Distributed dynamic channel allocation in mobile computing system

Qian Zhang
University of Nevada, Las Vegas

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Thesis Approval
The Graduate College
University of Nevada, Las Vegas

NOVEMBER 21, 2003

The Thesis prepared by

QIAN ZHANG

Entitled

DISTRIBUTED DYNAMIC CHANNEL ALLOCATION IN MOBILE COMPUTING SYSTEM

is approved in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE IN COMPUTER SCIENCE

Examination Committee Co-Chair

Examination Committee Member

Examination Committee Member

Graduate College Faculty Representative
ABSTRACT

Distributed Dynamic Channel Allocation
in Mobile Computing System

by

Qian Zhang

Dr. Ajoy K Datta, Examination Committee Chair
Professor of Computer Science
University of Las Vegas, Nevada

Channel allocation problem is one of the most important issues in mobile computing networks. The purpose of this thesis is to develop a new distributed dynamic channel allocation algorithm. The proposed algorithm attempts to reuse channels in different cells to optimize the channel usage. It also assigns a large number of channels to the heavily loaded cells, and a few channels to the lightly loaded cells according to the traffic patterns of mobile computing network in real time. Co-channel interference is prevented in this algorithm. Moreover, the proposed algorithm is deadlock-free, interference-free, and achieves that maximum channel utilization.
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ACKNOWLEDGMENTS

I am grateful to Dr. Ajoy K Datta and Dr. Frank Petit for their instruction on designing the algorithm and discussions about this work as it progressed. Special thanks go to Dr. Ajoy K Datta for introducing me to the field of channel allocation on mobile computing system.
CHAPTER 1

INTRODUCTION

Mobile computing is rapidly growing as a main trend in the mobile communication network. It took over 100 years to connect 1 billion people to the communication network, but it will take less than 5 years to connect another 5 billion people [24]. However, the frequency spectrum is a scare resource in such a network, the limitation of spectrum requires to reasonably use of frequency channels. In order to supporting thousands of communication sessions that may arise in a mobile communication environment, efficient allocation of the limited spectrum, wireless channels, is an important issue in the mobile network.

In the mobile network, the geographical area is divided into small cells. A cell is a hexagonal shaped as shown in figure 1.

![Cellular network architecture](image_url)

Figure 1. Cellular network architecture.
Each cell has a base station (BS) located at the center of the cell. Base stations are inter-connected by a wired network. The function of a BS is to terminate the wired link in the network side of the user-to-network interface. This involves a controller as well as spectrum-frequency in a small system; dynamic distribution channel allocation can be achieved in a BS. Every mobile host (MH) in the cell communication is with other MHs in the network through the BS via a channel. The communication is established by a wireless link between MH and its own BS.

The wireless spectrum is divided into channels, which support communicated sessions. If a given channel of a certain frequency is used in an area of the radius, then the same channel can be used simultaneously in another area. That area consists of a cell or a set of cells. Cells using the same channel frequency, called co-channel cells, are apart to a sufficient distance from each other. That is to avoid the unacceptable interference of the same channel, referred as co-channel interference. This distance is greater than or equal to the minimum reuse distance [17]. In other words, the same channel cannot be used in different cells if their geographical distance is less than the minimum reuse distance. Therefore, efficient channel allocation algorithm should have the following features:

1. Maximize the channel re-usage crossing the entire network without co-channel interference.

2. Distribute the channels with meeting a demand of traffic patterns in the network.

Many schemes have been proposed for channel allocation problem in the past. Those schemes can be broadly classified into a number of different categories:
In FCA schemes, the area is partitioned into many cells. A number of channels assigned proportionally to each cell for its own exclusive use. A definite relationship is assumed between each channel and each cell according to co-channel reuse constraints [26]. The total numbers of available channels (C) in system is divided into sets, and the minimum number of channel sets (N) required to service the entire coverage area is related to the reuse distance (S) as followings [14] [26]:

\[ N = (1/3)\sigma \]

Here \( \sigma \) is denoted as \( D/R_a \), where \( R_a \) is the radius of the cell and \( D \) is the physical distance between the two cell centers.

In a simple FCA scheme, the same number of channels is assigned to each cell. If the traffic distribution of the system is uniform, this channel allocation scheme is efficient. However, the traffic in the cell network system cannot be uniform with temporal and spatial fluctuations. A uniform allocation of channels to every cell may lead in high blocking in some cells and others may have a great number of spare channels. Therefore, it is appropriate to distribute the different number of channels to cells according the load of traffic patterns by using non-uniform channel allocation schemes [18] [31] or static borrowing schemes [2] [8].

In a non-uniform channel allocation scheme, the number of channels assigned to each cell depends on the expected traffic profile of that cell. Heavily loaded cells are allocated...
more channels than lightly loaded cells. An algorithm [31], non-uniform compact pattern allocation, is proposed for allocating channels to cells according to the traffic distribution in each of them. Although the blocking probability using non-uniform compact pattern allocation is always lower than the blocking probability of uniform channel allocation scheme, an expected traffic in the cellular system may not be matched to a real traffic distribution. In the static borrowing schemes, unused channels are transferred from lightly loaded cells to heavily loaded cells when distances are bigger than the minimum reuse distance $\sigma$. Although in static borrowing schemes channels are permanently allocated in each cell, the number of nominal channels assigned in each cell may be rearranged periodically according to spatial inequities in the load. Because of short-term temporal and spatial variations of the traffic in mobile systems, FCA schemes are not able to gain high channel efficiency. In contrast to FCA, there is not fixed relationship between channels and cells in DCA. During the past 25 years, DCA schemes have been studied to overcome the flaw of the FCA.

In DCA schemes, all channels are kept in a central pool and are assigned dynamically to radio cells as new communication requests arriving in the system [19]. The channel may or may not return to the central pool after a communication is completed. A channel can be used in any cells in which signal interfere constraints are satisfied. Since more than one channels might be available to the cell that makes a channel requirement, some strategies must be implemented to select the assigned channel. The selected cost function might depend on the future blocking probability in the vicinity of the cell. The usage frequency of the candidate channel, the reuse distance, channel occupancy distribution under current traffic conditions, radio channel measurements of individual mobile users,
or the average blocking probability of the system [28]. Based on the type of controller that DCA schemes use, they can be classified into centralized and distributed schemes.

In centralized DCA schemes, a channel in the central pool is allocated to a cell for communication session by a centralized controller. The difference between many centralized DCA schemes is the functions used for pick up one of the candidate channels. For instance, in locally optimized dynamic assignment, the selected cost function is designed to base on the future blocking probability in the vicinity of the cell in which a communication session is initiated. However, in the ring strategy [13], a candidate channel is chosen which is in use in the most cells in the co-channel set. Centralized DCA schemes are effective in maximizing channel usage, but the cost is high centralization overhead and a small failure in the central computer will bring entire system unable. Thus, distributed schemes are more attractive for mobile computing networks.

