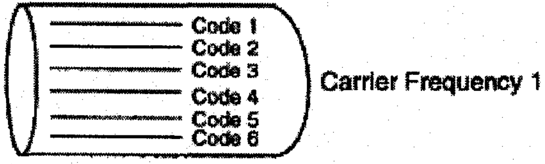


Figure 2.3: CDMA scheme (reproduced from [23])

To summarize, economical and competitive mobile wireless services require efficient sharing of channel resources. All sharing methods in practice introduce interference of one sort or another which are proportional to the transmitter powers. Therefore, transmitter power control is a key technique to achieve better balance between the received signal and the interference, which in turn enables more efficient channel resources sharing.

2.1.2 Channel Assignment Schemes

In mobile communications, channels are generally assigned in a fixed manner, depending upon the position of a mobile and the available channels in the cell where the mobile is positioned. As a mobile crosses the cell boundary, a new channel is assigned. In this arrangement, the number of channels in a cell is normally fixed. The use of a central controller provides an opportunity to change the cell boundary and thus to adjust the number of channels in each cell as the demand changes due to changing traffic situations. This provides the means whereby a mobile or group of mobiles may be tracked as it moves and the cell boundary may be adjusted to suit this group.

Various channel assignment schemes have been proposed to find better ways to assign channels to a call and to achieve higher level of channel reuse. Generally, channel assignment schemes are divided into three categories; fixed channel-assignment (FCA), dynamic channel-assignment (DCA), and hybrid channel-assignment (HCA).

2.1.2.1 Fixed Channel Assignment (FCA)

In FCA [45], a set of channels are assigned permanently to each cell in advance on the basis of predetermined estimated traffic load. The same set of channels is reused by another cell at some distance away. Therefore a definite relationship is exists between each channel and each cell, in accordance to co-channel reuse constraints. In a cell, a channel can be assigned to a call using FCA, only if there are unoccupied channels available in the predetermined set in that cell. Otherwise, the call might be rejected even though there are many free channels available in the network. Thus the efficient use of channels is difficult in FCA.

2.1.2.2 Dynamic Channel Assignment (DCA)

Fixed Channel Allocation schemes are simple, but it does not adapt to the changes in traffic conditions. In order to overcome these deficiencies, Dynamic Channel Allocation (DCA) schemes [45] have been introduced. In DCA, the channels are assigned randomly on a call-by-call basis in a dynamic fashion and the entire set of channels is accessible to all the cells. Cells have no channels themselves but refer all calls to the MSC, which manages all channel allocation in its region. All channels are kept in a central pool and are assigned dynamically to radio cells as new calls arrive in the system. After a call is completed, its channel is returned to the central pool. The advantage of dynamic channel assignment is flexibility and traffic adaptability, since channel assignment is based on the current network conditions. DCA makes wireless networks more efficient, especially if the traffic load distribution is not known or changes with time. DCA methods have better performance than fixed channel assignment methods for light to medium traffic load. DCA methods are more complex, and their overhead is higher.

To better understanding about DCA scheme [41], let us consider a mobile network system with C cells and F channels. Let k denote the cell where a new call arrives, $P(k, t)$ denote the set of ongoing calls in the cell k, and $Q(k, t)$ denotes the set of channels being used by the neighboring cells of k at time t. Then the set of eligible channels or free channels in cell k at time t is given by $\mathrm{I}(k, t)=F-(P(k,) \cup Q(k, t))$. The problem of DCA scheme is how to choose channels from the set $I(k, t)$.

2.1.2.3 Hybrid Channel Assignment (HCA)

DCA schemes provide flexibility and traffic adaptability. However, DCA strategies are less efficient than FCA under high load conditions. To overcome this drawback, hybrid assignment [45] techniques were designed by combining FCA and DCA schemes. HCA is nothing but a combination of FCA and DCA that tries to achieve the lowest blocking rate of each technique depending on traffic intensity. The total number of channels available for service is divided into fixed and dynamic sets. The fixed set contains a number of nominal channels that are assigned to cells as in the FCA schemes and, in all cases, are to be preferred for use in their respective cells. The second set of channels is shared by all users in the system to increase flexibility. When a call requires service from a cell and all of its nominal channels are busy, a channel from the dynamic set is assigned to the call. The ratio of fixed to dynamic channels is a significant parameter that defines the performance of the system. In general, the ratio of fixed to dynamic channels is a function of the traffic load and would vary over time according to offered load distribution estimations. The ratio of FCA:DCA is set a priori by cellular network designer. For example, the representative ratios for a set of 70 channels could be: 35:35, 49:21 and 21:49. In low traffic intensity the DCA scheme is used; in heavy traffic situations the FCA strategy is used.

2.1.3 Channel Assignment Constraints

When dealing with different channel assignment schemes in cellular networks, some constraints have to be considered for assigning a certain channel to a call in a cell. In literature [42], channel assignment constraints are generally classified as hard constraints and soft constraints, which can be further divided as follows:

2.1.3.1 Co-Channel Constraints

Assignment of the same channel simultaneously to certain pairs of the cells i.e. pair of cell within the re-use distance causes the co-channel interference in the system [42]. If co-channel interference is not minimized, it decreases the ratio of carrier to interference powers (C/I) at the periphery of cells, causing diminished system capacity, more frequent handoffs, and dropped calls. The co-channel constraints ensure that the same channel can not be assigned to certain pairs of radio cells simultaneously which causes co-channel interference.

2.1.3.2 Adjacent Channel Constraints

Assignment of adjacent channels (e.g., fi and fi+1) to certain pairs of cells simultaneously introduce adjacent channel interference in the network [42]. The adjacent channel constraints ensure the channels adjacent in the frequency domain can not be assigned to adjacent radio cells simultaneously.

2.1.3.3 Co-Site Constraints

Assignments of channels in the same cell that are not separated by some minimum spectral distance introduce co-site interference [42]. The co-site constraints ensure any pair of frequencies or channels assigned to a radio cell must have certain distance in the frequency domain.

The above mentioned constraints are known as electromagnetic compatibility constraints. These constraints have to be satisfied before assigning any radio channel to a call in any cell. It is not possible to use the same channel in two interfering cells in a network. As the above mentioned conditions cannot be violated so we also refer to them as the hard constraints. If a channel is selected according to a suitable channel assignment algorithm that does not satisfy these constraints, the corresponding call will be blocked.

Other than the hard constraints and traffic demand constraints, some constraints need to be considered to improve the performance of the dynamic channel assignment techniques. They are packing condition, the resonance condition, and the limitation of reassignment operations conditions [Sandalidis 98a]. These conditions are called soft constraints and were introduced in [Del Re 96]. Soft constraints differ from the hard ones for the fact that they can be contravened at the cost of a slight decrease in the allocation performance.

2.1.3.4 Packing Condition

The packing condition tends to use the minimum number of channels every time a new call arrives to satisfy the global channel demand [Sandalidis 98a]. The impact of this condition on the assignment is to prefer channels already used in other cells, without violating the hard conditions. If more choices are possible, channels used in nearest cells are taken into account.

2.1.3.5 Resonance Condition

The resonance condition tends to assign the same channels to cells that belong to the same reuse scheme [Sandalidis 98a], obtained by jumping from one cell to another with steps of length exactly equal to the reuse distance. For an example, figure 2.4 is a representation of a cluster of seven cells, which will give us a better understanding about the significance of resonance condition. The numbers inside the cell indicates the reuse scheme number. Let us assume that a call comes to cell 1 which belongs to reuse scheme 1 (cells: 1, 10, 12, and 13). The resonance condition tries to assign channels, which are already in use in the remaining cell of reuse scheme 1. The advantage of this approach is that this will leave channels to be allocated to cells other than this reuse scheme without causing co-channel interference with cells belonging to reuse scheme 1. This reduces the call blocking probability. The objective function should select a combination of channels that makes maximum use of channels already in use in the reuse scheme to which the cell involved in call arrival belongs. This condition tends to give an optimum assignment in the presence of a uniform distribution of incoming calls among the cells. When a non-uniform traffic is present, this condition still seems to work well by arranging the assignment in an ordered way without interfering with the dynamic assignment concept.

2.1.3.6 Limiting Reassignment Condition

In a cellular system whenever a channel is assigned to a new call in a cell, it may introduce interferences to the other ongoing calls in the cell which in turn may cause the forced termination of an ongoing call. This requires the reassignment of channels for the ongoing calls to the entire network. Channel reassignment in the entire cellular network upon a new call arrival will obviously result in lower call blocking probability, but it is complex both in terms of time and computation. Therefore, the reassignment process should be limited to the cell involved in new call arrival. On the other hand, excessive reassignment in a cell may lead to increase in blocking probability. So a process called limiting reassignment is considered which tries to assign, where possible, the same channels assigned before, thus limiting the reassignment of channels. A violation of this condition means the impossibility of serving an incoming call which is obviously blocked. To better understand this process; let us consider a cellular system with nine cells and 10 channels available to the whole system [Sandalidis 98a] in figure 2.4. Let us assume that a call arrives in the cell no 7 and digit 1 shows the specific channels are already been using in that cell.

	← channels →									
	1	2	3	4	5	6	7	8	9	10
Cell No. 7	1	0	0	1	0	1	0	1	0	1

Figure 2.4: Channels in use in cell no. 7

From the figure above, we see that the channels are free to serve a new call are: 2,3,5,7 and 9. But considering the co-channel interference scenario let us assume that only channel 6 of this cell can serve a new call. Taking this apparent scenario into account and without considering reassignment the new call will be blocked obviously. With reassignment some of the ongoing calls in cell 7 made it possible to acquired channel 6 as the free channel to serve the new call. A possible reassignment might look like the channel assignment shown in figure 2.5.

	← channels →									
	1	2	3	4	5	6	7	8	9	10
Cell No. 7	0	0	1	1	1	1	0	0	0	1

Figure 2.5: A possible channel assignment after reassignment in cell number 7

Hence, the reassignment process greatly affects the call blocking probability. We have considered reassignment only in the cell involved in the new call arrival due to computational reasons as in [Sandalidis 98a]. All these conditions lead to the definition of our fitness function or energy function to introduce power control of our HCA-PC strategy.

2.2 Reuse of Channel

The total number of channels in a cellular network system is limited, which limits the capacity of the system to maintain simultaneous calls. The capacity may only be increased by using each frequency channel to carry many calls simultaneously. One way of accomplishing this is to use the same channel again and again. To do so, mobile terminals using the same channel have to be far away from each other in order to avoid interferences. A minimum distance between two cells using the same channels is required, known as the channel reuse distance *Ds*. The capacity of the system depends on this distance. The concept of channel reuse may be understood from Figure 2.7, which shows how three frequencies *A, B,* and *C* are assigned to various hexagonal-shaped cells. Assignment of frequencies to different cells is accomplished by starting with a cell and assigning it a frequency, for example, *A*. Then the three branches, which are separated by 120, are successively assigned frequencies *B, C, A, B, C,* and so on. Next, a cell with frequency *B* is taken as a center cell, and frequencies *C, A, B, C, A, B,* are assigned to the three branches, which are separated by 120. Similarly, when a cell with frequency *C* is taken as center cell frequencies *A, B, C, A, B, C* are assigned to the three branches. The procedure may be repeated if desired to complete the assignment to all cells. For this case, the minimum distance between any two cells using the same frequency is equal to one arm of the hexagon. The cells that use the same set of channels are known as co-channel cells. The cells with frequency *A* in figure 2.7 are co-channel cells.

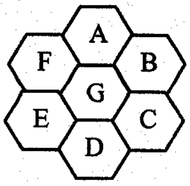


Figure 2.6: Cluster of 7 cells

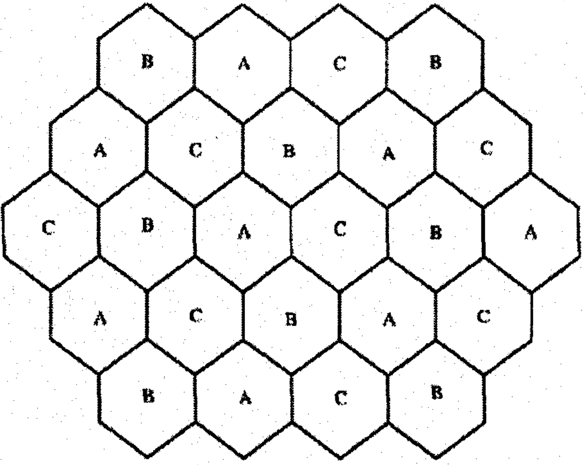


Figure 2.7: Frequency re-use pattern with Ds=2 cell unit

The interference caused by the radiation from these cells is referred to as co-channel interference. For the system to function properly, this interference needs to be minimized by limiting the power transmitted by the mobiles as well as by the base stations in co-channel cells. The co-channel interference is measured by a required Carrier to Interference Ratio (CIR). Some papers use Signal to Interference Ratio (SIR) instead of CIR. Another measure of co-channel interference is Bit-

Error Rate (BER). Due to the introduction of co-channel interference, all channels cannot be reused in every cell.

