Distributed Wireless Channel Allocation in Cellular Systems with Mobile Base Stations *

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1 Introduction

Most existing models describe a mobile computing system as a network of mobile nodes and stationary nodes [3]. The geographical area served by the mobile computing system is divided into regions referred to as cells. Each cell has a fixed base station referred to as the *mobile support station* (MSS). The mobile support stations are connected to each other by a fixed wireline network. Several mobile nodes, referred to as *mobile hosts* (MHs), may be present in a cell. A mobile host can communicate with other nodes in the system only through the MSS of the cell in which it is present. The MH-MSS communication link is wireless.

In their present form, mobile computing systems based on cellular architecture are either entirely unacceptable or less than suitable for a variety of scenarios, *e.g.*, battlefield and emergency response operations.

Battlefield: Fixed nodes are attractive targets, therefore highly vulnerable, in a battlefield. The destruction of such a node acting as the communication hub and proxy for a number of mobile hosts will disrupt several communication sessions. Moreover, movement of troops (MHs in the present context) in a battlefield is highly unpredictable. As troops move from one place to another, their communication network needs to move with them as well.

A system containing nodes that are designed to be stationary will not be able to adapt to this dynamic nature. A better alternative is to have base stations (MSSs) mounted on mobile platforms like helicopters and tanks. As the troops move these platforms may change their formation to provide the best possible coverage to the infantry (mobile hosts).

Another battlefield scenario is the air-dropping of a group of paratroopers behind enemy lines and a quick establishment of a wireless mobile communication network among them. Once again, the base stations need to be mobile.

Emergency response operations: Search and rescue missions in the wake of natural disasters or terrorist attacks require that the communication system be deployed quickly. If the coverage area is small, existing wireless communication systems that employ broadcasting are suitable. However, broadcasting with enough power to cover the entire field of operation is not a scalable option when

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the field of operation and/or the number of communicating devices is large. Messages should be routed through several short hops between source and destination.

Most search and rescue missions exhibit temporal locality, and are reactive. The entire area of operation is not searched continually. The region to be searched next depends on the data obtained from searches performed so far. In such situations, deploying a communication network that covers the entire area all the time is an expensive solution. Instead, a smaller network that can be quickly moved and reconfigured is desirable.

Hence, there is a need for mobile computing and communication systems that are completely reconfigurable, do not require the presence of fixed nodes or a wireline backbone, and can quickly adjust to stimuli external to the system.

Problem Description

In systems with fixed cell layout the *channel reuse pattern* is well known. As long as a channel is not used to support multiple concurrent communication sessions in a *cluster* of cells that are within co-channel interference range, there is no interference. For fixed cell layouts, clusters do not change with time. Several fixed, dynamic, or hybrid channel allocation algorithms have been proposed for systems with fixed cell layout [1, 2, 3, 4, 5, 7, 8, 9, 10, 11, 15, 16]. Some of these algorithms employ centralized controllers, while others are distributed in nature [1, 3, 8, 10].

When the cell layout is dynamic, due to the mobility of base stations, the cluster of cells within co-channel interference range changes with time. As a result, the channel reuse pattern is highly dynamic. Most existing channel allocation algorithms are not applicable in such a situation as they are not designed to handle the dynamism. Hence, there is a need for new wireless channel allocation algorithms for mobile computing systems with mobile base stations.

Moreover, the base stations also need wireless channels to communicate amongst themselves. We will refer to channels used for inter-base station communication as backbone channels. At any given time instant, a subset of the frequency spectrum allocated for mobile computing systems will be used to support backbone communication, and consequently, will be unavailable for base station-MH communication. A fully wireless cellular network can be schematically represented by Figure 1.

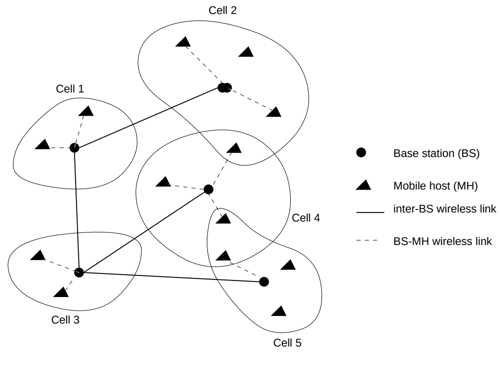

Figure 1: A fully wireless cellular network.