In distributed DCA schemes, much early work has been proposed by using either signal strength measurements [1][10][25] or local information of the current available channels in the cell (cell-based) [12][13][20][21]. In a scheme on signal strength measurements, a BS employs only local information without communication with any other BSs in the mobile network. Thus, the system is self-organizing and channels can be allocated to everywhere as needed. The schemes offer fast real time processing and maximal channel packing that refers to the area where a channel cannot be reused and how closely these areas are packed. Whereas the risk of increased co-channel interference may cause interruption, instability and deadlock. In cell-based schemes, a channel is assigned to support a communication session by a BS, at which a communication
requirement is initiated. Each BS has its own information about the currently available channels. The information of channels is updated by exchanging status information between BSs.

In hybrid channel allocation (HCA) schemes, FCA and DCA techniques are mixed. The total number of available channels is divided into two sets, fixed set and dynamic set. The fixed set has a number of fixed channels that are assigned to cells as in FCA schemes, and the dynamic set is shared by all cells in the mobile system to achieve flexibility. When a communicated session is set up and all channels in fixed set are busy, a channel in dynamic set will be assigned to this session. In the system studied in [4], HCA schemes improve greatly on performance by producing a significant increase in channel occupancy. Whereas, a huge amount of computations for channel re-arrangement has to be required in a large system.

In FICA scheme, the set of available channels is divided into fixed and flexible sets. The channels in the fixed sets are assigned to the cells following FCA scheme which are sufficient for lightly loaded and the flexible channels are assigned to those cells whose channels have become inadequate under increasing traffic load either in scheduled as predictive manner [29].

In this thesis, the interest is to explore a new distributed dynamic channel allocation algorithm. A central network switch does not need in the algorithm. The BS of a cell plays a key role in a channel allocation decision based on the available information locally. Unlike FCA in which a set of channels is assigned for every cell permanently, the algorithm presented has ability to allocate the channels dynamically as change of traffic patterns. The change of traffic patterns is due to various reasons such as from a light
demand in an area during a daily time to a heavy demand during a business conference in this area. Whenever the traffic patterns change, the proposed algorithm is able to make the movement of channels among the cells to match the various traffic loads. To overcome some recent research in that disregards the channel reusability or does not always succeed in reusing channels, the presented algorithm is designed to mainly concern the possibility of channels reuse among those cells whose distances are exactly the minimum reuse distance to each other. The channels are used simultaneously in practical cells as many as possible without co-channel interference. This strategy successfully deals with creating the reuse pattern dynamically in the entire network.

The rest of paper is organized as follows. Chapter 2 clarifies the system model and definitions. In chapter 3, a distributed dynamic channel allocation algorithm is presented. In chapter 4, the propose algorithm is proved to be deadlock free, interference free, liveliness and maximum channel utilization, etc. Chapter 5 analyzes the contributions of the algorithm comparing with previous centralized and distributed dynamic channel allocation strategies. Chapter 6 introduces improvements on avoiding the channel starvation and handling handoffs. Chapter 7 states the conclusion of the study and offers prospects for further work.
CHAPTER 2

SYSTEM MODEL AND DEFINITION

The geographical area is divided into hexagonal shaped cells in a mobile cellular system. Each cell is served by a BS, which is in the center of the cell. The communication between BSs is through the wired network. A BS is to communicate with its MH through a wireless link (wireless channels), a radio channel. The MH can be either a mobile computer or a cellular phone.

An \( n \times m \) cellular system consists of \( n \) rows and \( m \) columns of cells. In Figure 2, it shows a \( 7 \times 7 \) cellular system.

![Figure 2. A 7x7 cellular network.](image)

All cells have six immediate neighbor cells except those at the boundaries of the region.
Let $C$ denote as a set of cells:

$$C = \{C_1, \ldots, C_k\}$$

The Cell $C_k$ located at row $i_k$ and column $j_k$ is denoted as $(i_k, j_k)$. For example, cell $C_{25}$ in figure 1 is at row 2 and column 4, $C_{25} = (2, 4)$. The distance between two cells is measured as same as the Euclidean distance between the centers of two cells. Thus, if the Euclidean distance between two cells $(0,0)$ and $(0,1)$ is 1, then the distance of any two cells, $C_i(i_1, j_1)$ and $C_i(i_2, j_2)$, is defined as the following:

$$D(C_1, C_2) = \sqrt{(i_1 - i_2)^2 + (i_1 - i_2)(j_1 - j_2) + (j_1 - j_2)^2}$$

In practice, the minimum reuse distance is chosen to be the distance between two cells, $(0, 0)$ and $(a, b)$. This distance is known as $D_{\text{min}} = (a^2 + ab + b^2)^{1/2}$ [17]. The nearest co-channel cells of cell $C_i$ are those cells whose distance to $C_i$ is exactly $D_{\text{min}}$. To maximize channel reusability, co-channel cells should use the same set of channels as cell $C_i$. The nearest co-channel cells of $C_i$ can be located as follows: starting at cell $C_i$, move $a$ cells along any chains of hexagons; turn counter-clockwise 60 degrees; move $b$ cells along the chain that lies on this new heading.

![Figure 3](image.png)  
Figure 3  An example of co-channel and neighboring cells.
Every cell has six nearest co-channel cells except of those on or close to the boundary of the cellular network. In figure 2, a = 2, and b = 0, the six nearest co-channel cells of (2, 3) are (0, 3)(0, 5)(2, 1)(2, 5)(4, 1)(4, 3). In figure 3, a = 4 and b = 3, the six nearest co-channel cells of cell C_i are those cells marked as x.

Given two cells A and B, if we say that A is a co-channel cell of B, then there must exist a sequence of cells (C_1 = A, C_2, ........... , C_k-1, C_k = B) such that C_i is a nearest co-channel cell of C_{i+1}. In this thesis, the co-channel cells (CO_i) specifically indicates six nearest co-channel cells of cell C_i:

\[ CO_i = \{C_k | D(C_{i}, C_k) = D_{min}\} \]

A frequency spectrum assigned to the mobile system is divided into a set of distinct channels; each channel is identified by its exclusive bandwidth. Typically, a 30 KHz bandwidth between each of successive channel is taken. This can avoid one of major interference (adjacent channel interference) in wireless system. Another interference is called co-channel interference. A channel cannot be concurrently used by more than one communication sessions originating in a cell or by more than one cell with their distance less than D_{min}. Thus each cell C_i has its own interference neighborhood (IN_i), which contains a set of cells whose distance from C_i is less than D_{min}:

\[ IN_i = \{C_j | D(C_{i}, C_j) < D_{min}\} \]

As shown in Figure 3, D_{min} = 2, IN_i is covered by a shaded area.