The nearest co-channel neighbors of a particular cell can be found by: (1) move i cells along any chain of hexagons and then (2) turn 60 degrees counter-clockwise and move j cells, where i and j are non-negative integers [42]. This is illustrated in figure 2.8 for $i=3$ and $j = 2$. In figure 2.8, cells marked with x are co-channel cells. The value of the number of cells per cluster (N) is determined by the equation $N = i^2 + j^2 + ij$ [9]. Thus a cluster can only accommodate 1, 3, 4, 7,..... cells. Figure 2.6 (adapted from [Rappaport 96]) shows a cluster of 7 cells with frequency spectrum divided into 7 groups (1,2,3..7) and figure 2.7 (adapted from [Rappaport 96]) shows the frequency

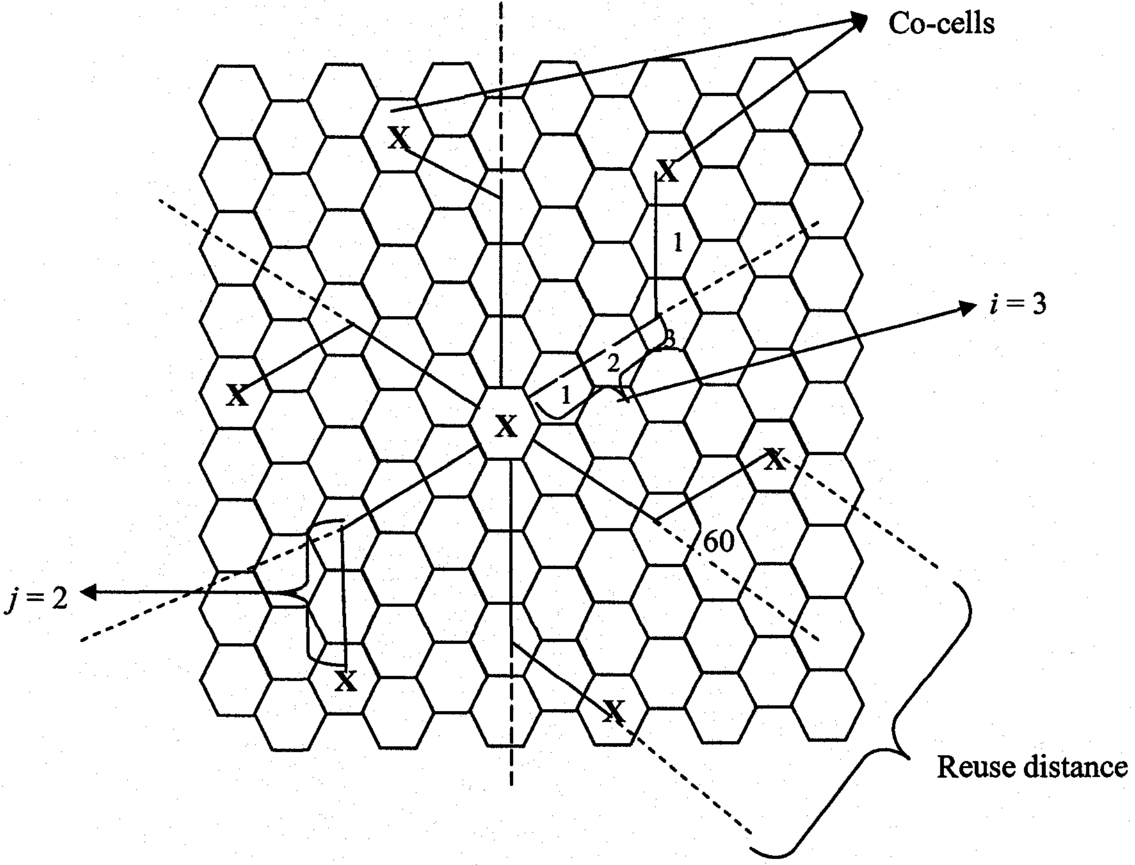


Figure 2.8: Method of locating co-cells in a cellular system

pattern with cluster of 7 cells and cells with same name are co-channel cells. N can be found out by the relation in the following equation $\sqrt{3N} = \frac{Ds}{R}$ [MacDonald, 1979; equation 2, pp. 23] where R is the radius of the cell and the ratio Ds/R is called the co-channel reuse ratio.

The longer the reuse distance is, the smaller the co-channel interference level. However, a long reuse distance increases the number of cells per cluster resulting in smaller reuse efficiency. Thus the frequency reuse pattern should be determined taking into consideration both the co-channel interference level and the reuse efficiency. In traditional FCA and DCA, the channel assignment is made considering the co-channel interference level determined by a fixed reuse distance, settled on during network planning.

2.3 A Brief Review of Channel Assignment

In order to assign channels properly and efficiently in wireless cellular networks different researchers have used different channel assignment strategy to solve FCA and DCA problem based on fixed or dynamic reuse distance concept. Some of the important strategies have been highlighted in the following sections.

2.3.1 Evolutionary Strategy (ES) Approach

The use of Evolutionary Strategy (ES) approach to the optimization of DCA and HCA has been proposed in [32] & [41]. Sandalidis et al. [32] formulated the channel assignment as combinatorial optimization problem with solutions represented as vectors of binary digits. In their problem formulation, the size of a solution is always equal to the total number of channels available. A similar approach is used in [41], where Evolutionary Strategy (ES) approach deals with a novel hybrid channel assignment based scheme called D-ring. D-ring strategy takes care of co-channel interference constraints in the host cell and its neighboring area. Vidyarthi et al. [41] proposed a novel way of generating the initial solution which reduces the number of channels reassignments and may generate a possibly better initial parent.

2.3.2 Dynamic Assignment Approach

All of the methods in [4], [5], [16] that follow this model perform dynamic channel-assignment which assigns channels using an on-demand basis in a network. These approaches do not take into consideration about the power savings or power controls in their analysis. Butala et al. [5] proposed the first MAC protocol where channel allocation is done based on the feedback of contention information occurs at the receiver. In [6], channel assignment is done through Fixed Channel Allocation (FCA) using MACAW, DBTMA, FAMA protocols where network throughput is very poor due to the collisions of data-packets because of hidden and exposed nodes. DCA in [5] provides higher normalized throughput by using the combination of RTS-CTS messaging, a query packet, and a busy tone as well as the contention information of the receiver which in turn avoids the collisions of data packets.

Although a similar technique is used by [Bao 2002] in the DCA scheme, but here channel allocation is mainly done with the detection of interference at the receiver which ensures the perfect reception data-packets under ideal conditions. The DCA methods have better performance for light traffic load, because they can balance the traffic load better. Under a heavy traffic load, the wireless network is near its full capacity; even DCA is not capable of avoiding high call reject rates.

Hać et al. [17] introduces a hybrid channel assignment to reduce the problems which arise in DCA methods under heavy traffic load. Since the hybrid channel allocation method is a mixture of fixed and dynamic channel allocation, it performs well as a fixed channel allocation method under light traffic. Also this technique gives better performance, especially under heavy traffic loads, because they can balance the traffic load better. Under the hybrid method, when traffic load increases, the percentage of blocking channel rate increases more slowly than for the traditional methods.

2.3.3 Two-Way Handshaking Approach

The major concern of this model is to assign channels dynamically by exchanging few messages between transmitter and receiver without any clock synchronization. All of the approaches [4],

[22], that follow the RTS-CTS two-way handshaking method carry out dynamic channel-assignment in ad hoc networks in an on-demand manner.

Another novel concept called Distributed Call Reservation Scheme (DVRS) introduced in [22]. As in DVRS, the sender sends a small packet called as RTS before data transmission which carries the destination address and the length of data. Even though in DVRS, two nodes send this packet at same time then only these small packets are destroyed i.e. no call blocking or call dropping arises.

2.3.4 Interference-based Approach

Under this scheme, all methods [4], [7], [25] assign channels on the basis of interference type at the receiver. A simple aggressive algorithm known as the Least Interference Algorithm (LIA) is presented in [7]. In LIA the instantaneous power measurement is used to select the channel with the least-received interference power. The selection of the least received interference channel minimizes overall interference power in the system and thus increases the network capacity.

While most of the existing algorithms for the channel-assignment problem are based on single interference, only the minimum-span frequency-assignment protocol (MS-FAP) in [25] takes into consideration multiple interference with minimize the span.

Another interference-based channel-assignment strategy is well discussed in [47], where some of the channel-assignment schemes have been studied to improve the performance of Dynamic Channel Allocation (DCA) schemes. These interference-based schemes are Random Channel Selection (RCS), Sensing-based Channel Selection (SCS), and Probing-based Channel Selection (PCS) schemes. The shortcomings in RCS and SCS schemes is that, here the interference could increase dramatically and force some transmissions to be dropped. On the other hand, in the PCS scheme the interference caused to other link's transmission power is reduced significantly.

2.3.5 Channel-Probing Approach

The channel probing schemes introduced in [47], under the interference-based model is based on the assumption that the set of active links is used to update their transmission power frequently, which in turn increases the interference in the channel quickly. But these active links experience additional interferences when a set of new links joins the channel and start to transmit.

2.3.6 Disk Graph Approach

The approach of the algorithms under this class is based on the concept that the direct collision and hidden-terminal interference in the network could be eliminating by introducing a variety of disk graphs model. From the other existing research it is shown that in Unit Disc (UD) graph, Intersection Disc (ID) graph, and Containment Disc (CD) graph, a node is represented as a single disc. The UD model is not realistic but it set a foundation for other classes of disc graph. The authors in [7] introduce a new class of disk graph called the interFerence Disk (FD) graph model, in which a heuristic algorithm is designed for graph coloring.

2.3.7 Assignment & Reassignment Approach

In [6], a channel-assignment and re-assignment protocol was proposed which prevents the co-channel interference when one pair of communicating hosts becoming closer to another pair of hosts using the same channel. It was claimed experimentally that channel-assignment and reassignment increases the network capacity as well as decreasing the rate of call dropping among hosts in cellular networks.

2.4 A Brief Review on Power Control

In literature, a number of papers have addressed the problem of power control. Using power-control may bring several advantages such as longer battery life time, may reduce co-channel interference among neighboring hosts, and it may enhance channel reuse. In order to increase the network capacity, efficient management of power-control is very important in wireless cellular networks, because of its impact on the battery life of wireless devices and on the capacity of the networks. Thus the energy savings and the efficient use of network resources make power-management one of the most interesting areas for researchers. For efficient power-control in cellular networks different researchers have used different power-control schemes.

2.4.1 CIR Measurement Approach

Power control scheme based on the CIR measurement have been addressed in [Bambos 98], [Aien 73], [Fujii 88]], [Zander 93]. In these schemes, the transmitter power is regulated such that the signal quality can maintain a desired CIR target. In [3], the power control problem is formulated as that of finding the smallest transmit power vector which will help maintain the CIR at all receiver nodes above a specified threshold level. An adaptive scheme (called DPC) is derived within this framework. Active link protection (ALP), voluntary dropout (VDO) and channel probing based on the DPC scheme have been investigated.

2.4.2 MAC Protocol Approach

All of the methods [29], [18], [39], [7], [7] that follow this scheme perform power savings under the MAC protocol and thus increase the network capacity. Among these approaches, different researchers use different schemes. For example [7], [39] use two-way handshaking (RTS-CTS) algorithms with their corresponding MAC scheme. Other approaches use different schemes under the MAC protocol.

In [39], a judicious power-control MAC protocol called PCMAC is used to enhance the original MAC protocol in the IEEE 802.11 standard by improving the handshaking mechanism and adding one more separate power control channel.