As inter-base station distance is significantly greater than base station-MH distance, backbone channel signals will have to be transmitted with a much higher power than signals transmitted along base station-MH links (short-hop links). Hence, the reuse distance of backbone channels will also be much greater than the reuse distance of other channels.

This raises some interesting issues:

1. Should the allocated frequency spectrum be divided into two distinct sets of channels: a set of backbone channels and another set of base station-MH communication channels?
2. If the answer to the first question is in the affirmative, how many channels should be designated as backbone channels? As the base stations move, their adjacency graph changes. Hence, the required number of backbone channels changes with time. Note that the separation of backbone channels from other channels will simplify the channel allocation problem at the cost of efficiency of channel utilization. If the adjacency matrix of base stations is sparse, several backbone channels may be unutilized, and they cannot be used for base station-MH communication either.
3. Multiple paths are needed between base stations to tolerate link failures, and to provide higher data rate along the wireless backbone. The required number of backbone channels will depend on the desired data rate and the desired degree of fault tolerance.

Concurrent presence of backbone and short-hop links with different signal strengths and range has some similarities with hierarchical cellular systems [14] having smaller microcells overlayed with larger umbrella cells. However, there are several important differences as well: (i) In hierarchical systems the relative configuration of microcells and umbrella cells remains unchanged. (ii) In hierarchical systems at least one node connected by a wireless link is fixed. However, in the proposed system both base stations connected by a backbone link may be moving. (iii) For hierarchical cell systems disjoint sets of channels are used at different layers of the hierarchy. Is this simplicity of approach worth the loss of efficiency?

Contribution of this paper

It is quite complicated to simultaneously address the problems of hand-offs involving multiple short-hop links when base stations move, and channel allocation for backbone and short-hop links. So, this paper only reports work in progress on integrated channel allocation for backbone and short-hop links in a fully wireless system. Bulk hand-off of short-hop links due to dynamic network configuration will be addressed in future work. Rappaport's analysis [11, 12] of hand-offs involving multi-unit platforms in traditional cellular networks can provide very interesting insights and a good starting point in that direction.

During channel allocation no distinction is made between channels used for backbone links and short-hop links. So, the same channel can be used concurrently for the two different types of links as long as they are not within co-channel interference distance. This is quite different from the strategy adopted by hierarchical cellular systems. It will result in better utilization of the frequency spectrum. Channel allocation problem is modeled as a generalization of the distributed mutual exclusion problem. Channel allocation decisions are made in a distributed fashion. Hence, the solution is robust and scalable. Dynamism of network configuration will be addressed in future work.

2 System Model

Let us assume a cellular communication system that divides the geographical region served by it into cells, with a base station in the center of each cell. The shape of the cells depends on various factors. Purely for the sake of illustration, let us assume that all cells are hexagonal. Figure 2 shows a part of such a system with 49 cells. In this figure all the cells, except those at the boundaries, have six neighbors. However, in an actual system, the adjacency of cells can change with time as base stations move. The proposed algorithm works regardless of any change in adjacency as long as the base station of a cell has accurate information about its adjacency.

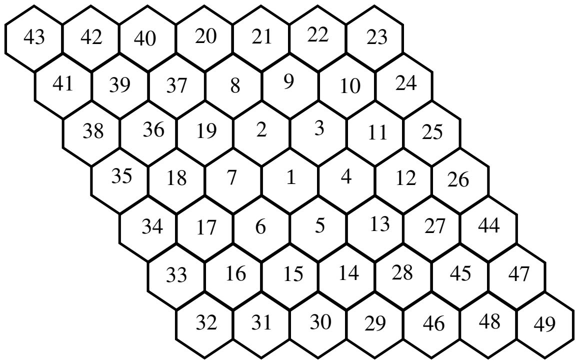

Figure 2: A cellular communication grid.