Some channels are set as control channels that are exclusively used for control messages between BSs and MHs, and rest channels are used as supporting communication sessions. A MH_i has to use BS_i as a connector to establish the communication requirement with other cells when a communication session is set up by
MH, or a BS, is informed an arrival requirement from another MH. All kinds of required messages are passed by BS through the wired link or the wireless link depending on the MH presenting inside or outside of a cell $C_i$. BS then examines whether a channel is possible to carry the communication. If the answer is positive, a channel is successfully allocated to cell $C_i$ to support the communication request. Otherwise the communication requirement is dropped. When a BS is informed that there is an arrival requirement from another BS, then BS determines whether there are some available free channels that might be shared or borrowed to another unit, and a message contain relative information is forward to that unit along the wire link. The decision of channels selection is made by another BS, which sends a request. When a communication is terminated by MH, the BS is informed that the channel supporting the communication can be used for a new requirement.
CHAPTER 3

PROPOSED ALGORITHM

A new distributed dynamic channel allocation algorithm is proposed in this thesis. Channel allocation decisions are made by BSs according to the knowledge on three sets (Allocate, InUse, Lend) of themselves, their co-channel cells and neighbor cells.

Data Structure

In the proposed schema, assuming all channels to be ordered according to their frequency bands. The first channel is with the lowest frequency band and the last channel is with the highest frequency band. Set Spectrum is used to represent all channels in the system. Each BS has knowledge on the set of six co-channel cells of \( C_i \) denoted as \( CO_j \) and a set of neighboring cells of \( C_i \) denoted as \( IN_i \). Each BS in the system maintains the following local variables and data structure:

- **Allocate**; is a set of channels allocated in \( C_i \), initially Allocate; for every cell \( C_i \) is an empty set.
- **InUse**; is a set of channels that are currently used to support communication sessions in \( C_i \). InUse; is a subset of Allocate; and an empty set initially.
- **Lend**; is a set of channels that are marked during the process of lending from \( C_i \) to other cells. Lend; is initially an empty set.
• Pending(i): is a Boolean variable. A pending flag is true when a request is sending from \( C_i \) and waiting for a result.

• priority(i): is a timestamp [16] based variable, which is related to the required message sent by cell \( C_i \).

• \( L_i \): is a local request list in \( C_i \) that contains arrival time stamped requests. It is not necessary a queue.

Message Types

Communications among BSs is fulfilled by various messages passing. The description of each type of messages is as follows.

Messages of request type:

• REQUEST\(_{co}(i)\): describes that BS\(_i\) of cell \( C_i \) is require a channel from its co-channel cells.

• REQUEST\(_{in}(i)\): describes that BS\(_i\) of cell \( C_i \) is require a channel from its neighboring cells.

All REQUEST messages are assigned timestamps [16] according to the time of generating requests.

Messages of reply type:

• GRANT\(_{co}(i)\): indicates that cell \( C_i \) responds to a message REQUEST\(_{co}\).
  The sender of REQUEST's message is a member of CO\(_i\). The message contains information about Allocate\(_i\).

• GRANT\(_{in}(i)\): indicates that cell \( C_i \) responds to a message REQUEST\(_{in}\).
  The sender of REQUEST's message is a member of IN\(_i\). The message
contains the information about Allocate; and Free; where Free; is a set of channels that are not instantly used in C; and lent to other cells.

- REJECT_{co}(i): describes that cell C; rejects the request from a cell which is a member of CO; The message contains information about Allocate;

- REJECT_{in}(i): describes that cell C; rejects the request from a cell which is a member of IN; The message contains information about Allocate;

Messages of inform type:

- INFORM(i): is a message which informs the receivers to remove the request sent by C; from their lists.

- AQUIRE(k): is a message which is sent from a BS of a cell to its all neighbor cells and informs that the channel k is no longer being Allocate sets of those cells except other events taking place to bring the channel k back.

- UNABLE(i): is a message which is sent from the BS of C; to its all neighbor cells when cell C; is not successful on borrowing a channel.

- RELEASE(k): is a message which informs a BS that the channel k is not in use and it is available for supporting another now session.

Algorithm Description

The presented algorithm can be roughly classified to following procedures: Self service procedure, a channel request in a cell can be satisfied without any messages exchange between BSs. Sharing procedure, a channel request in a cell is satisfied by sharing channels that have already been in co-channel cells of that cell. Importing
procedure, a channel request in a cell is satisfied by importing an unoccupied channel from the network. Borrowing procedure, a channel request in a cell is satisfied by borrowing an unused channel from its neighbor cell. The algorithm is designed according to the following structure as Figure 4.

When a request of communication is sent by MH to BS, the BS sets a pending flag, the cell Ci cannot make another channel request during a pending flag has been raised. A pending flag will be cleared only after the request is either succeeded or dropped. An available free channel that is not using locally by any other MHs in cell Ci and also not in
the process of lending to any other cells will be assigned to support the communication session by BS without any message exchange with other BSs. This refer to the procedure, Self service procedure. Tis channel must be no longer available for supporting other communication sessions from cell C_i or cells in interference region of C_i until the channel is released.

However, a cell C_i may transiently require more channels to meet the demands of communication sessions from MHs in C_i and no such free channels above are available in the cell C_i. To solve this problem, BS_i will send the channel request to all its six nearest co-channel cells and neighboring cells. The types of request is described as REQUEST_{co} and REQUEST_{in} in the proposed algorithm.

Once six co-channel cells receive the message REQUEST_{co}(i) from cell C_i, they will respond C_i by one of two-types of messages based on the condition, which is listed in line 2.02 of the algorithm. A GRANT_{co}(j) message will reply to cell C_i if no request is arisen from co-channel cell C_j, no request of higher priority in list L_j and there is at least one channel allocated in co-channel cell C_j. Otherwise, a REJECT_{co}(j) message that addresses the information of no available channels in C_j will be sent to cell C_i.

In addition, when neighbor cells of cell C_i receive REQUEST_{in}(i) messages from cell C_i, each neighbor cell will check their sets of free channels denoted as Free_j, where j is a member of neighbor cells of cell C_i. Channels in Free_j are contained in set Allocate_j, not currently used by local MHs in cell C_j and also not in the process of lending to other cells. After checking step above, neighbor cells will send either GRANT_{in} messages or REJECT_{in} message to cell C_i. As a result that there exists some free channels in Set Free_j,
A GRANT_{in} message will be sent out by cell C_j to cell C_i. Otherwise, a REJECT_{in}(j) message will be replied to cell C_i. Corresponding algorithm is described in line 3.01-3.06.

Obviously, there are four different cases happened after cell C_i receives all replying messages from its nearest co-channel cells and its neighbor cells: Case 1, at least one GRANT_{co} message is received by cell C_i; Case 2, no any GRANT_{co} messages are received, but there is a possibility to bring a channel from the system. Case 3, no any GRANT_{co} messages are received, but at least one GRANT_{in} is received. Case 4: all replying messages are REJECT type.