Similar work, reported in [29], mainly focuses on battery-power savings which will ultimately enhance the network capacity and throughput. In [18], it is observed that there is a tradeoff relationship between RF transmission power and the packet retransmission. But reduction of transmission power may cause a packet error, thus resulting in excessive retransmission, which is very power does not consuming. It means reducing of transmission power not necessarily save the battery life.

For light network traffic, another MAC protocol DPC/ALP came into the scenario [20], which can deliver an extremely short session without excessive delay in the power-up phase. An access-control scheme called adaptive probing has been developed which is capable of deciding the maximum allowable data rate.

In [7], a power-control MAC protocol referred to as the BASIC scheme, based on the RTS-CTS handshaking protocol is proposed. Under this scheme the RTS-CTS are transmitted using the highest power level and DATA-ACK is transmitted using minimum power levels in order to save energy or battery life considerably. However, this BASIC scheme increases collisions and retransmissions, which can result in more energy consumption, and throughput degradation. To overcome these difficulties, the authors proposed another Power Control MAC protocol, PCM, which periodically increases the transmit power during data transmission. PCM protocol achieves energy savings without causing throughput degradation where the status of interference level was not considered at all.

Following [7], a similar report is presented in [44], which combines the intelligence of power control, RTS-CTS dialogue, and busy tones to increase the power savings as well as the channel utilization. Under this environment a sender used relatively low power level so that the channel reuse can be increased. Thus, together with the extra benefit such as saving battery energy and reducing channel interference shows a hopeful path to enhance the performance of Mobile Cellular Networks.

2.4.3 Transmit Power Level Approach

All the methods [32], [1], [12], [14], [35] that follow this scheme accomplish power-control in cellular networks by controlling the transmission power, i.e., either keeping the transmit power fixed or adjustable.

In [32], a power-control loop algorithm is used to allow all nodes to communicate with their neighbors by choosing different transmit power levels for each of them. Thus interference is reduced and energy consumption is increased by 10-20%, and the overall throughput is increased by 15%.

The authors in [1], have introduced a power control algorithm in the single channel case and multi-channel cases. New request probes several channels for the fastest and feasible admission to the network based on the number of iteration to reach required SINR. In [6], three power controls: CLUSTERPOW, Tunneled CLUSTERPOW and MINPOW algorithms are proposed to enhance the drawback of [14]. Here a power level is chosen so that all the intra-cluster communication is possible with a lower transmit power level and all the inter-cluster (different cluster) communication use a higher transmit power level.

2.4.4 Local Information Approach

This model is followed by the approaches described in [11], [36], [38], where power savings carried out by the local information of the next hop in a network. Such as in [11], the next-neighbor transmissions are focused where transmitters send packets to their respective receiver on the basis of SINR. It limits the multi-user interference to increase single-hop throughput and reduce power-control to increase the battery life.

There are two power-control schemes addressed in [41], a distributed power-control scheme and a distributed joint-scheduling and power-control algorithm. The first scheme provides an optimal solution that minimizes the power consumption incorporation with the desired SINR at the receivers and the second algorithm solves some of the specified power-control problem by eliminating the comparatively strong interferences.

In [36], each node in a multi-hop wireless cellular network takes local decisions by itself about the transmit power which collectively strives towards global connectivity. Here a node gets the directional information of its closer neighbor nodes in all directions and increases it's transmit power until a node is discovered.

2.4.5 Wakeup-Sleep Approach

All of the approaches [2], [15], that follow this model significantly save energy consumption without a significant compromise of network capacity and connectivity. In [2], a power-saving technique named span is used where each node takes the decision whether it will go to sleep or wake up to help as a coordinator for communication between two of its neighbors. The authors demonstrate that the system lifetime can double, using this technique.

In [15], a distributed power-management scheme is proposed where a power device could be activated remotely by any sort of waking-up signal using a simple RF tag technology. In that way a node may enter a sleep state if it is not currently used and will wake up when traffic is to bet transmitted by this node. Also a node can select a sleep pattern according its QOS and battery status, as well as it can enter a sleep state only if they are idle. At heavy traffic load a 24% of power gain is possible to obtain in this scheme.

2.5 Integrated Channel Assignment and Power-Control

Channel-assignment and power-control are two effective means to improve the capacity of wireless networks. By integrating these two, the network capacity and throughput can be further increased. A distributed approach to the optimization of integrated channel assignment (DCA) and power control has been proposed in [16] and [28]. Both papers use an interference region and the neighboring cells exchange the channel usage information periodically. In [28], every cell maintains a list of the priority of available (free) channels. Ni et al. formulated a cost function to determine the priority of a channel based on the use of the channel in a cell's vicinity. The cost function is such that farther a given channel is from the current cell, the lower is the cost. The lower the cost the higher is the priority of a channel. After a channel is selected, the proposed algorithm applies power control to check the CIR value. In [16], every cell maintains a channel table. The channel table contains channel usage information in a cell's neighborhood and the CIR value for each channel. Each cell also maintains the record of the number of co-channels for each channel. When a new call come to a cell, the proposed algorithm searches for a free channel with desired CIR and with highest number of co-channels from the channel table.

In [8], an autonomous algorithm is presented to combine the dynamic channel-assignment (DCA) and power control. Here the DCA algorithm is based on the determination of paired channels that have very low level of interference or have very low possibility of causing interference. The power-control algorithm uses local estimations of carrier-to-interference-ratio (CIR) at a receiver which leads to adjustment of power on the desired transmitter. But this scheme has limitations when the hosts have higher mobility.

Kulkarni et al. [21], have studied a power control and channel assignment algorithm to minimize transmit power per bit by finding minimum incremental power, and compared this with least interference algorithm. This is not a distributed algorithm, but can be used as upper bound to the performance of distributed algorithm.
A similar report has been presented in [28], where the pedestrian mobility along with a low power-update rate is considered. The shortcomings in [8] are overcome under this scheme, and a system could achieve a higher capacity level than is possible either in DCA or in PC. These integrated algorithms are very robust at higher degrees of mobility. But a higher cost is needed for reassignment, due to the motion of the users.

A simple Kalman filter was designed under an integrated dynamic channel and power allocation (DCPA) [32] that provides the measurement of both the channel gains and the interference power among nodes. It is shown that the DCPA scheme performs better call droppings, call blockings and a fewer channel reassignments are required.

Power-control is also incorporated with distributed dynamic channel assignment (DDCA) algorithms [8], [12], but successful incorporation is difficult due to the near-far distance effect. In other words, it is very difficult to understand whether nodes are very far using higher power rates or nodes are very close using low power. Chuang et al. significantly reduced call interruptions by integrating an autonomous algorithm.

In [15], the authors point out that call dropping occurs when the same channel is activated within a vulnerable geographical region within the cell. Here, the independent algorithm (IA) measures channels in sequence and the least interference channels (LIC) are selected if the interference level is below the threshold value. Another paired duplex algorithm (PDA) significantly reduces call dropping provided that if the CINR value is above the MINCINR. Then a power-control algorithm is applied to the PDA algorithm to adjust the transmitter power.

2.6 Proposed Hill-Climbing (HC) Approach

Typically, this approach is used for problems where finding a goal state is more important than finding the shortest or most economic path to the goal state. Our main goal to find a best solution i.e. to find a best channel for a call so that efficient frequency utilization is possible as well as the elimination of frequency interferences. We have a solution space and each solution has an associated objective value or fitness value evaluated by a fitness function. The objective value is the representation of the individual solution's performance in relation to the parameter being optimized. It also reproduces an individual solution's performance in relation to other potential solutions in search space. Hill-climbing is a greedy technique where a candidate solution is produced by applying mutation on a given parent solution. The best solution selected from one generation becomes the parent for the next generation. The process of selection and application of mutation is repeated until some terminating criteria are reached. When the termination criterion is reached, the solution to the problem is represented by the best individual so far in all generations. The basic steps of an HC algorithm can be summarized as follows:

a) Generate an initial solution of 1 individual.
b) Evaluate the individual according to the fitness function.
c) Select the initial solution as the best solution so far.
d) Apply mutation to create next child solution from the initial solution.
e) Go to step b unless a termination criteria have been satisfied.

There is big difference of producing offspring between our approach and Sandalidis et al. [32] as well as Vidyarthi et al. [41]. In both the approach [32] and [41], parents produce λ offspring. These two approaches behave same in the selection of individuals for the next generation. In [32] & [41], the (μ, λ)-ES, μ best individuals from the set of λ offspring are selected to form the next generation. But in our approach, initial solution or first individual is selected as the best individual to form the next generation. Figure 2.9 shows a typical example of hill climbing approach.

Hill Climbing Approach might face one of the following three problems:

- The foothill problem: Hill climbing can get stuck on local maxima.
- The mesa problem: Hill climbing flounders in regions where all moves in the solution space yield similar marginal improvements in solution quality.
- The needle-in-a-haystack problem: Hill climbing (like all other search algorithms) has problems when the best solution is a singularity in the solution quality surface.

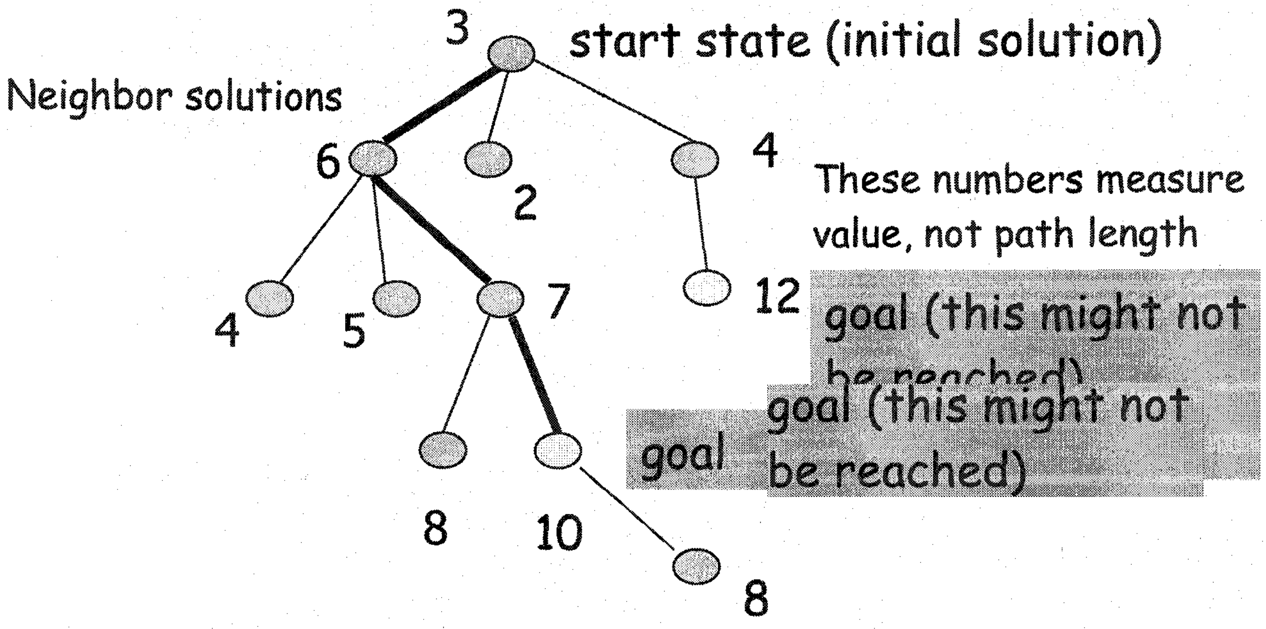


Figure 2.9: Example of hill climbing approach

For fixing these unforeseen problems we have also extended our HC algorithm by implementing a method called hill climbing with random restarts strategy. If we find a solution, it is guaranteed to be a valid solution. If no solution is found, it does not necessarily mean that there is no solution to the problem. One can further pass the problem to the hill climbing with random restarts method until a solution has been found or a predetermined number of generations have been produced.