The wireless channels are independent (orthogonal) of each other. So, adjacent channel interference can be neglected. However, a channel should not be concurrently used for more than one communication session in the same cell or in neighboring cells that are within interference range of each other.

Interference Pattern

Unlike earlier models of cellular systems, the interference characteristics of a channel depend on whether it is being used to support a backbone communication or a short-hop communication. For example, if a channel is being used for a short-hop communication between a mobile host and the base station in cell 1, we assume that the same channel cannot be used concurrently to support any kind of communication in cells $2-7$. However, beyond this ring of cells the channel can be concurrently used for short-hop communication without any interference.

Let a channel be used by the base station of a cell to support a backbone communication session. We assume that it cannot be concurrently used in that cell and a number, say x, of innermost concentric rings of cells around that cell to support any other communication.[1] This region will be referred to as the *no-use region*. The ring of cells beyond the no-use region where the channel can be concurrently used to support short-hop sessions *only* will be referred to as the *partial-use region*. Beyond the partial-use region, where the channel can be concurrently used for either backbone or short-hop sessions will be referred to as *full-use region*. Purely for the purpose of explanation, let us assume that x is equal to 2. So, the no-use region will consist of a cell and the two concentric rings of cells around it. Therefore, in Figure 2, with respect to cell 1, its no-use region corresponds to cells $1-19$, the partial-use region is cells $20-37$, and all the other cells belong to the full-use region.

Let a channel be used to support a backbone communication between the base station of cell 1 and the base station of cell 2. The transmitted power along this channel is higher than channels used for short-hop communication as the inter- base station distance is greater than mobile host - base station distance. So, the channel cannot be concurrently used to support any kind of communication in cells that belong to the *no-use* region of either cell 1 or 2, *i.e.*, cells $1-22$, 36 and 37. These cells are said to belong to the no-use region of backbone link $\overline{B_{1,2}}$. If a cell C belongs to the no-use region of cell 1 and partial-use region of cell 2, or vice-versa, then the channel cannot be used to support any kind of communication in cell C. Also, if a cell C' belongs to the partial-use region of cell 1 and full-use region of cell 2, or vice-versa, then the channel can only be used for short-hop communication in cell C'. Such cells (C') are said to belong to the partial-use region of backbone link $\overline{B_{1,2}}$. Therefore, the same channel can be used concurrently in cells $23-35$ and $38-40$ to support a short-hop communication session. All other cells beyond the no-use and partial-use regions of $\overline{B_{1,2}}$ belong to the full-use region with respect to $\overline{B_{1,2}}$.

We assume that besides the wireless *communication channels* used for backbone and short-hop links there are some other wireless *control channels*. The control channels are used exclusively for the control messages exchanged for channel allocation/release for backbone and short-hop links.

A mobile host can communicate with other units, mobile or static, only through the base station of the cell in which it is present. If mobile host a in cell A wishes to communicate with mobile host b in cell B, signals travel from a along a short-hop link to the base station of A, then along the backbone network to the base station of B and from there along another short-hop link to b.

3 Summary of Results

This paper presents a distributed, dynamic channel allocation algorithm. The salient features of the algorithm are:

1. Communication channels do not have to be partitioned into disjoint sets, used exclusively for either backbone links or short-hop links. As a result, channel utilization is high.
2. There is no central switch charged with making all channel allocation decisions. Instead, the responsibility for channel allocation is distributed among all the base stations. Hence, the

[1] The value of x will be a function of the transmission power, size of cells, and the terrain.

solution is robust and scalable.

3. Principles of mutual exclusion, pertaining to distributed computing systems, are employed to develop the algorithm and prove its correctness. Unlike standard notions, mutual exclusion in the context of channel allocation has to be considered at two levels: (i) Short range: when a channel is used for short-hop communication. As signal strength is low, interference range is small and the set of cells among which mutual exclusion is to be supported is small; (ii) Long range: when a channel is used for backbone communication. So, for the same resource (channel) and user (cell) pair, the mutual exclusion requirements of the resource vary, depending on the nature of its use.

