Characteristics of load balancing and channel assignments in mobile communication systems

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Abstract

We have seen a remarkable growth of the mobile communication users in recent times. Radio frequency channels are a scarce resource and have to be reused as much as possible. Many channel assignment schemes such as fixed channel assignment (FCA), dynamic channel assignment (DCA) and hybrid channel assignment (HCA) have been proposed to assign frequencies to cells with a goal to maximise the frequency reuse. In this paper, we make a review of the characteristics of various channel assignment schemes.

1. Introduction

We have seen a remarkable growth of the mobile communication users in recent times. The fact that a very limited radio frequency spectrum allocated to this service means that the frequency channels have to be reused as much as possible in order to support the many thousands of simultaneous calls that may arise in a typical mobile communication environment.

A cellular mobile network consists of a collection of geometric areas, called cells (typically hexagonal-shaped), each serviced by a base station (BS) located at its centre. A number of cells (or BS’s) are again connected to a mobile switching centre (MSC) which acts as a gateway of the cellular network to the existing wire-line networks like Public Switched Telephone Network (PSTN), Integrated Services Digital Network (ISDN) or even the Internet.

In cellular mobile communications field, frequency channels are a scarce resource. To use the frequency channels efficiently, many channel assignment schemes such as fixed channel assignment (FCA), dynamic channel assignment (DCA) and hybrid channel assignment (HCA) have been proposed to assign frequencies to cells with a goal to maximize the frequency reuse [1]. Channel assignment must satisfy some constraints to avoid interference between channels. The following constraints have usually considered in channel assignment problem:

(a) The cochannel constraint: The same radio frequency cannot be reused in the cells within a certain distance from each other.
(b) Adjacent channel constraint: Any pair of channels in adjacent cells must have a specified distance.
(c) The co-site constraint: Any pair of channels in the same cell must have a specified distance.

In the FCA strategy a set of nominal channels is permanently allocated to each cell for its exclusive use. Users in a cell can be served only by the channels belonging to that cell. In order to maximize reuse efficiency, the same set of channels is reused in cells exactly a minimum reuse distance apart. FCA schemes are simple, however, they do not adapt to changing traffic conditions and user distribution. In the DCA scheme, all channels are kept in a central pool and are assigned dynamically to cells as new calls arrive in the system. After a call is completed, its channel is returned to the central pool. However, DCA strategies are less efficient than FCA under high load conditions. To overcome this drawback, HCA techniques were designed combining FCA and DCA schemes.

More recently, a channel borrowing scheme called channel borrowing without locking (CBWL) is proposed where channels of each base station are divided into seven distinct group to eliminate channel locking for co-channel cells [2]. The conventional approach to this problem relied on sequential heuristic techniques, but parallel distributed methods may also be used [3].

In this paper, we discuss the performance analysis of various channel assignment schemes including...
FCA, DCA, HCA and CBWL under changing tele-traffic load conditions and QoS measures.

2. Fixed Channel Allocation

In a fixed channel allocation scheme, a set of channels is permanently allocated to each cell. In a simple uniform channel distribution scheme, the overall average blocking probability of the mobile system is the same as the call blocking probability in a cell. In a non-uniform channel allocation, the number of channels allocated to each cell depends on the expected traffic profile on the cell. Heavily loaded cells are allocated more channels than lightly loaded cells. Given the traffic load in each cell and the compact pattern allocation of channels, non-uniform pattern allocation algorithms attempt to find a compact pattern that minimise the average blocking probability in the entire mobile system. Simulation results show that the blocking probability in a non-uniform compact pattern allocation is always lower than the uniform channel allocation [10].

2.1 Channel Borrowing Scheme

In a channel borrowing scheme, a cell that has used all its nominal channels can borrow free channels from its neighbouring cells to accommodate new calls, provided these channels do not interfere with existing call. When a channel is borrowed, several other cells are not allowed to use that channel. This is known as channel locking [6]. Channel borrowing schemes can be classified into simple and hybrid.