Chapter 3

Proposed Methodology

In this thesis we propose a combined hybrid channel assignment and power control (HCA-PC) method to increase the capacity of a wireless cellular network using dynamic reuse distance concept. We assume that each base station has a controller or a computer to serve a cell and all mobile terminals are connected to other networks in the system through the base stations. Information about the present status of all calls and neighbors in each cell is being exchanged to each other using the controllers of each cell. Each controller of the specific base stations assigns channel with HCA scheme [41] based on the level of interference measured on each of the free channels immediately prior to the commencement of the call. The channels are measured dynamically by reproducing child with a mutation process and the least interfered channel (LIC) is selected for the new call, provided the interference level is below a set interference threshold. Thus a channel is assigned to a new call and the communication is established which might affect on other ongoing calls already on the channel. If the interference level of any ongoing call rises above the interference threshold, the specific ongoing call will be forcibly terminated from the network. To avoid the forced termination of ongoing calls, we implement the reassignment terminology which will reassign channels to the ongoing calls if it is necessary. We have modeled a fitness function or energy function in our approach based on the soft conditions and hard conditions using a dynamic channel assignment scheme and centralized power control. The minimization of this energy function gives the optimal channel assignment and power control.

In this thesis, we introduce a Hill Climbing (HC) based approach using an efficient problem representation and a simplified energy function as compared to the one proposed by Vidyarthi et al. [41]. The hard constraints, soft constraints and power control are taken care of by this energy function or fitness function. The feasibility of the solution has been guaranteed by the chosen problem representation and the mutation operator. We develop a hill climbing algorithm which optimizes channel assignment and power control using our problem representation and the proposed channel assignment scheme.

The characteristics of our proposed HC approach including the generation of initial solution, fitness function and mutation operator to generate child from a given parent solution, and the algorithm are described below.

3.1 HCA with Power Control

Channel assignment allows the efficient use of the available spectrum and hence has been a topic of intense research for many years. But the interference between reused channels limits the spectrum efficiency. Power control on the other hand, can suppress adjacent channel interference, co-channel interference, and minimize the consumption of power in terminals. Thus the problem of channel assignment is highly correlated to power control. When a call arrives and a channel is assigned without considering the CIR level, it may cause the CIR of ongoing call drop below the required threshold value, thereby causing force termination of ongoing calls. But it is found in literature that the users tend to prefer of call blocking of new calls instead of call dropping of ongoing calls. Thus the energy savings and the efficient use of network resources are the two components that make power-control one of the most challenging research topics for the researchers in wireless communication.

We propose a new HCA-LIC strategy to integrate the problem of channel assignment and power control concurrently. In this strategy channel assignment is made by the controller of the specific base station on the basis of interference level on the available free channels. The least interfered channel (LIC) is selected for the communication providing that the interference level is below the interference threshold. If the interference level of LIC is above the set interference threshold then the new call will be blocked. The channel usage information in the neighbors of a given cell is obtained from an allocation matrix. The allocation matrix, which is a $C \times F$ binary matrix (where C is the total number of cells in the system and F is the total number of channels available to the system), acts as the central pool. Each element a_{ij} in the matrix is one or zero such that

$$a_{ij} = \begin{cases} 1 & \text{if channel } j \text{ is assigned to cell } i \\ 0 & \text{otherwise} \end{cases}$$

The allocation matrix is updated every time a channel is assigned and released in the network.

3.2 Problem Representation

Assume a cell k is already serving d calls before the arrival of a new call at k in a cellular network. After arrival a new call at cell k, $d+1$ is the new traffic demand at cell k. Our problem is to assign a channel for the new call, also with possible re-assignment of channels to the d ongoing calls in cell k, so as to maximize overall channel usage in the entire network. Assume a potential solution, V_k, is an assignment of channels to all ongoing calls and the new call, at cell k. We call such solution an initial solution. We will represent V_k as an integer vector of length $(d+1)$, where each integer is a channel number being assigned to a call in cell k and $(d+1)$ is the new traffic demand at k. For example: if k=1, demand=4, available channel numbers = [1,2,3,4,5,6,7,8,9], then a possible solution can be $V1$ = [7, 2, 5, 3]. Our representation is efficient than Sandalidis et al. [32] and Vidyarthi et al. [41]. Sandalidis et al. [32] have used a binary representation where the size of a solution vector is equal to the total number of channels in the central pool. The disadvantage of this representation is that although they are interested only on the demand $(d+1)$ number of channels, but extra memory is consumed in storing the information about other channels. On the other hand, Vidyarthi et al. [41], have used the Evolutionary Strategy, where the initial parent solution is selected from a set G of λ solution vectors where $\lambda = |I|$. Here I is the set of eligible channels i.e. the set of available free channels. Each solution vector in G is evaluated according to the fitness function, and the individual solution with the best fitness is selected as initial solution. Thus in [41], if there are n elements in the set of free channels, then the time complexity will be $\boldsymbol{n}$ to select the initial solution. On the other hand in our strategy, the first element of solution vector in G is evaluated as per the fitness function and it is considered as the initial solution. Therefore in our approach, the time complexity to select an initial solution is constant (1). Another advantage of our representation is that the size of the solution vector is short so it is easier and faster to manipulate the vector.

3.3 Initial Solution

When a call arrives in a cell k, we determine the set of free channels I. Here $I=T-(P \cup Q)$, where T is the total set of available channels, P is the set of channels of the ongoing calls in cell k and Q is the set of channels in use in the neighboring area of cell k. This information is obtained from the allocation matrix. The first element from a set G of λ solution vectors (where $\lambda = |I|$) is selected as the initial solution (that is the very first solution) S_0. The initial solution is evaluated according to the fitness function, and considered as the best solution, so far. In case of a cell with demand strictly greater than 1, G is not generated in a totally random manner. Each solution in G contains a unique integer selected from $\boldsymbol{I}$ i.e. from the set of free channels. The remaining (d) integers in all solution vectors are the same channels of the ongoing calls in the cell i.e. P. For instance, let us consider the following example: a call arrives in cell 2, where P=[2, 5], T=[1, 2, 3, 4, 5, 6, 7, 8, 9] and Q=[1, 3, 6, 7, 8]. Therefore, the set of free channel is I=[4, 9], and λ=2. Here demand will be 3; therefore the size of a solution vector in G is 3. The possible two solution vectors in G are: $G1$= [2, 5, 4] and $G2$ = [2, 5, 9]. Out of these two solution vectors $G1$ and $G2$, $G1$ vector is selected as initial solution S_0. This way of generating initial solution will reduce the number of channel reassignments, reduce the time complexity to select the initial solution and therefore yields a easier and faster running time as well as the lower space complexity. The initial parent might be a potentially good solution since channels for ongoing calls were already optimized.

3.4 Channel Reassignment

In our formulation, a centralized DCA involves a single controller selecting a channel for each cell and results in a more efficient assignment than distributed DCA schemes which involve a number of controllers distributed across the network [37]. In our strategy, when a new call arrives to a particular cell, the ongoing calls i.e., the calls that are being already serving by some other channels are reassigned together with the assignment of the new call. Channel reassignment is an important operation in dynamic assignment schemes and improves the grade of service even more. By the reassignment we denote the process by which a call is transferred to a new channel without call interruption [4].

To better understand the meaning of reassignment; let us assume that we have a cellular system with nine cells and ten channels available [41]. Also assume that a new call arrives at the 3rd cell and the state status of this cell regarding the available channels is given by the following vector: [1 0 0 1 0 1 0 1 0 1]. This means that the first, fourth, sixth, eighth, and tenth channels in that cell are busy. Hence the second, third, fifth, seventh, and ninth channels are free and may serve for new calls. Again assume that only the sixth channel is the proper channel which is the least interference channel (LIC). Therefore, if no reassignment occurs, the incoming call will be blocked apparently. If we reassign the calls that are being served to other channels, then a way could be found out easily that the call in the sixth channel to be transferred to another channel without blockage. Hence, the sixth channel becomes free and may be now assigned to the new call. A possible vector after reassignment will now contains six busy channels and may be of the following form: (0 0 1 1 1 1 0 0 1 1) (the sixth channel is now dedicated to the new incoming call). Hence, the process of reassignment of the calls that is being served, affects to a large extent the blocking probability of the incoming calls.

Reassignment of the calls that are being served takes place simultaneously with the assignment of the new call to new channels. The outcome of this process is to find proper combinations of channels every time a call arrives so that cause of interference could be avoided. The process of reassignment is difficult to be accomplished by algorithmic allocation methods due to the increased complexity. When a call arrives in a particular cell, the rearranging channels in the whole cellular structure could obviously result in a lower blocking probability [4]], but it is too time consuming to be practical. Therefore, only reassignment in the cell involved in a new call arrival is considered [9].

3.5 Problem Statement

We consider the integration of channel assignment with power control concurrently for the uplink (mobile terminal to base station) only. We consider a cellular system with C cells and F channels. M denotes the number of users communicating in the same channel. The goal is to determine whether there exists a channel to serve a new call so that each mobile's CIR is acceptable and if it exists find an assignment of channels that minimizes the total transmitted power. Let P_i denote the transmitter power of mobile i and T_i denote the base station of the cell where mobile i is located. The CIR of mobile i at base station T_i is then given by equation 3.1.

$$T_i = \frac{P_i g_{ii}}{\sum_{k \neq i}^{M} P_k g_{ki} + N_i} \qquad (3.1)$$

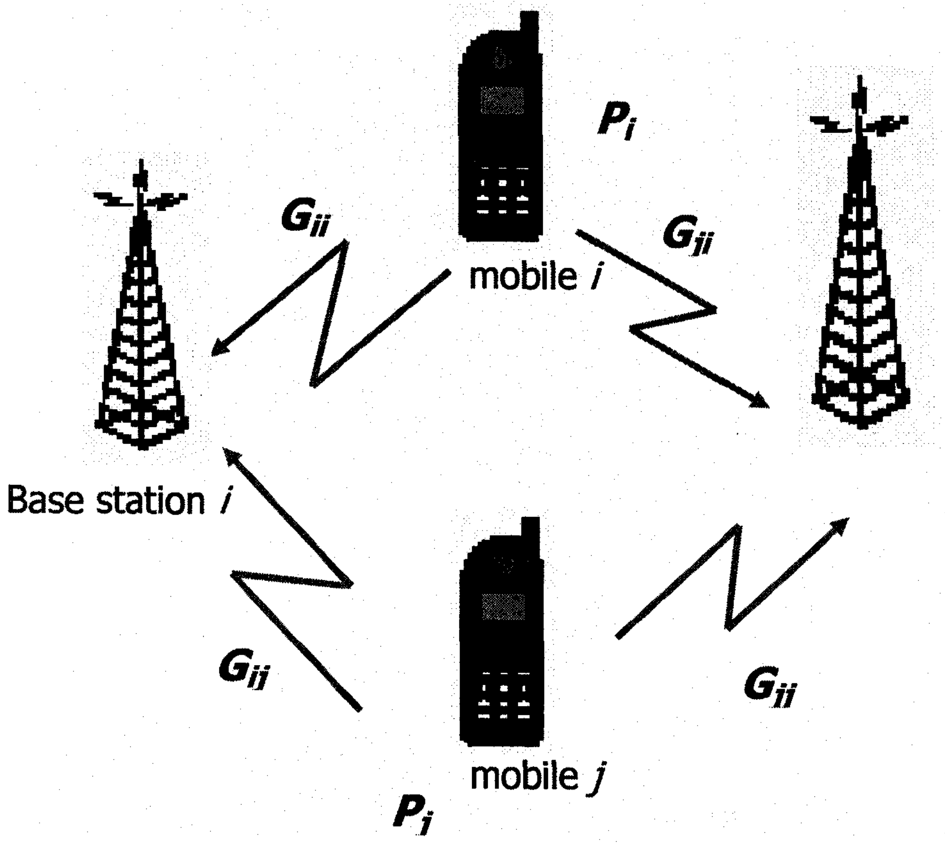


Figure 3.1: Link gain from mobile terminal to base station (Reproduced from [41])

where g_{ki} is the link gain (actually power loss) from the transmitter of the k^{th} link to the receiver of the i^{th} link, and N_i is the receiver noise at base station T_i. The link gain includes free space loss, multi-path fading and other radio wave propagation effects. It depends upon the particular propagation model of the channel [32]. The signal quality is acceptable if it is above a certain threshold γ_0 i.e.

$$T_i \geq \gamma_0, 1 \leq i \leq M \qquad (3.2)$$

When describing the signal on several links simultaneously it is more suitable to switch to a matrix notation. In matrix form equation 1 and 2 can be written as follows [29]:

$$[I - \gamma_0 F] P \geq U \qquad (3.3)$$

where $P = (P1, P2, \cdots, P_M)$ is the vector of the transmitter power, U is the vector with elements u_i defined as $u_i = \frac{\gamma_0 N_i}{g_{ii}}$ (3.4)

where i lies in this range $1 \leq i \leq M$, and I is $M \times M$ identity matrix, and finally F is a matrix defined as $[F]_{ij} = \begin{cases} 0 & \text{if } j = i \\ \frac{gji}{gii} > 0 & \text{if } j \neq i \end{cases}$ (3.5)

U is a vector of noise powers rescaled by CIR requirement and link gains, and F is a cross-link power gain [32]. The power control problem we solve has the form [29]

$\min \sum_{i=1} P_i$ (3.6) subject to $[\mathrm{I} - \gamma_0 F]P \geq U$.