4. Channel rearrangement and directional locking during channel transfer are very important to achieve high channel utilization and low rate of request denials.

5. Allocation of channels for short-hop communication requires a very small number of messages to be exchanged between neighboring base stations. Backbone channel allocation requires a greater number of messages to be exchanged. However, in both cases, the number of messages needed for channel allocation is a constant. Assuming that base stations move much less frequently than mobile hosts, and the life of backbone links is much longer than the duration of a short-hop communication session, the communication overhead is reasonable. Channel requests that occur often (short-hop) incur lower overheads while those that occur less frequently (backbone) incur higher overheads. Thus, the algorithm makes the *common case fast*.

4 Channel Allocation Algorithm

The data structures and the strategy to allocate channels for short-hop links are similar to those described in an earlier work in which the author participated [10]. So, they will not be repeated here. Only the modifications to the earlier data structures and the additional operations required to allocate channels for backbone links are described here.

4.1 Data Structures

All the communication channels in the system are collectively represented by a set $Spectrum$. We assume that all the channels can be totally ordered.

The set of channels allocated to cell C_i is represented by two sets: $Allocate_{s,i}$ representing channels that can be used by C_i for short-hop links, and $Allocate_{b,i}$ representing channels that can be used for backbone links. Initially, $Allocate_{b,i}$ and $Allocate_{s,i}$ are empty sets for every cell C_i. The subset of allocated channels being used in a cell constitute its busy set. Unlike [10], the busy channels of cell C_i are distinguished into $Busy_{s,i}$ and $Busy_{b,i}$ denoting the channels being used for short-hop and backbone links, respectively. Also, unlike [10], cell C_i maintains two transfer sets, namely $Transfer_{s,i}$ and $Transfer_{b,i}$ consisting of the channels earmarked as candidates for possible transfer from C_i to one of its neighbors to support short-hop or backbone communication links involving their base stations. *Transfer* sets are initially empty at all the cells. All these sets are maintained by the corresponding base stations.

Several new communication requests may originate in a cell concurrently. These new requests, originating in the same cell, may be ordered according to a policy decided *a priori*. Only after the mobile service station has made a channel allocation decision about one locally originating request, does it process the next locally originating communication request in the sequence.

In traditional cellular communication systems there is only one kind of wireless link: the short-hop link. So, channel allocation algorithms for such systems, for example [10], only need to maintain and operate on the short-hop data structures $Allocate_{s,i}$, $Busy_{s,i}$, and $Transfer_{s,i}$, etc.

4.2 Backbone Channel Allocation

4.2.1 Basic Idea

When a backbone link needs to be established, all the cells in the no-use and partial-use region for the prospective backbone link are queried to identify channels that are suitable candidates for link establishment.

When a short-hop link is to be established between a base station and a mobile host in the same cell, only the cells in the immediate neighborhood are queried to find their channel usage.

This could lead to the following problem. A cell C_i may start using a channel l if it finds that l is not being used locally or in the immediately neighboring cells to support a short-hop link. However, channel l may have already been assigned two cells away in cell C_k to support a backbone link. This will lead to co-channel interference as C_i lies in the no-use region of C_k. Such a situation is avoided by simulating dummy short-hop communication sessions using channel l in all cells in the no-use region of the backbone link involving C_k (which includes C_i). The dummy sessions corresponding to channel l are removed when the backbone link using l terminates. So, when C_i needs to allocate a channel for a short-hop link it finds channel l to be in $Busy_{s,i}$ and does not use it. Thus future co-channel interference is avoided without incurring extra communication cost for short-hop channel allocation.

Let us assume that the base stations are less mobile than the mobile hosts, and that short-hop links are usually established for small time durations. Then, the backbone links have a much longer lifespan than short-hop links. So, the one-time communication costs incurred in simulating dummy calls at the time of establishing the backbone link will be more than offset by the savings derived by avoiding the communication costs for multiple short-hop channel allocations in cells belonging to the no-use region.