In Case 1, the proposed algorithm takes the union of all sets of Allocate_j, where j is a member of co-channel cells of cell C_i and cell C_j replies to cell C_i by GRANT_{co}(j) message. The result is stored in set CoChannel_i. In order to eliminate co-channel interference, every cell C_i in mobile networks must have itself knowledge about the possible interference channel set, which is denoted as InfeChannel_i. The InfeChannel_i set is only gained by uniting all Allocate_j sets and its own Allocate_i set. Let a new set, CoUse_i, be a result of subtracting InfeChannel_i from set CoChannel_j, the purpose of CoUse_i set is to figure out if there are some channels in co-channel cells of cell C_i that can be use simultaneously by MHs in cell C_i without co-channel interference. Thus channels in CoUse_i are added to the set Allocate_i if there are some channels in CoUse_i set, sharing procedure takes place. The lowest frequency channel is chosen to support the communication session requested by one MH in cell C_i. A INFORM(i) message will be sent to every co-channel cell and neighboring cell. It informs them to remove the request sent by cell C_i from their lists. Otherwise no channels in co-channel cell can be used in cell C_i. Corresponding algorithm is described in line 4.01-4.07.
In Case 2, the algorithm is designed to verify if there are some unoccupied channels available in the entire network. The collection of those free channels is denoted as set Free. The Free is gained by subtracting all Allocate set from set Spectrum that is a set of total channels in the entire network, where Cj is a member of co-channel cells and neighbor cells of cell Ci.

If set Free is not an empty set, importing procedure executes. A lowest Frequent channel from it is assigned to cell Ci and a communication request is successful to meet. As a result, this channel is owned to set Allocatei, and also added into InUsei. Similarly, cell Ci sends INFORM (i) message to co-channel cells and neighboring cells of cell Ci to remove the request from their lists. In case of an empty set Free, either Case 3 or Case 4 will take place depending on the certain conditions.

In Case 3, when cell Ci receives at least one GRANTin message from its neighboring cells, set Free and set SameChannel need to be calculated, where set Free is different with the one in the Case 2. It is a union of all Freej sets. Cj is a neighbor of cell Ci, which gives a GRANTin message to cell Cj. The information of Freej is received by Cj with message GRANTin(j), a collection of channels that are neither in InUsej nor in Lendj. Set SameChannel is taken intersection operations of any pairs of Allocatea and Allocateb and unite them together, where a and b are neighboring cells of cell Ci and is not a neighborhood of b. In other words, a and b are not in their interference regions mutually. Let the set, CanUse, be a guard to verify whether or not cell Ci can borrow a channel from its neighbor cells. Set CanUse is obtained by subtracting set SameChannel from set Free. The reason of using the CanUse set is to double check whether there is no co-channel interference happened if a channel is borrowed by Cj. If CanUse is not an empty set, it
means some available channels are qualified to lend to cell C_i, then borrowing procedure will take place. A highest frequent channel from set CanUse is chosen to support a communication session in cell C_i. This channel must be counted into set Allocate; and InUse. In order to inform all neighbor cells that a channel has already borrowed by cell C_i, a message, ACQUIRE(k), is sent to all neighbor cells of cell C_i. The purpose of ACQUIRE(k) is to remove the request of cell C_i from neighbor cells. Channel k will no longer be a member of Allocate_j, and Free_J and channel k are subtracted from Len_j, where j is a neighbor of cell C_i. Cell C_i sends INFORM(i) message to co-channel cells to remove the request from their lists. Otherwise, CanUse is an empty set, no channel can be borrowed, and the request is dropped. Then an UNABLE message is sent to all neighbor cells of cell C_i to remove the request of cell C_i from neighbor cells' lists and Free_j is subtracted from Len_j, where j is a neighbor of cell C_i. Cell C_i sends INFORM(i) message to co-channel cells to remove the request from their lists. The corresponding algorithm is described in line 4.10 - 4.17.

However every case above may not be satisfied, all co-channel cells and all neighbor cells of cell C_i reply REJECT messages to cell C_i. Finally, the algorithm precedes case 4. The request for a channel from cell C_i is dropped. There is no channel available for cell C_i's communication session.

Proposed Algorithm

Constants:

priority(i): timestamp of REQUEST(i)

CO_i: a set of co-channel cells of C_i
IN_i: a set of neighbor cells of C_i

Spectrum: all channels in the entire system

Upon BS_i receiving a request from cell C_i:

1.01 set a pending flag
1.02 \( Free_i = Allocate_i \setminus InUse_i \setminus Lend_i \)
1.03 if \( Free_i \neq \perp \) then
1.04 Self service procedure
1.05 else send REQUEST_co to cells to CO, and REQUEST_in to IN_i
1.06 end-if

Upon BS_i receipt of a REQUEST_co(j)

2.01 place this request in L_i
2.02 if \(-pending \land (priority(j) > priority(L_i)) \land Allocate_i \neq \perp \) then
2.03 send GRANT_co to C_j
2.04 else send REJECT_co to C_j
2.05 end-if

Upon BS_i receipt of a REQUEST_co (j)

3.01 place this request in L_i
3.02 \( Free_i = Allocate_i \setminus InUse_i \setminus Lend_i \)
3.03 if \(-pending \land (priority(j) > priority(L_i)) \land Free_i \neq \perp \) then
3.04 \( Lend_i = Lendi \cup Free_i \)
Upon BS_i receipt of GRANT_{co} or REJECT_{co} from all cells in CO_i, GRANT_{in} or REJECT_{in} from all cells in IN_i,

4.01 if at least one GRANT_{co(j)} then

4.02 CoChannel_i = \bigcup \{ \text{Allocate}_j \mid C_j \in CO_i \}

4.03 InfeChannel_i = \bigcup \{ \text{Allocate}_x \mid x \in IN_i \} \cup \text{Allocate}_i

4.04 CoUse_i = CoChannel_i \setminus InfeChannel_i

4.05 if CoUse_i \neq \bot then

4.06 Sharing procedure

4.07 end-if

4.08 else if Free = Spectrum \setminus (\bigcup \{ \text{Allocate}_x \mid x \in CO_i, IN_i \}) \neq \bot then

4.09 Importing procedure

4.10 else if at least one GRANT_{in(j)} then

4.11 Free = \bigcup \{ Free_j \mid j \in IN_i \}

4.12 SameChannel = \bigcup \{ \text{Allocate}_a \cap \text{Allocate}_b \}

/** a,b \in IN_i, a and b are not neighbor cells **/

4.13 if CanUse = Free \setminus SameChannel \neq \bot then

4.14 Borrowing procedure

4.15 else send UNABLE to cells in IN_i, INFORM(i) to cells in CO_i

4.16 request is dropped, clear the pending flag
4.17 end-if

4.18 else the request is dropped, clear the pending flag

4.19 send INFORM(i) to cells in CO, and IN_i

4.20 end-if

Upon BS_i receipt of INFORM(j)

5.01 remove request of C_j from L_j

Upon BS_i receipt of a ACQUIRE(k) from cell C_j

6.01 remove request of C_j from L_i

6.02 Allocate_i = Allocate_i \ {k}

6.03 Lend_i = Lend_i \ (Free_i \ {k})

Upon BS_i receipt of a UNABLE(j)

7.01 remove request of j from Q_i

7.02 Lend_i = Lend_i \ Free_i

Upon a cell C_i decides to release a channel k

8.01 send RELEASE (k) to BS_i.