The matrix F has a few important properties [29]. One such property is that: The target CIR γ_0 is achievable if the spectral radius of F denoted by $\rho(F)$ is less than $\frac{1}{\gamma_0}$, the power vector $P' = [\mathrm{I} - \gamma_0 F]^{-1} U$ solves the optimization problem. Therefore the CIR requirements of all the links are satisfied simultaneously. This property is modeled as a function that takes care of the co-channel interference constraint as shown in the equation below. $\sum_{j=1}^{d_k} \mathrm{int}\,erf\,(V_{k,j})$ (3.7)

where d_k represents the number of channel assigned to cell k, j is the index of vector V_k and V_k means the output vector for cell k with dimension d_k carry the same meaning as described in section 4. This function combined with packing condition and limiting reassignment can be modeled as energy function as shown in the next section, equation no. 3.8.

3.6 Fitness Function

In literature, the co-channel interference is considered as a hard constraint. Other conditions that may improve the performance of the assignment technique and are considered as soft conditions are the packing, the resonance, and the limitation of reassignment operation. These conditions were introduced in [9] and are also used in our approach. The soft condition permits lowering the call blocking probability. With the packing condition, the minimum number of channels is tried to be used every time a call arrives. This condition allows the use of channels that are already used in other cells without violating the co channel constraint. If more choices are possible then channels used in adjacent cells are considered. The resonance condition, which assigns the same channels to the cells that belong to the same reuse scheme, is automatically removed from our formulation, since it is in fact accounted by the co-channel interference constraints.

Finally, with the last condition, we try to restrict rearranging the reassignment into acceptable levels by reassigning the same channels because excessive reassignment may lead to undesirable results as far as the blocking probability is concerned. Reassignment in the entire cellular network upon a new call arrival will obviously result in lower call blocking probability, but it is complex both in terms of time and computation [58]. Therefore, the reassignment process is limited to the cell involved in new call arrival. But excessive reassignment may lead to increase in blocking probability [58]. So a process called limiting reassignment is considered that tries to assign, where possible, the same channels assigned before, thus limiting the reassignment of channels.

One of the major soft constraints, the resonance condition is taken care by the hard constraint, co-channel interference. This simplifies our fitness function as compared to Sandalidis et al. [32] and Vidyarthi et al. [41], where there is a separate term in the fitness function that takes care of resonance condition limitation. This also leads to a faster fitness calculation than Sandalidis et al. [32] and Vidyarthi et al. [41]. The problem representation also takes care of traffic demand constraint. The hard and soft conditions can be modeled as energy function as shown in equation 1. The minimization of this function gives the optimal channel assignment [58].

$$fitness = W_1 \sum_{j=1}^{dk} \text{int}\,er\, f(V_{k,j}) - W_2 \sum_{j=1}^{dk} \sum_{i=1\, i \neq k}^{C} A_{i,V_{k,j}} . \frac{1}{dist(i,k)} - W_3 \sum_{j=1}^{dk} A_{k,V_{k,j}} \qquad \textbf{(3.8)}$$

k : Cell where a call arrives

D_k : Number of channel assigned to cell k (traffic demand in cell k)

C : Number of cells in the network

V_k : Output vector for cell k with dimension d_k

$V_{k,j}$: j^{th} element of vector V_k

$A_{i, V_{k,j}}$: the element located at the i^{th} row and $V_{k,j}^{th}$ column of the allocation matrix A

dist (i, k) : distance (normalized) between cells *i* and *k*.

rest (i, k) : Function returns a value of one if the cells *i* and *k* belong to the same reuse scheme, otherwise zero.

W1, W2, W3 are positive constants [41]. The first term expresses the hard condition i.e. the co-channel interference constraint. The function *interf(Vk,j)* returns a value of one if the CIR of channel *j* drops below the target value, otherwise zero. This information is obtained from the matrix *CxF* as stated in property 1. The energy increases if the CIR of any element of vector V_k is below the required threshold. The minimization of this function gives an optimal assignment of channel. The second term expresses the packing condition. The energy decreases if the j^{th} element of vector V_k is also in use in cell *i*, and the cells *i* and *k* are free from co-channel interference. The decrease in energy depends upon the distance between the cells *i* and *k*. The last term expresses the limiting re-assignment. This term results in a decrease in the energy if the new assignment for the ongoing calls in cell k is same as the previous assignment. The value of the positive constants determines the significance of the different terms. We use the energy function as our fitness in the Hill-climbing Strategy. When a new call arrives, the cellular system applies the HC algorithm to find a solution vector with minimum energy. The vector includes channels for all the ongoing calls and the new call. If the CIR of any of the assigned channels of the vector is below the desired level, the solution vector is rejected and the new call is blocked. Otherwise, the call is successful. The allocation matrix is updated, and the existing calls are reassigned if any. This completes a call arrival process.

3.7 Mutation

A child or next solution is generated from a parent or initial solution by randomly swapping values of the initial solution vector with the corresponding vector of free channels. The number of swaps lies between 1 and *N* (inclusively). The parameter *N* is the maximum number of swaps and takes the value of the length of the initial solution vector or the numbers of free channels whichever is less. Given N, we generate a random number S between 1 and N (inclusively). The parameter S represents the actual number of swaps. For example, if total number of available channels $F = 10$, call arrives in cell k = 1, demand of channels in k is 4, and the initial solution vector $p = [7, 2, 5, 3]$, then the vector of free channels f of p is $f = [1, 4, 6, 8, 9, 10]$. Here $N = 4$, and if number of swaps is $S = 2$, then one possible next solution $O = [7, 4, 5, 10]$. Since mutation does not affect the length of the parent vector, and does not result in duplicate copy of any position, the algorithm always produces feasible solutions.

3.8 Hill-Climbing Approach

At a given generation, we randomly generate 1 offspring from the actual parent solution by mutation. We evaluate this solution by the fitness function and consider it as the best solution so far. Again we generate a next solution from this child solution and evaluate it by the same fitness function. Compare the fitness of these parent and child solutions. If the child solution's fitness is better than the former parent's value, then the latter one is the best solution so far. If the child solution's fitness is worse than the former parent's value, the algorithm tries to locally optimize this value. When the local optimization fails to find a better child solution within a predefined number of generations, a process called random restart strategy been applied with the HC algorithm. The proposed HC algorithm is shown in figure 3.2.

When a new call arrives in a cell, the cellular system looks for channels which are not in use in the cell and its neighboring area. If no such channel is found the new call is blocked, otherwise the HC algorithm finds a solution vector V_k with least interference level or minimum energy level by implementing HCA-LIC strategy. This vector includes channels for all the ongoing calls and the new call. The allocation matrix is updated, and the existing calls are reassigned if necessary. This completes a call arrival process.

3.9 Hill-Climbing Algorithm

Assume that the state description contains all of the information needed for a solution. Also assume the path by which the solution is reached is irrelevant. Also assume that we have an evaluation function or fitness function for the whole solution.

Algorithm:

```
  Generate initial random solution $S_0$
  Evaluate initial solution $S_0$ according to fitness function $f$
  Select $S_0$ as the best solution, best_so_far
  $loop = 0$
  Repeat
        $loop = loop + 1$
        $success$ = false
        Generate next solution $S_1$ from $S_0$ by mutation
        Evaluate $S_1$ according to fitness function $f$
        Compare $f(Si), f(Si+1)$
        If $f(Si+1) > f(Si)$
            best_so_far = $Si+1$
            $success$ = true
        endif
UNTIL $success$ = true or $loop = 20$

If $success$ = false ( apply hill-climbing with random restart strategy)
     $success1$ = false
     $counter = 0$
     $Best\_child1$ = best_so_far
Repeat
     $counter = counter + 1$
     $Parent1 = Best\_child1$
Generate 1 child Best_child2 of Parent1 by mutation
Evaluate Best_child2 according to fitness f
```

```
If f(Best child2) > f(best_so_far)
    best_so_far = Best_child2
    Best = Best_child2
    success1 = true
Until counter = 20 OR success1 = true
If success1 = false
    Blocked the call
```

Figure 3.2: Proposed HC approach with Random Restart Strategy

In our algorithm, from a given a parent, we randomly generate 1 child by mutation and select it as the best (i.e. the fittest) solution so far. If the fittest individual's fitness is worse than the former parent's value, the algorithm tries to locally optimize this value. When the local optimization fails to find a better child within a predefined number of generations, a strategy called HC with Random Restart is applied. This process is used to escape from the local optimum.

3.10 Complexity Analysis

Our algorithm

In each generation, we mutate and evaluate each solution:

- Complexity to do the mutation is $O(d_k)$.
- Complexity of evaluating a solution according to equation 3.8 is $O(d_k.C)$.
- Since each generation we have 1 child, therefore complexity of a generation is $O(1.d_k.C)$ *i.e.,* $O(d_k.C)$.

Algorithm of Vidyarthi et al. [41]

In each generation, each solution is mutated and evaluated:

- Complexity of doing the mutation is $O(d_k)$.

- Complexity of evaluating a solution according to equation 3.1 in [Vidyarthi 03] is $O(2d_k . C)$.
- Since in each generation there are λ offspring, therefore complexity of a generation is $O(\lambda . 2d_k . C)$.

Algorithm of Sandalidis et al. [32]

In each generation, each solution is mutated and evaluated:

- Complexity of doing the mutation is $O(1)$.
- Complexity of evaluating a chromosome according to equation 2 in [Sandalidis 98a] is $O(3F . C)$.
- Since in each generation there are λ offspring, therefore complexity of a generation is $O(\lambda . 3F . C)$.

The parameter λ in [41] represents the number of free channels available in the system is much greater than the constant number 1 in our approach. On the other hand, the parameter F in [32], which represents the total number of channels available in the system, is also much greater than our approach at a particular time instant. Therefore it clearly shows that the time complexity of our proposed algorithm is less than the one proposed in Vidyarthi et al. [41] and lesser than the Sandalidis et al. [32].

Chapter 4

Experiments and Results

In literature, several techniques are being using to evaluate the performance of the channel assignment and power control schemes under both uniform and non-uniform traffic load conditions. From a system performance perspective, a very important issue is how often users are denied service. Due to the larger number of requests for channels, the user in the cellular network system experiences a much higher call blocking probability. In our thesis, we have used a call blocking probability factor to evaluate the performance of the proposed channel assignment and power control concurrently [41]. At a particular traffic load, the new call blocking probability factor *Pn* can be assessed as the ratio between the new calls blocked and the total number of call arrivals. Thus ,

$$P_n = \frac{\text{number of new calls blocked in the system}}{\text{number of total call arrivals to that system}} \qquad \textbf{(4.1)}$$

The following sections are a brief description about the cellular model assumption, traffic model used in the simulation, and the experimental results obtained from the simulations.

4.1 Cellular Model Consideration

In this thesis, we applied the Hill-Climbing (HC) approach to the mobile cellular model proposed in Del Re et al. [9]. A brief description of the basic attributes of the model is as follows:

1. A group of hexagonal cells form the topological model that form a parallelogram shape including equal number of cells along x-axis and y-axis as shown in the figure 4.1 (Adapted From Del Re et al. [9], Fig. 1, pp.26). In our approach, we have used 49 cells to design the network simulation.