Channel Rearrangement

Let there be two cells C_k and C_l more than one cell apart from each other. So, they can simultaneously use the same channel for short-hop links. Also, let these cells lie in the no-use region of a prospective backbone link $\overline{B_{i,j}}$. Let channel l_1 be in use in C_k, but not in C_l, to support a short-hop link. Similarly, let channel l_2 be in use in C_l, but not in C_k, to support another short-hop link. In such a situation, neither l_1, nor l_2 can be used to support $\overline{B_{i,j}}$. However, if both C_k and C_l were to use the same channel (either l_1 or l_2) then the other channel could be used for $\overline{B_{i,j}}$. Let us call such a situation a *fragmentation* of the frequency spectrum.

It is obvious from the above example that it is very important to avoid spectrum fragmentation. Fragmentation can be avoided through *channel rearrangement*. In the context of traditional cellular systems rearrangement means that whenever a channel is allocated or freed, effort is made to ensure that all the channels in use lie towards one end of the spectrum, while the free channels lie towards the other end of the spectrum. In the context of fully wireless cellular systems, as described here, we define channel rearrangement to mean that all channels used for short-hop links lie along the lower end of the spectrum, while those for backbone links lie towards the higher end of the spectrum.

In [13], it has been stated that channel rearrangement reduces the call blocking probability in traditional cellular systems where all links are essentially short-hop links. We expect channel rearrangement to have an even greater impact in the present context because of the following reason. *The interference range of backbone links is greater than the interference range of short-hop links. Hence, each channel rearrangement will favorably impact channel availability in a larger number of cells, both for backbone and short-hop links.*

4.2.2 The Algorithm

Let us assume that a channel is needed to establish a backbone link between two neighboring cells C_i and C_j. Rather than having base stations of both cells initiate channel search (and therefore conflict with each other), let us assume that C_i's base station initiates channel search. Let us also assume that each base station maintains Lamport's clock [6].
(A) When C_i requests a backbone channel the following actions are taken by its base station:

1. Send timestamped REQUEST messages to each base station in $\overline{B_{i,j}}$'s *no-use* and *partial-use* regions (this includes cell C_j).
2. When C_i's base station has received REPLY messages from each base station to which it sent the REQUEST, it takes the union of $Busy_{b,i}$, $Busy_{s,i}$, $Transfer_{b,i}$, $Transfer_{s,i}$, and the *Busy* and *Transfer* sets received in the REPLY messages. The result is stored in $Interfere_i$.
3. If $Free_i \leftarrow Spectrum - Interfere_i = \Phi$, then it is not possible to allocate a backbone channel without causing interference. So, the channel request is dropped. Otherwise, the channel of the highest order in $Free_i$ is chosen for the transfer.
4. Let the channel selected for transfer be l.
   $Busy_{b,i} \leftarrow Busy_{b,i} \cup \{l\}$; $Busy_{b,j} \leftarrow Busy_{b,j} \cup \{l\}$;
   If ($l \notin Allocate_{b,i} \cap Allocate_{b,j}$) then: $Allocate_{b,i} \leftarrow Allocate_{b,i} \cup \{l\}$;
   C_i's base station sends TRANSFER(l) messages to all the cells in $\overline{B_{i,j}}$'s *no-use* and *partial-use* regions whose *Allocate* sets have l as a member and waits for replies. Let S denote the set of these neighbors.
5. If all the cells in S reply AGREED:
   - Channel l is used to support a backbone link.
   - C_i's base station sends RELEASE(l) messages to all the cells in S.

- Go to Step 6.

Otherwise: /* Some cells have sent REFUSE message. */

- $Allocate_{b,i} \leftarrow Allocate_{b,i} - \{l\}$;
- $Busy_{b,i} \leftarrow Busy_{b,i} - \{l\}$; $Busy_{b,j} \leftarrow Busy_{b,j} - \{l\}$;
- C_i's base station sends KEEP(l) messages to all the cells in S.
- C_i's base station selects the next highest channel from $Free_i$, with order less than that of l, and steps 4 and 5 are repeated. [2] To avoid excessive channel transfer overheads, under heavy load situations, the number of transfer attempts can be limited to the minimum of a THRESHOLD value (parameter of the algorithm) and the cardinality of $Free_i$. If all attempts to transfer a channel fail, the communication request is dropped.