Upon BS_i receipt of RELEASE(k)

9.01 InUse_i = InUse_i \ {k}
Self service procedure {
}

10.01 \textit{InUse}_i = \textit{InUse}_i \cup \{k\}

\texttt{/* k is a lowest frequency channel from Free */}

}

Sharing procedure {

11.01 Allocate_i = Allocate_i \cup CoUse_i

11.02 \textit{InUse}_i = \textit{InUse}_i \cup \{k\}

\texttt{/* ** k is the lowest frequency channel from CoUsei **/}

11.03 send INFORM(i) to cells in CO_i and IN_i

11.04 clear the pending flag

}

Importing procedure {

12.01 Allocate_i = Allocate_i \cup \{k\}

12.02 \textit{InUse}_i = \textit{InUse}_i \cup \{k\}

\texttt{/* ** k is the lowest frequency from Free **/}

12.03 send INFORM(i) to cells in CO_i and IN_i

12.04 clear the pending flag

}

Borrowing procedure {

13.01 Allocate_i = Allocate_i \cup \{k\}
13.02 \( \text{InUse}_i = \text{InUse}_i \cup \{k\} \)

/** k is the highest frequency channel from CanUse**/

13.03 send ACQUIRE(k) to cells in IN_i, INFORM(i) to cells in CO_i

13.04 clear the pending flag

}
CHAPTER 4

CORRECTNESS PROOF

Lemma 1: The channel allocation algorithm is deadlock free.

Proof. Since messages can be sent concurrently and autonomously, the synchronization problem of time for channel requests is as same as that in a distributed system, thus the use of timestamp is necessary in the algorithm to avoid circular waiting. According to Lamport's timestamp [16], the channel request messages originated from different cells must be totally ordered by their timestamps. As described in Section 3, a cell receiving the channel request sends either GRANT message only when the channel request is with lowest timestamp and there exists available channels or REJECT message. Contrarily, since the time ordering of all requests is known by all BSs in all cells, there is no possibility to have a loop for delaying GRANT or REJECT messages among cells. Thus, the cell sending a request for a channel with the lowest timestamp always gets either GRANT or REJECT from its co-channel cells or neighbor cells. Once a cell receives all reply messages corresponding to its request messages, the BS of this cell immediately decides which case described in Section 3 will have effect. In case 1, after the BS determines the condition shown in line 4.05 of the proposed algorithm to be successfully fitted, it sends INFORM messages to all cells which reply its requests by GRANT or REJECT messages. In case 2 (importing procedure), the INFORM messages are also feedback. In case 3, depending on the condition listed in line 4.13, the
ACQUIRE or UNABLE messages will be sent back to all cells that respond to the channel request. In any cases, the messages of the inform type (INFORM, ACQUIRE, UNABLE) contain the information that give orders to the received cells to remove the current request in lists and then the next request has a chance to proceed. That leads all requests will be solved in a certain order, and there is no circular waiting.

In addition, in case all cells receiving request messages will send back REJECT messages, the request for a channel has to be dropped. Although the reject function may cause some requests that might be supported in the near future, being dropped, it totally eliminates a circular waiting. Therefore, the algorithm is guaranteed to be deadlock free.

Lemma 2 (interference free): Neighboring cells do not use the same channel concurrently in the proposed channel allocation algorithm.

Proof: let INi denote the set of neighboring cells of C; . The following assertion needs to be proved: for all Cj ∈ INi, InUsei ∩ InUsej = ⊥.

The assertion is obviously true when InUsei and InUsej sets are empty initially. In line 1.02, when Freei ≠ ⊥, assume the channel k is select by cell C; to support a new communication session. Since Allocatei, Allocatej, InUsei, and InUsej are initially empty sets, InUsei ∩ InUsej = ⊥. For the selection of channel k in cell C; , k ∈ InUsei, the assertion still holds, (InUsei ∪ {k}) ∩ InUsej = ⊥. Now we consider the following situations for the change of the InUsei:

1. Freei = ⊥ in line 1.02, at least one GRANTco received in line 4.01 and CoUsei ≠ ⊥ in line 4.05: the channel k ∈ CoUsei = CoChanneli \ InfeChanneli might be selected and added to InUsei, and Allocatei. The assertion is proved by contradiction. Assume that the
cell \( C_i \) and cell \( C_j \) use the channel \( k \) concurrently; the cell \( C_i \) is a neighbor of the cell \( C_j \).

Since cell \( C_j \) use the channel \( k \), \( k \in \text{InUse}_j \subseteq \text{Allocate}_j \) and \( \text{InUse}_i = \bigcup \{ \text{Allocate}_x \mid x \in \text{IN}_i \} \cap \text{Allocate}_i \), then \( k \in \text{InUse}_i \). According to the statement in line 4.04, \( \text{CoUse}_i = \text{CoChannel}_i \setminus \text{InUse}_i \), \( k \) will never be an element in the set \( \text{CoUse}_i \). So \( k \) cannot be selected to support communication session in the cell \( C_i \). That contradicts to assumption.

2. \( \text{Free} \neq \bot \). In step 4.08: Channel \( k \in \text{Free} = \text{Spectrum} \setminus \left( \bigcup \{ \text{Allocate}_x \mid x \in \text{CO}_i, \text{IN}_i \} \right) \), Channel \( k \) can be selected to support a call in cell \( C_i \). The assertion is proved by contradiction. Assume the channel \( k \) is used in the cell \( C_i \) and cell \( C_j \) currently, \( C_j \in \text{IN}_i \). Then \( k \in \text{InUse}_j \subseteq \text{Allocate}_j \). As a neighbor of the cell \( C_j \), \( C_i \) will never has the channel \( k \) to be assigned because \( k \) is subtracted from the set spectrum, and \( k \notin \text{Free} \). That contradicts to assumption.

3. At least one \( \text{GRANT}_m \) received in step 4.10 and \( \text{CanUse} \neq \bot \): The channel \( k \in \text{CanUse} = \text{Free} \setminus \text{SameChannel} \). Channel \( k \) can be selected to support a communication session in the cell \( C_i \). The assertion is also proved by contradiction. Assume the channel \( k \) is used by cell \( C_i \) and cell \( C_j \) currently; \( C_i \) and \( C_j \) are neighboring to each other. As a result, \( k \in \text{InUse}_j \subseteq \text{Allocate}_j \). Since in step 4.11, \( \text{Free} = \bigcup \{ \text{Free}_j \mid C_j \in \text{IN}_i \} \), and in step 3.01, \( \text{Free}_j = \text{Allocate}_j \setminus \text{InUse}_j \setminus \text{Lend}_j \), then \( k \notin \text{Free}_j \) and also \( k \notin \text{Free} \). So \( k \) will never appears to the \( \text{CanUse} \) set. That contradicts to assumption.

In conclusion, neighboring cells do not use the same channel concurrently. For all \( C_j \in \text{IN}_i \), the assertion, \( \text{InUse}_i \cap \text{InUse}_j = \bot \), is always true.
Lemma 3: Let $k$ be a channel. If two different cells $C_i$ and $C_j$ use $k$ concurrently, then $C_i$ and $C_j$ are co-channel cells.