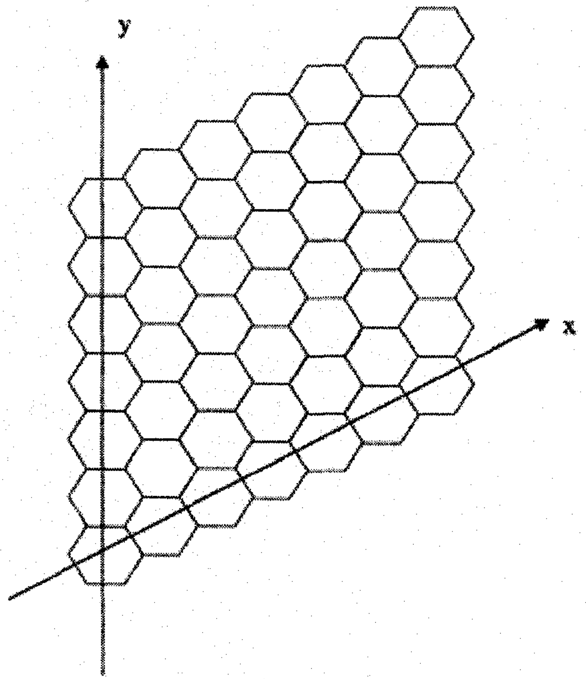


Figure 4.1: Cellular network model.

3. We have used a total number of 70 channels for the entire network simulation. In FCA, the available channels are distributed among the cells permanently. In DCA, all channels are put in central pool and a channel is assigned to an incoming call by a central controller that supervises the whole cellular network.

4. Incoming calls at each cell may be served by any of the system channels.

5. The selection of a channel is subject to the power control and only LIC channel will be assigned for a new call.

6. A call is blocked if there are no channels available to serve the call i.e. the whole set of channels are being using by the involved cell and its neighborhood. Also a call will be blocked if there is no channel available that satisfies the interference threshold level or the interference level of any ongoing calls rise above the interference threshold.
7. Existing calls in a cell involved in a new call arrival may be rearranged if necessary.

By using these model assumptions we compare and investigate our results with those obtained by Sandalidis et al. [32] and Vidyarthi et al. [41].

4.2 Implementation Details

To implement the network simulation a computer based simulation is performed using C++ programming language. A detail description of the implementation procedure and various parameters used in the simulation are as follows.

4.2.1 Determination of Allocation Matrix

An allocation matrix (a two dimensional array) of size *CxF* is used to maintain the channel usage information of the selected cell for a call and its surrounding cells as well as the entire network. Where *C* is the number of cells in the system and *F* is the number of total channels available for the system. The allocation matrix acts as the central pool of all the available channels. At the start of the simulation, the allocation matrix is initialized with zero. The allocation matrix *A* is dynamic and it is updated every time a call is successful and a call is released from the system.

4.2.2 Determination of Reuse scheme

In our simulation, we consider a network model of 49 cells that forms a parallelogram shape with equal number of cells in x-axis and y-axis. The cells are numbered starting from 0 to $C-1$, where $C=49$ as shown in figure 4.2. The coordinates of a cell can be calculated as simply counting the index number in a two dimensional array. For example, the coordinate of cell 17 is (3, 2) and that of cell 32 is (4, 4) as shown in the 4.3.

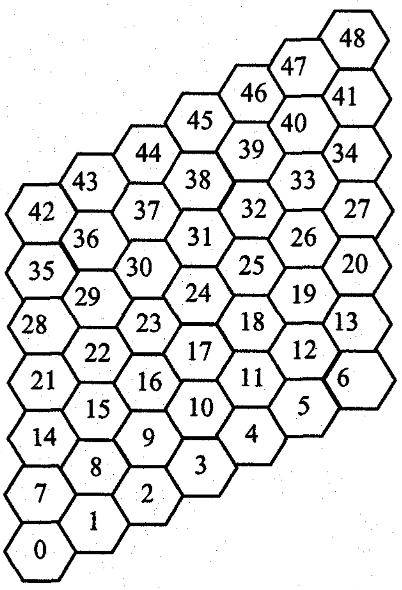
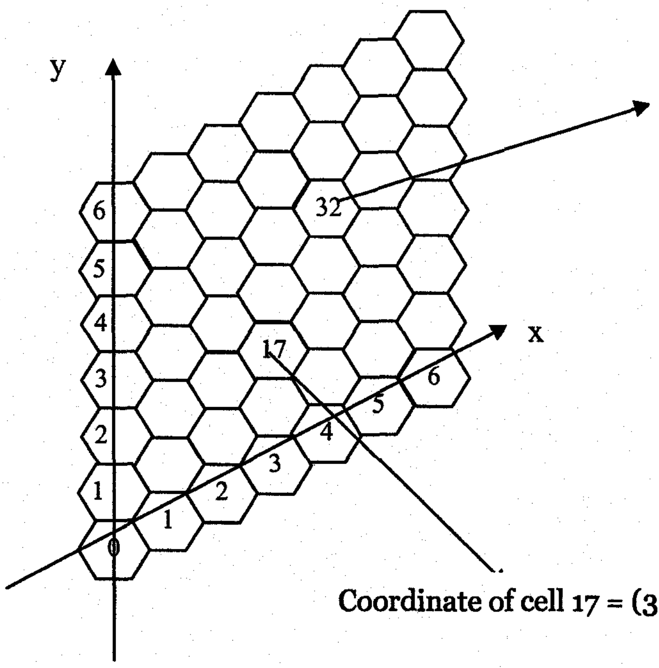


Figure 4.2: Numbering cells in the model *(Reproduced from [41])*



Coordinate of cell 32 = (4, 4)

Coordinate of cell 17 = (3, 2)

Figure 4.3: Coordinate of a cell (Reproduced from [41])

4.2.3 Determination of Distance between Two Cells i and k

The distance between two cells can be calculated as the Manhattan distance [41]. The minimum number of steps needed to move form the center of one cell to the center of the other cell is the distance between any two cells. A step is the distance between the centers of two adjacent cells, and is considered as the unit distances i.e. an equivalent value of 1. For example, if we consider two example, if we consider two cells $i = 0$ and $k = 24$ as shown in figure 4.2. The minimum number of steps required to go from cell i to cell k is 6, thus the distance between i and k is 6.

4.3 Traffic Model

In our model, we assume the traffic model follows the blocked-calls-cleared queuing strategy [41]. An incoming call is served immediately if a free channel is available and the interference level of this channel is below the interference threshold value, otherwise the call is blocked and there is no queuing of blocked calls. The most fundamental characteristics of this model include:

1. Number of users is infinite
2. Number of available channels is finite
3. Arrival of requests is memory-less
4. Call arrival follows a Poisson process with mean arrival rate of λ (calls /hour)
5. Call duration is exponentially distributed with mean x.

The traffic load offered to the cellular network can be found out by the product of mean arrival rate and the mean call duration. The traffic in the cellular network may either follow uniform or non uniform distribution. In uniform traffic distribution, every cell has the same traffic load. In non uniform traffic distribution, every cell has a different call arrival rate. As traffic loads are changing dynamically, the non uniform traffic distribution is more realistic in mobile communication. For non uniform traffic distribution, we consider the traffic patterns proposed in Vidyarthi et al. [41] shown in figure 5 and 6. The numbers inside each cell represent the mean call arrival rate per hour in the cell. The time to hold each call is 180 seconds.

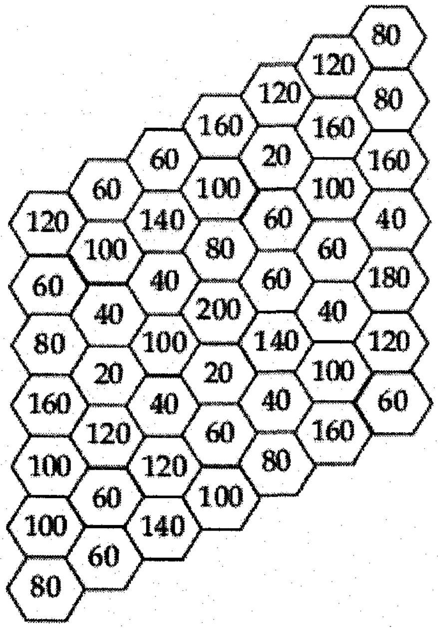


Figure 4.4: Non Uniform traffic distribution pattern 1 with initial Poisson arrival rates (Calls/hour). (Reproduced from [41])

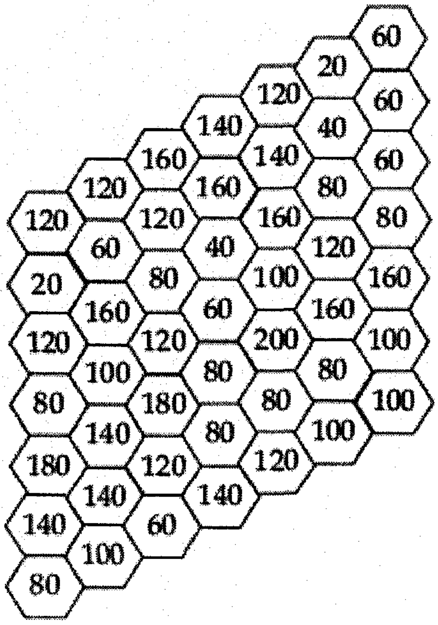


Figure 4.5: Non Uniform traffic distribution pattern 2 with initial Poisson arrival rates (Calls/hour). (Reproduced from [41])

4.4 Simulation Procedure

The simulation procedure is carried out following a virtual wireless cellular mobile environment using computer based simulation. For example, we consider a wireless network system with 49 cells and 70 channels for HCA-PC strategy. The performance of our scheme is compared with the HCA scheme proposed in the literature. A considerable reduction in the blocking probability of the system with HCA-PC is observed as compared to the system with HCA only i.e. without consideration of power control. In our simulation model, call arrivals and call releases are modeled as Poisson processes and 'time' is equivalent to the number of iterations.

For better understanding how the simulation works, let us consider the table 4.1 which includes the entire event from the commencement of a call until it is released [41]. The column headed with "Simulation clock" represents the time as the simulation progresses, the column headed with "Future Event List (FEL)" represents the list of events to occur in future with the first entry showing the arrival of a call event, and the second entry showing the release of a call event. The column headed with "Comment" explains the events in order that have occurred during that particular time. a* and r* represent the generated inter arrival call time and call duration time respectively.

Simulation Clock (in seconds)	**Future Event List (FEL)**	**Comment**
0	(A, 2.03), (R, 4)	1. First Arrival Of Call Occurs. 2. (a*= 2.03) Schedule the next arrival of call A. 3. (r*= 4) Schedule the first release of a call.
0 + 2.03=2.03	(A, 1.5), (R, 4)	1. Second Arrival Of call occurs. 2. (a*= 1.5) Schedule the next arrival of call A.
2.03 +1.5=3.53	(A, 5), (R, 4)	1. Third Arrival of call occurs. 2. (a*= 5) Schedule the next arrival of call A.
3.53 + 4=7.53	(A, 5), (R, 6)	1. First Release of a call occurs. 2. (a*= 6) Schedule the next arrival of call A.

Table 1: A Sample Simulation Table

At time Clock= 0, the first call arrives in the system, and both a call arrival event (A, 2.03), and a call release event (R, 4) are entered into FEL. As soon as Clock=0 is complete, the simulation begins. At time 0, the pending event is (A, 2.03). The clock is advanced to 2.03, the call arrival event (A, 2.03) is removed from FEL, a call arrival event is executed, and a next call arrival time (A, 1.5) is entered into FEL. Next the clock is advanced to the next pending event time, which is an arrival event, a call arrival event is executed, and next arrival event is entered into the FEL. In this way the simulation progresses by executing the pending event and advancing the simulation clock accordingly until the simulation clock reaches 3600 seconds. After processing each event, the channel usage information of the cell involved in call arrival is updated. The number of new call arrivals and new calls blocked in the system is recorded to measure the system performance. Figure 4.6 shows the flowchart for the implementation of call arrival events, and figure 4.7 shows the flowchart for the implementation of call release events for HCA-PC approach.

4.5 System Performance

While a new call cannot be served due to the unavailability of free channels or none of the channels have the interference level below the interference threshold then the new call will be blocked. Therefore the user in a cellular network experiences a much higher call blocking probability due to the extremely larger number of request for channels. Thus the researchers in mobile communication consider the blocking probability of calls as a proper performance index of channel assignment techniques [Vidyarthi 03]. In our thesis, the performance of the proposed HCA-PC strategy also has been derived in terms of the call blocking probability factor (P_n) as shown in equation 4.1.

4.5.1 Experimental Results

Experimental results were carried over through the analysis of the simulation output files for each run, where the total set of available channels is divided into two sets: a fixed set and a dynamic set. When a new call arrives at a randomly selected cell, the cellular system first tries to assign channel from the fixed set of channels. If all the channels in the fixed set are busy, then the cellular system applies HCA-PC using HC algorithm to find a suitable least interfered channel.