6. Once a cell has decided to drop a request or to use a channel to support the corresponding communication session it sends all the deferred REPLYs to its neighbors.
7. When a backbone link $\overline{B_{i,j}}$ is *torn down*, the channel used for the link has to be freed. However, freeing-up the channel while lower ordered channels are being used to support backbone links will lead to fragmentation. So, backbone links using lower ordered channels are switched to higher ordered channels that are being freed, provided this does not lead to any interference. Then, the lowest order channel, say l, that is no longer needed for backbone links is deleted from $Busy_{s,i}$ and $Busy_{b,j}$. Also, cell C_i sends a FREE(l) message to all cells C_k in the no-use region of $\overline{B_{i,j}}$.

(B) When cell C_k's base station receives a timestamped REQUEST message from C_i's base station:

Cell C_k's base station sends a REPLY message to C_i if C_k is not requesting a channel, or if the timestamp of C_i's request is smaller than the timestamp of C_k's request. Otherwise, the REPLY is deferred. If C_k lies within the *no-use* region of $\overline{B_{i,j}}$, its base station sends two sets in the REPLY: (i) union of $Busy_{s,k}$ and $Busy_{b,k}$, (ii) union of $Transfer_{s,k}$ and $Transfer_{b,k}$. If C_k lies in the *partial-use* region of $\overline{B_{i,j}}$, its base station sends the following: $Busy_{b,k}$ and $Transfer_{b,k}$.

As C_i only uses the union of the $Busy$ and $Transfer$ sets received in the REPLYs, and never uses the two sets separately, the communication overheads can be reduced by taking their union at C_k and sending the result, rather than both the sets separately, in the REPLY message. Therefore, the REPLY message contains two sets: (i)$Allocate_k$, and (ii) the union of all or some of $Busy_{s,k}$, $Busy_{b,k}$, $Transfer_{s,k}$, and $Transfer_{b,k}$.

(C) When cell C_k's base station receives TRANSFER(l) message from C_i:
If ($l \in Busy_{s,k}$) OR ($l \in Busy_{b,k}$) OR ($l \in Transfer_{s,k}$) OR ($l \in Transfer_{b,k}$)
send REFUSE(l) message to C_i;
Otherwise
$Transfer_{s,k} \leftarrow Transfer_{s,k} \cup \{l\}$; $Transfer_{b,k} \leftarrow Transfer_{b,k} \cup \{l\}$;
Send AGREED(l) message to C_i.

(D) When C_k's base station receives a RELEASE(l) message:

$Allocate_{b,k} \leftarrow Allocate_{b,k} - \{l\}$;
$Transfer_{b,k} \leftarrow Transfer_{b,k} - \{l\}$; $Transfer_{s,k} \leftarrow Transfer_{s,k} - \{l\}$;

[2] The KEEP messages can be piggybacked on TRANSFER messages, if they are going to the same cell.

Also, if C_k belongs to the no-use region of $\overline{B_{i,j}}$ then:

$Busy_{s,k} \leftarrow Busy_{s,k} \cup \{l\}$; /* start of dummy short-hop session */

(E) When C_k's base station receives KEEP(l) message:

$Transfer_{b,k} \leftarrow Transfer_{b,k} - \{l\}$; $Transfer_{s,k} \leftarrow Transfer_{s,k} - \{l\}$;

(F) When C_k's base station receives a FREE(l) message:

$Busy_{s,k} \leftarrow Busy_{s,k} - \{l\}$; /* end of dummy short-hop session */

Note that in step (D), when a channel is being used to support a backbone link, dummy short-hop use of the same channel is simulated in all the cells in the no-use region of the link. Thus, the channel cannot be simultaneously used for short-hop links in the no-use region. Also, as the channel is deleted from the backbone allocate sets of all cells in the no-use and partial-use regions of the backbone link, the channel cannot be concurrently used to support any other backbone link in this region. Thus co-channel interference is avoided.