Proof: let $CO_i$ denote as the set of co-channel cells of $C_i$, IN$_i$ denote as the set of neighboring cell of $C_i$. As we known, concurrent use of channel $k$ in $C_i$ and a cell in IN$_i$ will cause co-channel interference. We need prove the following:

$$ k \in \text{InUse}_i \land k \in \text{InUse}_j \rightarrow C_j \in CO_i $$

Without loss of generality, $C_i$ and $C_j$ are located within the minimum reuse distance to each other. Let $k$ be a channel which is currently using by $C_i$, $k \in \text{Allocate}_i$. In order to channel $k$ to become a current use channel in $C_j$, there are following two situations needed to consider:

1. Channel $k$ is already used in $C_j$, then $k \in \text{Allocate}_j$ and $k \in \text{InUse}_j$. Since $k \in \text{InUse}_i$, $\text{InUse}_i \cap \text{InUse}_j = k$. According to lemma 2, the proposed algorithm ensures that $\text{InUse}_i \cap \text{InUse}_j = \emptyset$ if $C_j \in \text{IN}_i$. It is obviously that $C_j$ cannot be a member of neighbor cells of $C_i$. Thus $C_j$ is co-channel cell of $C_i$.

2. Channel $k$ tends to be used and to be finally used in cell $C_j$ simultaneously when $k$ is currently used in cell $C_i$. In cell $C_j$, channel $k$ might be gained by several approaches: sharing channel $k$ with co-channel cells of $C_j$. Importing channel $k$ from the Free set described in 4.08 or borrowing channel $k$ from neighbor cells of $C_j$.

First of all, considering channel $k$ is coming for a co-channel cell of $C_j$. As we known, channel $k$ is currently used by a cell $C_i$. if channel $k$ is used in the interference region of $C_j$, channel $k$ doesn't allow to be assigned to cell $C_j$ according to lemma 2. Since $C_i$ must not be in the interfere area of $C_j$ and no neighbor cells of $C_j$ use the channel $k$, the
conditions listed from 4.01 to 4.05 satisfy. Therefore, channel k is sharing by C_j. C_j is a co-channel cell of C_i.

Secondly, considering the possibility of obtaining the k channel from the spectrum set. Due to the reason of the k channel's current use in cell C_i, C_i is either co-channel cell or neighbor of C_j, k ∈ InUse; ⊆ Allocate. In line 4.08 of the proposed algorithm, channel k must be subtracted from set Spectrum; k is definitely not an element in the set Free. So channel k cannot be obtained from set Free when it is currently used in cell C_i.

Finally, considering the chance of channel k borrowed from C_i. In fact, channel k cannot be borrowed from cell C_i because of conflict of InUse; ∩ InUse_j = ⊥ in Lemma 2. However, is there possible if C_j borrows the channel k from other neighbor cells instead of C_i? The answer is no. From the description of line 4.12 in the proposed algorithm, k has to be an element of set SameChannel. Since CanUse = Free \ SameChannel and the channel that can be borrowed must contain in the CanUse set, the channel k doesn't have a chance to be borrowed and used by cell C_j when k is currently using in cell C_i. Therefore, if k is not currently used in cell C_j and C_j has a favor to use k, the only approach is to share channel k with its co-channel cell C_i.

In conclusion, k ∈ InUse; ∩ k ∈ InUse_j → C_j ∈ CO;

Lemma 4 (live ness): Every request for a channel is eventually satisfied or dropped.

Proof: It is easy to verify that every cell C_i that requests for a channel is eventually satisfied or dropped. Request can be responded under three situations:
1. When a request is set up in cell $C_i$, the BS$_i$ determines the condition that is listed in line 1.02 of the proposed algorithm, and a positive result leads this request quickly satisfying locally without any message exchange.

2. When the request in cell $C_i$ cannot be satisfied locally, the request is as REQUEST$_{co}$ and REQUEST$_{in}$ to send for help to co-channel cells and neighbor cells of $C_i$. Once both of conditions listed in line 2.02 and line 3.02 of the algorithm make negative result, then the cell $C_i$ will receive all REJECT responses. According to the proposed algorithm in line 4.18, the request for a channel is eventually dropped.

3. However, it may happen that the conditional examinations listed in line 2.02 and line 3.02 cause one or both positive results. Accordingly, the GRANT message will respond to the request of cell $C_i$. The algorithm described from 4.01 to 4.15 will measure what will take place after $C_i$ receives GRANT messages. In this segment of the proposed algorithm, the judgment of satisfying the request or dropping the request will be finally established. The request for a channel will be approved when conditions listed in line 4.01 and 4.05 are ensured, the condition described in line 4.08 met or conditions in line 4.10 and 4.13 are satisfied. Otherwise, the algorithm in line 4.15 will make decision to drop this request for a channel in cell $C_i$.

Consequently, every request for a channel is eventually either satisfied or dropped.

**Definition 5 (Predicate $P$):** A request $R$ from cell $C_i$ satisfies Predicate $P$ if there are no any request $L$ from cell $C_j$ and timestamp of $R$ is lower than timestamp of $L$ when the request $R$ arrives at cell $C_j$. 

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Lemma 6 (Maximum channel utilization): If Predicate P holds, request is dropped iff there exists no free channel.

Proof: Case 1 $\Rightarrow$. From the proposed algorithm, we can see request is dropped under two situations shown in line 4.15 and line 4.19 of the proposed algorithm.

1. The situation shown in line 4.18 occupies due to failure the following conditional examinations. Although at least one permit from co-channel cell $C_j$ is given to the cell $C_i$ which requests a channel, all channels in set $\text{CoChannel}_j$ conflict with channels in $\text{InfoChannel}_j$. To obey lemma 2, the algorithm in line 4.04 calculates set $\text{CoUse}_i$ to be an empty. That means no free channel available. The failure of the next condition listed in line 4.08 is clearly to address that there is no free channel available in the entire network. In the same manner, although some $\text{GRANT}_{in}$ messages in earlier stage are obtained by cell $C_i$, dropping request means that the condition listed in line 4.13 also fails. Set $\text{Free}$ contains no channels that do not conflict to the channels in set $\text{SameChannel}$. According to lemma 2, the algorithm in line 4.15 displays the result that no free channel is available.

2. When the situation listed in line 4.18 is happened, we know that all co-channel cells and neighbor cells of cell $C_i$ reject the requests from cell $C_i$. Since predicate P holds, then dropping request describes that all Allocate sets of co-channel cells in line 2.02 and Free sets of all neighbor cells are empty. That clearly addresses there are no free channels for the request.

Case 2 $\Leftarrow$. When there exists no free channel in the network, a request for a channel from the cell $C_i$ cannot be satisfied by $\text{BS}_i$ locally. Thus the $\text{BS}_i$ sends request to its all co-channels and free sets of neighbor. However, due to no free channel, Allocate sets of co-channel cells and free sets of neighbor cells are empty sets. As a result, the evaluations
of conditions listed in line 2.02 and line 3.02 are negative. Co-channel cells and neighbor cells send REJECT messages to respond to the request of C_i. Dropping a request is leaded at line 4.18 in the proposed algorithm.