In our simulation, we also follow the representation ratio for FCA and DCA as proposed by Vidyarthi et al. [41] for the system performance analysis. There are three groups of representation ratios for FCA and DCA, such as; 21:49 (21 channels assigned to the FCA set and 49 channels assigned to the DCA set), 35:35, and 49:21.

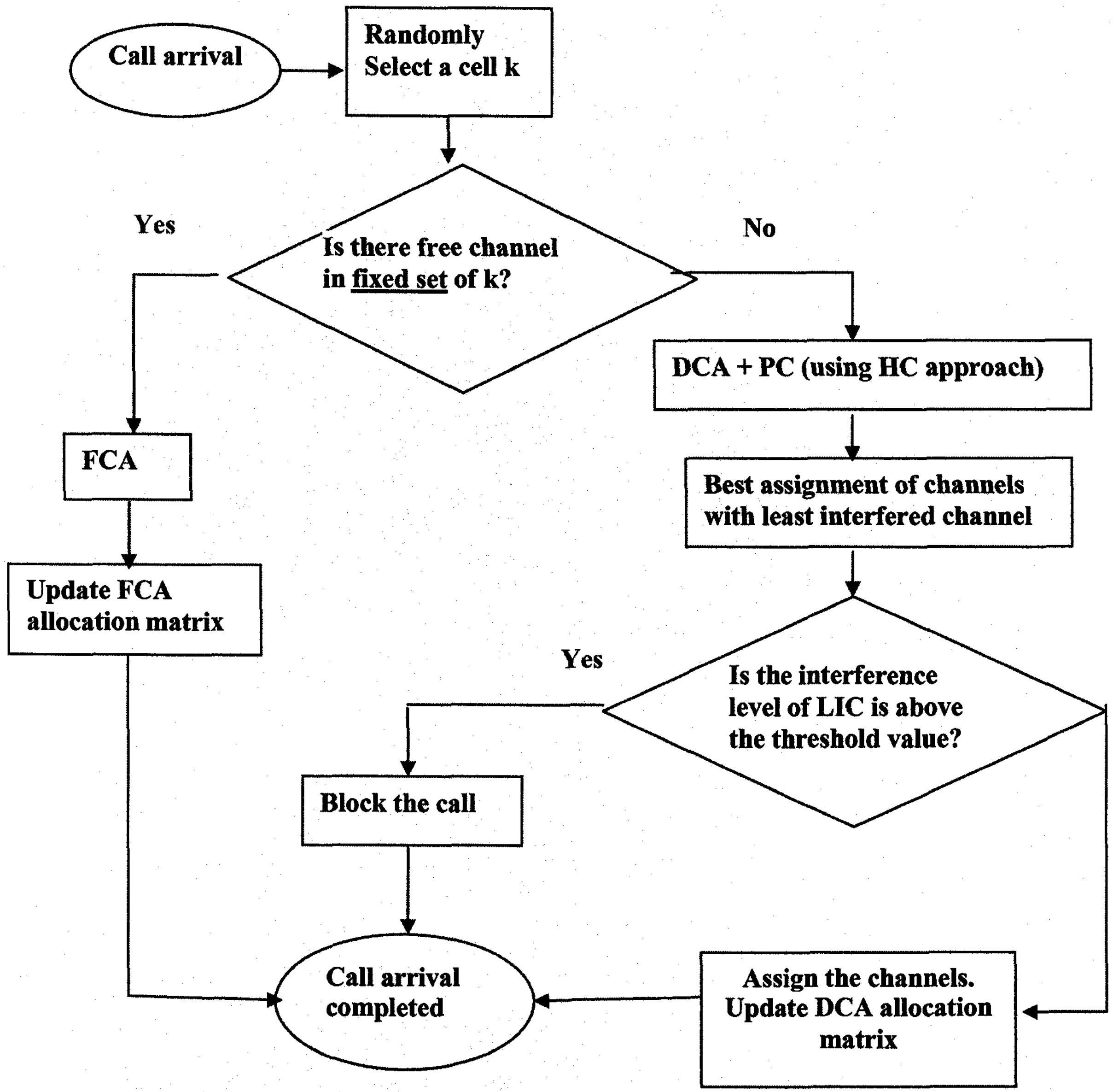


Figure 4.6: Simulation of call arrival event in integrated HCA and Power Control (Reproduced from [41])

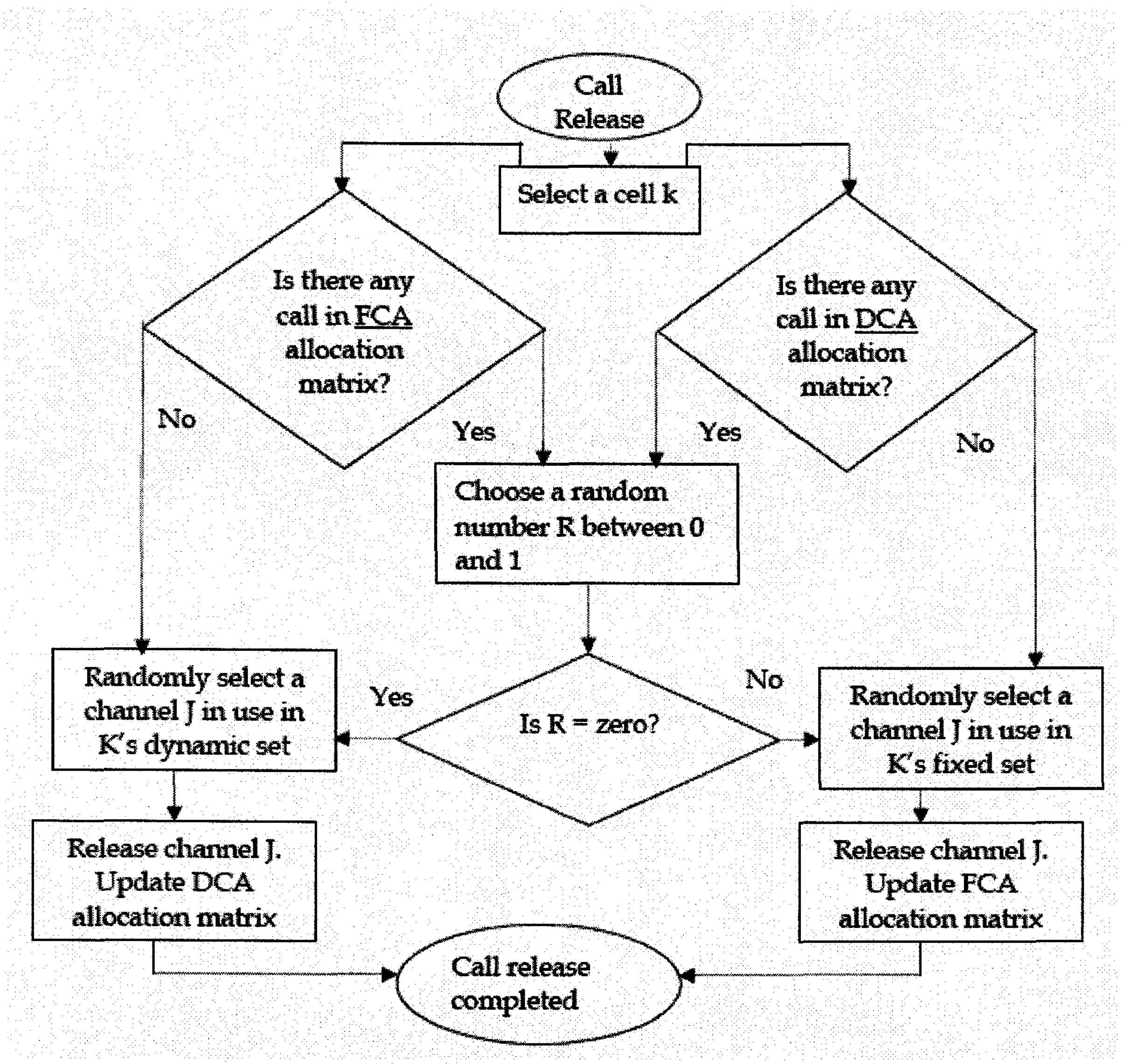


Figure 4.7: Simulation of call release event in integrated HCA and Power Control (Reproduced from [41])

The blocking probability is computed in each group of representation ratios for the entire network. The values of the positive constraints used in our fitness function are as follows: *W1*=1.5, *W2*=0.5, and W3=1, same as in Vidyarthi et al. [41]. For clarity we have plotted and summarized the simulation results, i.e. the call blocking probability vs traffic loads in three different graphical

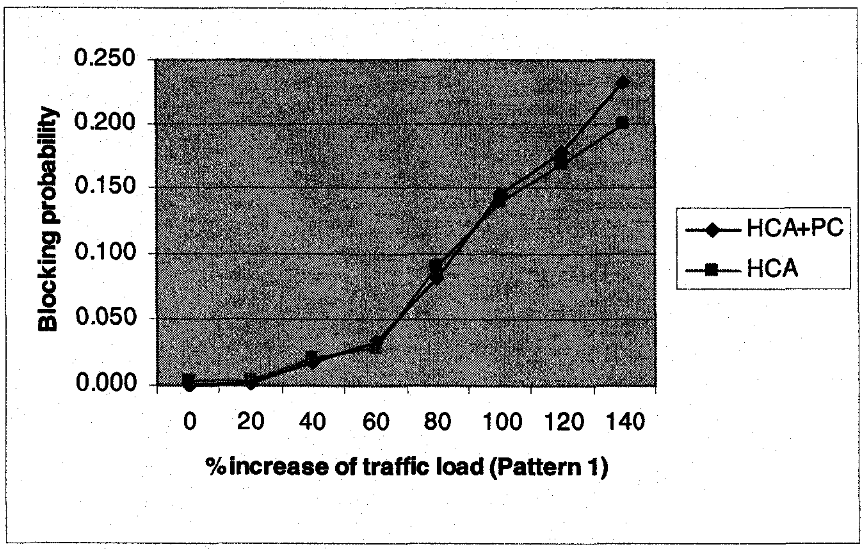


Figure 4.8: Performance of the proposed HCA-PC strategy using HC algorithm in terms of blocking probability for channel distribution ratio of (21:49) of Pattern 1.

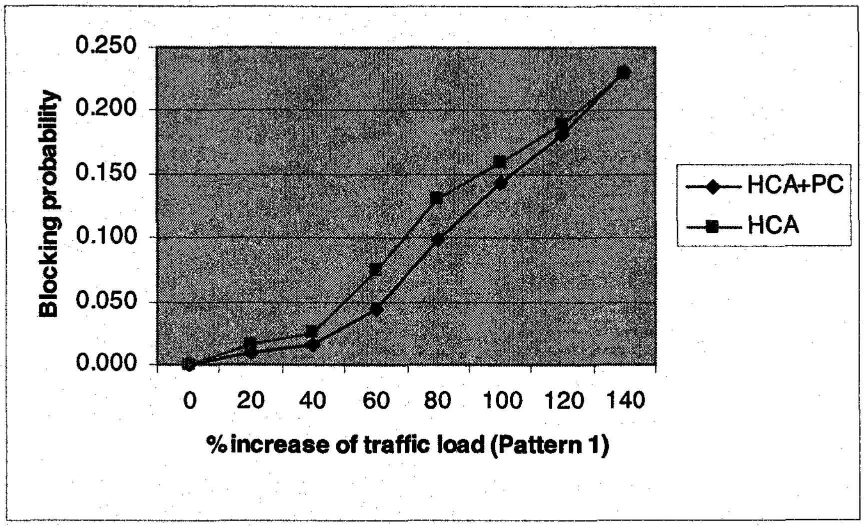


Figure 4.9: Performance of the proposed HCA-PC strategy using HC algorithm in terms of blocking probability for channel distribution ratio of (35:35) of Pattern 1.