4.3 Proof of correctness

Lemma 1 *The channel allocation algorithm avoids co-channel interference and deadlocks.*

Proof Outline: Let a channel l be in use to support a short-hop link in a cell C_i. An immediate neighbor C_j trying to allocate a channel to support a short-hop or backbone link does not use l as it finds l to be in $Busy_{s,i}$ in a REPLY message received from C_i. So does cell C_k trying to establish a backbone link if it is not an immediate neighbor of C_i but is close enough so that C_i lies in the no-use region of the prospective backbone link involving C_k. Therefore, C_k does not use channel l. If channel l is being used in C_i to support a backbone link $\overline{B_{i,j}}$, a dummy communication session using l is simulated for the duration of the backbone link in all cells that lie in the no-use region of the backbone link. So, these cells cannot concurrently use channel l to support any kind of link. If cells in the partial-use region of $\overline{B_{i,j}}$ themselves need to establish a backbone link, they receive a REPLY from C_i containing l in $Busy_{b,i}$. So, they cannot use channel l either.

Also, once a channel has been tentatively marked in cell C_i for possible transfer to C_j, all other transfer attempts for that channel are refused until a final transfer decision has been made with regard to it. So, a channel cannot be simultaneously transferred to multiple cells that may be in each other's interference range.

Processing of channel allocation REQUESTs is prioritized on the basis of their respective timestamps. No wait is involved in responding to other types of control messages. Hence, there is no circular wait, and no deadlock. ∎

5 Performance

The communication overhead of channel allocation for short-hop links, in terms of the number of messages exchanged, is expected to be the same as that in [10]: between $3-5$ messages in situations of moderate to high channel demand, and even fewer messages when channel demand is low. This is because the short-hop channel allocation strategy is exactly the same as that in [10].

We intend to measure the communication overhead for channel allocation for backbone links through simulation experiments. The channel allocation strategy is very similar for both short-hop and backbone links. The only difference being that a greater number of cells have to be probed before backbone link channel allocation. Therefore, we expect the number of messages required for backbone channel allocation to increase proportionally with the number of cells to be queried. So, the number of messages required for backbone channel allocation is expected to be around $15-20$. This is acceptable as the message overhead for channel allocation is still a constant value. The overhead is not incurred very often and is independent of any increase in the total number of cells in the system or the geographical expanse of the coverage area.

6 Conclusion and Future Work

A cellular model of mobile computing systems with no fixed nodes was presented. The problem of concurrently allocating channels for backbone as well as short-hop links was formalized. A distributed dynamic channel allocation algorithm for such a system was presented. The algorithm was shown to avoid co-channel interference and deadlock. Also, it does not impose high communication overheads. As channels are not partitioned into disjoint sets dedicated to backbone or short-hop links, channel utilization is expected to be high. Channel rearrangement is very important to minimize the probability of backbone channel requests being denied, and to maximize utilization.

This work will be extended to incorporate bulk hand-offs induced by base station mobility. Due to movement of base stations groups of mobile hosts will move out of the range of one base station and within the range of another. Establishing new short-hop links for all such mobile hosts, while at the same time tearing down and establishing new backbone links to account for the changed network configuration is a challenging problem that will be addressed.

Also, due to the mobility of base stations, there is a possibility that a backbone link using a particular channel starts interfering with some short-hop links in the *new* no-use region. In such a situation there are two possible solutions: (a) channel reassignment is done so that now the backbone link uses a different, non-interfering channel, (b) the short-hop links in the interference range switch to other channel(s). The first approach is simple as it requires only one communication session to switch channels. However, as shown earlier, backbone link establishment and termination incurs high communication costs. However, sometimes a channel switch for one backbone link may be more efficient than several less expensive channel switches for multiple short-hop links. In such a situation, a dynamic solution that chooses between the two approaches, depending on the number of short-hop links that are interfered with, would be most suitable. The performance of such a dynamic solution is proposed to be evaluated.

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