**Lemma 7**: Every new request for a channel originating from a cell C_i leads a finite number of message exchange complexity.

Proof: to prove the message complexity, the following situations need to be considered:

1. In Step 1.02, if the channel request can be satisfied locally in a cell C_i, then no messages need to be exchanged between BSs.

2. CoUse_i ≠ ⊥ in step 4.05 and Free ≠ ⊥ in step 4.08, 2M+2N messages generate for sending requests to and getting all reply messages (GRANT_co, GRANT_in or REJECT) from co-channel cells and neighbor cells, where M is number of co-channel cells of the cell C_i, N is number of neighboring cells in co-channel interference region of the cell C_i. After selecting a channel in the cell C_i, N+M INFORM messages are required to complete the task of allocating a channel and remove that request from lists of co-channel cells and neighbor cells of the cell C_i. Hence, totally 3M+3N messages exchange in this situation.

3. CanUse ≠ ⊥ in step 4.13 and CanUse = ⊥ in step 4.15, 2M + 2N messages for sending requests and getting replies remain unchanged. M INFORM messages are still required, N messages of ACQUIRE or UNABLE are returned to the neighboring cells of C_i, so there are also 3M + 3N messages to be exchanged.

Since M = 6, M ≤ N. The message complexity is O(N)
ANALYSIS OF THE PROPOSED ALGORITHM

Through studying with earlier work on channel allocation strategies for mobile computing systems, the proposed algorithm has its contributions and benefits. In centralized dynamic channel allocation algorithm, a control center is required to handle channel allocation or hand-off among all cells. The control center as the central network switch must gain local information from all cells in a given cellular network. A single point of failure in the control center will bring down the entire network with increasing of network size or high traffic load in some cells. The central control switch increases its duty to make fit of the network or traffic load extension, existing channels have to be replaced by the channels that have a higher bandwidth. As a distributed algorithm, the nature of the proposed algorithm overcomes the disadvantage of centralized algorithm. Each base station carries the responsibility of its own cell. It makes channel allocation decision locally. Message exchanges for supporting the communication session in a cell are only restricted to its co-channel cells and neighbor cells. Tasks between corresponding base stations are becoming heavy only when the high request load in these cells, and they are no direct relation to a increasing networks size.

In recent years, most of the distributed channel allocation algorithm [5] [6] [15] [23] [30] focus on the strategies in which a BS borrows a channel that is not used by any cells in the interference region according to the change of the traffic pattern. As soon as a
request for a communication session channel is not satisfied locally, the BS will import a channel from a collection set of all channels in the system. Under the continuous load of channel requests, the limitary channel resources are distributed soon to the network and borrowing procedure has to be taken place in next step when a new request arises. Beyond a doubt, the strategies above have a strong ability to re-allocate channels regarding the dynamic change of communication traffics. But it is not hard to notice that less consideration is placed to the channel reuse ability. As we known in chapter 1, the channel reuse ability is an important character in channel allocation problem. Maximizing utilization of this property is directly associated with earning an effectively scheme to solve the channels allocation problem. As a result, the algorithm presented in this thesis, a sharing procedure in this thesis that attempts to reuse the channels in co-channel cells launches immediately as soon as a request for a communication session fails locally. After a request is handed over to co-channel cells, all channels in co-channel cells can be reused by the cell originating the request with observing the restriction of co-channel interference. Unlike the strategies above, the proposed algorithm is to make a best effort for reusing channels that have already been used in the network, and to save as many as possible channels in the collection set for meeting other demands that a sharing procedure cannot reach. Similarly, the abilities of importing channels from a collection set of all channels in the system and borrowing unused channels from neighbor cells are also possessed in the proposed algorithm. Thus, besides the features of the above strategies, the proposed algorithm produces and adjusts the co-channel reuse pattern dynamically with the change of channels loading traffic. Moreover, no matter what channel is using or not concurrently in the co-channel cells without confliction between neighbor cells, not
only one channel can be brought to the cell originating a request from its co-channel cells. More channels brought to a cell imply that more requests can be satisfied locally without exchanging any messages with other BSs in this cell.

In proposed algorithm, the computation involves only simple operations between sets of channels such as union, intersection and subtraction. The operations are on bit-streams, and each bit is for a channel, so the cost of the hardware, a central controller, is reduced by inexpensive microprocessor at the base station instead.

As mentioned above, the borrowing procedure has its feature. The unused channels can be moved to high request loaded cells from light request loaded cells. The high load of request may happen due to the needing of a conference or a great volume of data transfer residing in a cell. After a channel is transferred from a lightly loaded cell to a heavily loaded cell, it will not be return to the former cell. Therefore, the unused channels tend to be assigned and become members of Allocate set in the heavily loaded cell. Over a period of time, the size of Allocate sets of cells can match up with the traffic variety. Most channel requests originating in heavily loaded cells can be frequently maintained because of increased probability of available channels in Allocate sets. In addition, instead of employing Transfer message [23] in the borrowing procedure, set SameChannel is introduced in the proposed algorithm. The operations of Union and intersection between each pair of interference cells build set SameChannel to consist of all duplicated channels in the interfere region of a cell. By subtracting SameChannel from set Free, all available channels that are eligible to be move from neighbor cells are put to set CanUse. The CanUse ensures that all resident channels can be borrowed confidently to a cell from its neighbor without co-channel interference. For fulfilling the same
purpose, the improvement in the proposed algorithm reduces messages' exchange. Comparing with the strategies above, although a sharing procedure is added to the algorithm, the messages needed to make a channel allocation decision are not increased enormously. In the strategies above [23][15], at least 8N messages needed to be exchanged in the worse case. Whereas the algorithm presented in this thesis guarantees at most 3N+3M messages exchanged under all circumstances, where N is the number of neighbor cells and M is the number of co-channel cells, M is not bigger than N.

Unlike the channel allocation is completed by the base station and the mobile host together, the mobile host has to expand energy during each behavior in channel allocation, and the energy loaded in a mobile host will be soon exhausted. In the proposed algorithm, the actions involved to mobile hosts during the channels selecting decision are only to sending requests and receiving selected channels. In other words, little involvement of mobile hosts will bring imperative savings for energy.
CHAPTER 6

IMPROVEMENT

There is a possibility to some cells that are starved for channels when the algorithm is trying to avoid the deadlock. In the proposed algorithm, REJECT messages that are replied to the cell requesting a channel may lead to some requests that can be supported in a little bit sooner, being dropped. In addition, the channel allocation algorithm presented in the previous sections did not take into account the effect of handoffs in networks. In General, when a mobile host is using a channel and moving out of the cell, the channel must be rearranged in order to avoid congestion.