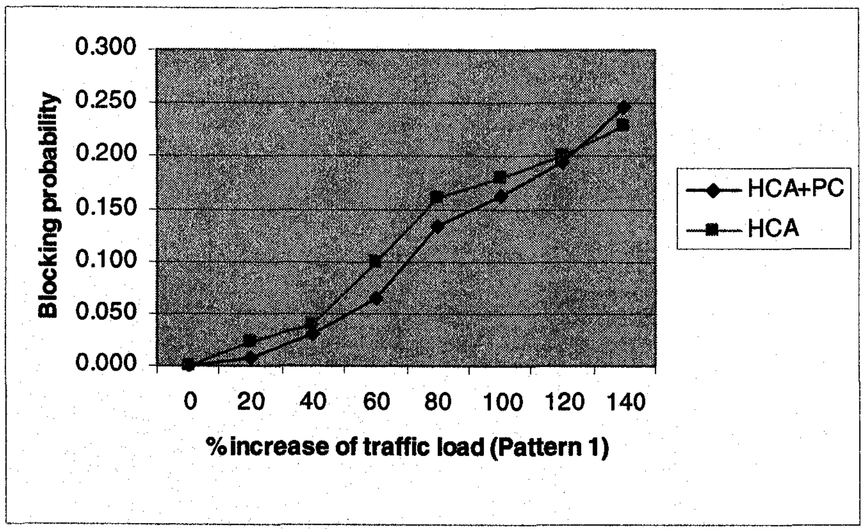


Figure 4.10: Performance of the proposed HCA-PC strategy using HC algorithm in terms of blocking probability for channel distribution ratio of (49:21) of Pattern 1.

representations. Figures 4.8, 4.9, and 4.10 are the graphical representations of traffic pattern1 (shown in figure 4.4) for the channels representation ratio of 21:49, 35:35, and 49:21 respectively and figures 4.11, 4.12, 4.10 are for traffic pattern 2 (shown in figure 4.4). The results were obtained by increasing the traffic rates in step of 20% for all the cells of both the patterns by a percentage ranging from 0-140 with respect to the initial rates of the specific cell (as in [Vidyarthi 03]).

4.5.2 Comparison with HCA Approach

The proposed HCA-PC strategy is compared with the HCA strategy [41]. In the above mentioned figures, the legends with HCA-PC show our results and those with only HCA shows the results obtained in [Vidyarthi 03]. The performance of our proposed algorithm has been compared with the channel assignment schemes proposed in [Vidyarthi 03] for various call arrival rates. According to our simulations the proposed algorithm produces better results for all the representative ratios for traffic pattern 1 (Figure 4.4) in comparison with Vidyarthi et al. [41] both for moderate and high traffic loads in the system. This means our HCA-PC strategy using HC approach significantly reduces the call blocking probability than those by HCA strategy using ES approach in Vidyarthi et al. [41].

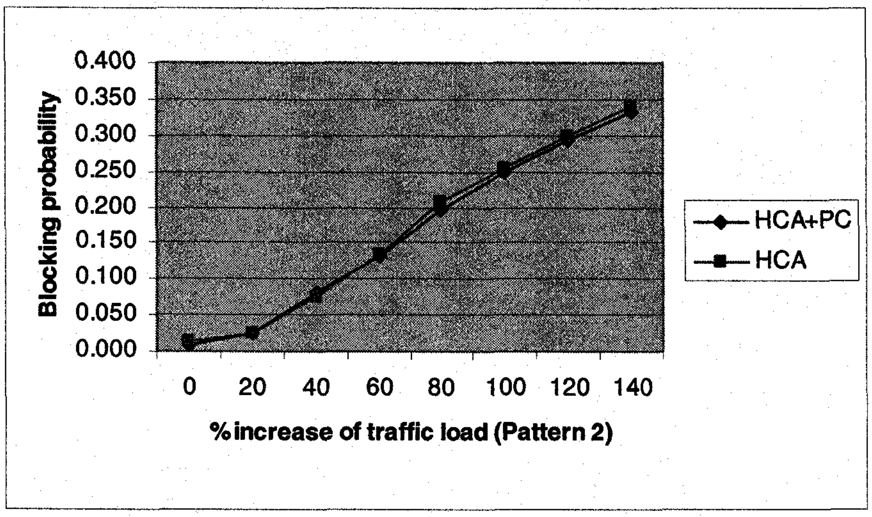


Figure 4.11: Performance of the proposed HCA-PC strategy using HC algorithm in terms of blocking probability for channel distribution ratio of (21:49) of Pattern 2.

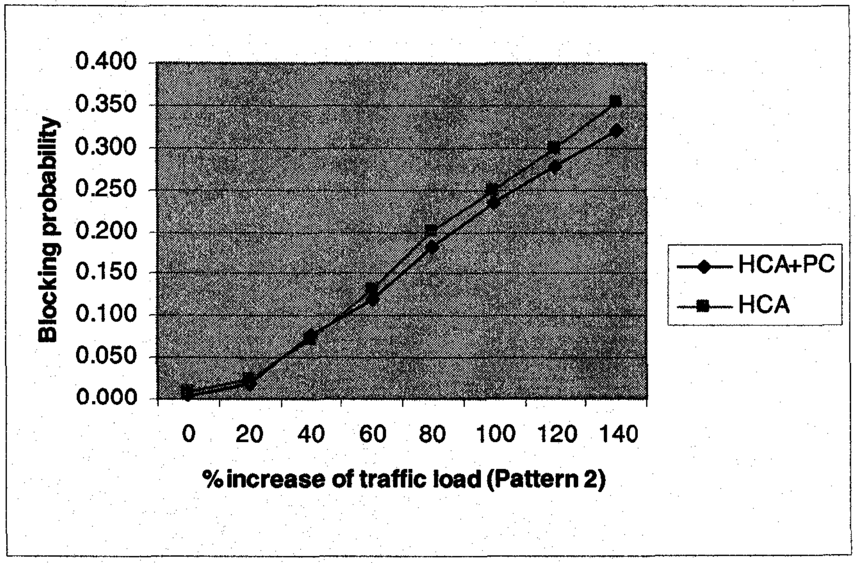


Figure 4.12: Performance of the proposed HCA-PC strategy using HC algorithm in terms of blocking probability for channel distribution ratio of (35:35) of Pattern 2.

Thus, our approach improves the system capacity and network throughput. Furthermore, we have incorporated power control with a channel assignment (HCA-PC) strategy, which in turn assigns the least interfered channel (LIC) for transmission. A new call established through LIC makes the new call less vulnerable for other ongoing calls in respect to interference. Because of the LIC, a mobile terminal could reduce the transmitter power level required to maintain the CIR up to an acceptable level, which ultimately improves the battery life as well as the network capacity.

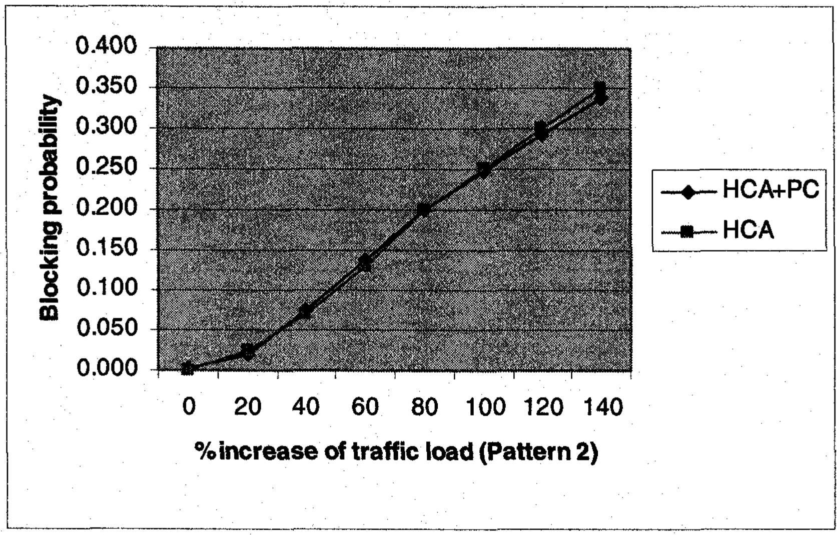


Figure 4.13: Performance of the proposed HCA-PC strategy using HC algorithm in terms of blocking probability for channel distribution ratio of (49:21) of Pattern 2.

Among all the representative ratios, the best performance was obtained with the 21:49 scheme. However, in terms of running time 49:21 is more time efficient. The convergence of the proposed HCA-PC is shown in table 2 and it shows the average and standard deviation of blocking probability for traffic pattern 1 (Figure 4.4) with the entire set of ratios for ten runs. For traffic pattern 2, our algorithm out performs [41] all the representative ratios except for slight discrepancy in 49:21.

Channels Distribution	**% increase in traffic load**	**Blocking Probability**	
		Average	**SD**
FCA=21;DCA=49	0	0.000	0.000
	20	0.001	0.001
	40	0.016	0.002
	60	0.030	0.002
	80	0.099	0.004
	100	0.143	0.001
	120	0.182	0.004
	140	0.231	0.006
FCA=35;DCA=35	0	0.001	0.000
	20	0.004	0.001
	40	0.030	0.002
	60	0.048	0.009
	80	0.103	0.002
	100	0.158	0.004
	120	0.195	0.005
	140	0.247	0.005
FCA=35;DCA=35	0	0.000	0.000
	20	0.002	0.000
	40	0.017	0.002
	60	0.032	0.002
	80	0.081	0.007
	100	0.145	0.004
	120	0.179	0.005
	140	0.233	0.003

Table 2: Convergence of the proposed HCA+PC (Pattern 1)

Chapter 5

Concluding Remarks

The last decade has witnessed an incredible growth of wireless cellular communication. This is because of its resources smaller size, portability, fast installation, fault tolerance, connectivity, mobility, and cheaper cost. This exponential growth of wireless cellular network services has required careful management of radio resources to improve system capacity. Mainly due to the insufficiency of radio spectrum, sharing of radio frequency must be considered. In practical, the sharing of radio frequency introduces interferences among users, which in turn limit the system capacity and decayed the battery life. Power control on the other hand can suppress co-channel interferences, adjacent channel interference and limits the consumption of power. Thus channel assignment and power control are highly correlated to each other in wireless cellular networks.

In this thesis we have discussed some of the issues and approaches related to channel assignment in wireless cellular networks. The discussed issues include channel sharing schemes, channel assignment strategies, fitness function, power-control, least interfered channel, and call blocking probability as well as their influence on network performance.

In this thesis we proposed a new channel assignment strategy called HCA-PC to integrate the channel assignment and power control simultaneously using dynamic reuse distance concept. We also introduced a new method named DCA-LIC (dynamic channel assignment with least interfered channel) such that the efficient utilization of channel assignment is possible as well as the elimination of interference level. A fitness function or energy function is modeled in our approach based on the soft conditions and hard conditions using dynamic channel assignment scheme and centralized power control. We also devised an analytical model to compute the call blocking probability for a cellular network system.

We implemented a simple Hill Climbing (HC) based approach using an efficient problem representation and a simplified energy function. The advantage of our representation as compared to the one proposed by Vidyarthi et al. [41] is that it increases the system capacity as well as it reduces the computation time involved in the calculation of reuse distance and evaluation of best solution among others in each generation. Another important improvement is that our algorithm uses the least interfered channels which help to increase the battery life as well as the system capacity. Our algorithm also deals with the local optima. If the current solution is stuck in a local optima then we apply a random restart strategy until the termination criteria is fulfilled. The chosen representation and the mutation operator guarantee the feasibility of the solution.

According to our simulations the proposed algorithm produces better results for all the representative ratios for traffic pattern 1 (Figure 4.4) and traffic pattern2 (Figure 4.5) in comparison with Vidyarthi et al. [41] both for moderate and high traffic loads in the system. This means our HCA-PC strategy using Hill-climbing approach significantly reduces the call blocking probability compared to the HCA strategy using ES approach in Vidyarthi et al. [41].

Future Research Directions

This is a research area where research is just in its infant stages. The following are some of the interesting open problems related to my research in this area.

- Our proposed approach to integrate channel assignment and power control in cellular networks may be applied to the peer-to-peer or mobile ad-hoc networks (MANET) communication.
    - In ad-hoc networks, a transmitter or caller may be considered as the mobile terminal and a receiver or callee may be considered as the base station.
    - A caller and callee node will have information about their neighbors and each node works independently as a small router.
- Algorithm proposed in our strategy can be re-investigated by implementing other heuristics like the one used in Vidyarthi et al. [41].

- We assumed that the base station assignment is known to us. Optimal assignment of base station along with channel assignment and power-control can be investigated.
- We have applied our strategy on the uplink only i.e. on the link from mobile terminal to the base station. The analysis can be extended for both the uplink and downlink in cellular systems with DCA.

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