Avoiding Starvations

An essential consideration is to focus on deferring the REJECT message by using a threshold that allows the request, rejected easily in the proposed algorithm, to have a chance of approving. The following improvements are made to enrich the algorithm:

In Step 2, the algorithm is modified as:

Upon BS, receipt of a REQUEST$_{co}(j)$

2.01 place this request in $L_i$

2.02 if $\neg pending \land (priority(j) > priority(L_i)) \land Allocate_i \neq \bot$ then

2.03 send GRANT$_{co}$ to C$_j$

2.04 else if $m < \text{THRESHOLD}$
2.05     go to 2.02

/ ** m is the number of attempts for gaining GRANT_{co} ** /

2.06     else send REJECT_{co} to C_j

2.07     end-if

In Step 3, the algorithm is rewritten as:

Upon BS_i receipt of a REQUEST_{co} (j)

3.01     place this request in L_i

3.02     Free_i = Allocate_i \ InUse_i \ Lend_i

3.03     if (¬pending ∧ (priority(j) > priority(L_i)) ∧ Free_i ≠ ⊥) then

3.04     Lend_i = Lend_i ∪ Free_i

3.05     send GRANT_{in} to C_j

3.06     else if m < THRESHOLD

3.07     go to 3.03

/ ** m is the number of attempts for gaining GRANT_{co} ** /

3.08     else send REJECT_{in} to C_j

3.09     end-if

THRESHOLD is a constant value that is introduced as a parameter of the algorithm. A cell C_i can give a reply "GRANT_{co}" or "GRANT_{in}" to the request for a channel if Allocate_i or Free_i is not an EMPTY set and there is no pending request and requests of higher priority when the number of attempts for gaining "GRANT" is less than THRESHOLD. Thus channel starvation is somehow avoided. The channels distribution is varied with changing the value of THRESHOLD in the algorithm. Certainly, guarded
statements (2.02 and 3.02) do still function as before, the exploit of timestamp makes processes of requests accessing to their strict orders, that ensures the fairness in algorithm. And since the THRESHOLD limits times of attempts, any requests will not be leaded to a circular waiting. Therefore, the improvements to the proposed algorithm are deadlock free, not starvation and fairness.

Handling Handoffs

The communication session has to be handed off to adjacent cell. The communication session is forced to be blocked if the neighboring cells do not have channels to support the handoff. Two strategies for handling handoff can be easily merged to the algorithm presented in section 3:

1. Guard channel schemes: The concept of the guard channel was introduced in the middle 80s [3][7][11][22]. However, the policies have lately been employed in telecommunication systems [9]. Since from the sense of a mobile host forced termination of an ongoing communication is less desirable than blocking a new communication, the guard channel scheme offers a generic mean to improve the possibility of successful handoffs by simply reserving some channels exclusively for handoffs in each cell. The remaining channel can be utilized equally between handoffs and new requests. Nevertheless, due to fewer channels are available to new requests, the penalty is placed to the reduction of total carried traffic. Another disadvantage is taking the risk of insufficient spectrum resource.

2. Handoff Queuing Schemes: In the handoff queuing scheme [22][29], the probability that new requests are forced termination is reduced. The basic queuing
discipline in queuing handoff requests first-in-first-out (FIFO) [11]. A handoff request is ranked according to the degree of how close the mobile host stands to, and possibility how fast it is approaching. No new communication request is granted a channel before the handoff requests in the queue are served. Thus, a handoff communication has higher priorities to be reconnected fast by using available channels without any notice on intervals. However, a handoff call may still be dropped because the handoff requests can only wait until an upper bound is reached. The analysis results in [29] shows that the handoff Queuing scheme offers a better performance in quality of service.

As a result of incorporating the handoff scheme to the presented algorithm, it makes up the deficit that leads no solution to be applied for handling a channel's rearrangement when an ongoing mobile host crosses the boundary of the cell. The improvements of the algorithm not only enhance the aspect of avoiding starvations but also generate the function of handling handoffs.
CHAPTER 7

CONCLUSION AND FURTHER WORK

With the rapidly growing interest in the area of mobile computing in recent years, the wireless channel allocation problem has been attended significantly. As a result, a great amount of work has been done to this field. In this thesis, a new distributed dynamic channel allocation algorithm is presented. A sharing procedure is adopted as the principal criterion to choose channels from co-channel cells. Also, import of channels from the channel pool in outer network and borrowing procedure are mainly considered and participate to the algorithm.

The algorithm overcomes the centralized dynamic allocation strategies in which a failure of the centralized switch brings down the entire system by the distributed nature. The base station plays a role of the controller in the residing cell. Each base station in a cell carries the task of exchanging information among its co-channel cells and neighboring cells. Mobile hosts only involve sending requests to and receiving selected channels from corresponding base stations. The minimum utilization saves the limited energy stored at mobile hosts.

The algorithm, as a distributed dynamic allocation, possesses the feature that assigns a great number of channels to the heavily loaded cells and a few numbers of channels to the lightly loaded cells according to traffic patterns. In addition, the algorithm surmounts the shortage of most of distributed dynamic allocation strategies that places the less
concern in the channel reuse ability. The highest priority in the algorithm is to maximize
the channel usage in the co-channel cells and establishes a channel reuse pattern in
accordance with dynamic requirement of channels among cells.

The algorithm only involves the simple operations between sets such as union,
intersection and subtraction. The broad utilization of simple operations reduces the cost
of hardware and exchange messages in borrowing procedure. Due to reasonable design of
the algorithm, the message needed exchange for allocating a channel does not increase
much with the sharing procedure built in. The total message complexity is \( O(n) \) which is
as same as most of distributed dynamic channel allocation algorithms. However, the
combination of the sharing procedure and the borrowing procedure offer a more efficient
approach to allocate channels either by concurrent using channels in co-channel cells or
by transferring un-use channels from neighboring cells.

Improvements on the algorithm avoid channel starvation in the cell, and replenish the
function to handle handoffs. Co-channel interference is prevented in the algorithm. The
algorithm is proved to be deadlock free, live ness and maximum channel utilization, etc.
Moreover, the simplicity of the algorithm makes it easy to implement on a real mobile
network.

Further work needs to focus on evaluation of the performance of the algorithm. The
extensive simulation is expected to be done for the following aspects: A percent rate that
displays the successful channel allocation neither to the cell without inter-BS messages.
The average number of inter-BS messages needed to allocate a communication session
for each channel request. The probability of channel requests to be denied. Finally,
comparing with the existing distributed algorithm on the number of channels needed in the same requests loaded rate.
BIBLIOGRAPHY


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VITA

Graduate College
University of Nevada, Las Vegas

Qian Zhang

Home Address:
1600 E. University Ave, Apt. 220
Las Vegas, NV 89119

Degrees:
  Bachelor of Science, Analytic Chemistry, 1991
  Guilin Institute of Technology, P. R. China

Thesis Title: Distributed Dynamic Channel Allocation in Mobile Computing System

Thesis Examination Committee:
  Committee Chair, Dr. Ajoy K. Datta, Ph. D.
  Committee Chair, Dr. Frack Petit, Ph. D.
  Committee Member, Dr. Kazem Tagha, Ph. D.
  Committee Member, Dr. Wolfgang Bein, Ph. D.
  Graduate Faculty Representative, Dr. Zhongbo Yu, Ph. D.