In a simple borrowing scheme [6], channels in a cell can be borrowed by a neighbouring cell for temporary use. In hybrid channel borrowing strategies, the set of channels assigned to each cell is grouped into two subsets. One set is used only for the nominally assigned cell while the other set is allowed to be lent to neighbouring cells. The objective of the borrowing schemes is to reduce the number of locked channels caused by channel borrowing. The following are the several variations of the simple borrowing strategies that have been proposed [6].

- Borrow from the Richest (SBR)
- Basic Algorithm (BA)
- Basic Algorithm with Reassignment (BAR)
- Borrow First Available (BFA)

The performance comparison for SBR, BA and BFA schemes were evaluated by simulation in [6] with two-dimensional hexagonal layout with 360 service channels. The offered load was adjusted for an average blocking probability of 0.02. A summary of the comparison results were shown below [6].

<table>
<thead>
<tr>
<th>Scheme</th>
<th>Complexity</th>
<th>Flexibility</th>
</tr>
</thead>
<tbody>
<tr>
<td>Borrow from the Richest (SBR)</td>
<td>moderate</td>
<td>moderate</td>
</tr>
<tr>
<td>Basic Algorithm (BA)</td>
<td>high</td>
<td>moderate</td>
</tr>
<tr>
<td>BA with reassignment</td>
<td>high</td>
<td>moderate</td>
</tr>
<tr>
<td>Borrow First Available (BFA)</td>
<td>low</td>
<td>low</td>
</tr>
</tbody>
</table>

3. Dynamic Channel Allocation

Fixed channel assignment schemes are not able to provide high channel efficiency due to the non-uniform nature of traffic in a cellular system. In a dynamic channel assignment (DCA) scheme, all channels are kept in a central pool of channels and are assigned dynamically as new calls arrive in a system. After a call is completed, the channel is returned to the central pool [6]. In DCA, a channel can be used in any cell provided that signal interference constraints are satisfied. The main idea of DCA schemes is to use different cost functions to evaluate the cost of using a channel and select the one with minimum cost [10]. The cost function might depend on the blocking probability of the cell, how frequently the channel is used, the reuse distance and channel occupancy distribution [9]. Based on the type of control they employ, DCA schemes can be classified into the following categories [6]:

- Centralised DCA
- Distributed DCA
- CIR measurement DCA
- One dimension system

3.1 Centralised DCA Schemes:

In a centralised DCA schemes, a channel from the central pool is assigned to a cell based on a cost function. To evaluate the cost function, the following strategies are used [6]:

- First Available channel (FA)
- Mean Square (MSQ)
- Nearest Neighbour (NN)
- Nearest Neighbour plus One (NN+1)
Computer simulation of FA, MSQ, NN and NN+1 strategies show that NN is superior with low blocking probability followed by MSQ and FA under light traffic condition [6].

<table>
<thead>
<tr>
<th>category</th>
<th>low</th>
<th>medium</th>
<th>high</th>
</tr>
</thead>
<tbody>
<tr>
<td>Blocking probability</td>
<td>NN</td>
<td>MSQ</td>
<td>NN+1</td>
</tr>
<tr>
<td>Forced termination</td>
<td>NN+1</td>
<td>MSQ</td>
<td>FA</td>
</tr>
<tr>
<td>Channel changing</td>
<td>NN+1</td>
<td>MSQ</td>
<td>FA</td>
</tr>
<tr>
<td>Carried traffic</td>
<td>NN</td>
<td>MSQ</td>
<td>FA</td>
</tr>
</tbody>
</table>

3.2 Distributed DCA Schemes

Due to the simplicity and ease of design algorithms, the distributed DCA schemes are more suitable for implementation in micro-cellular system. These algorithms use local information about the availability of channel in the cell (cell-based) or signal strength measurements. The cell-based distributed DCA scheme provides close to optimal channel allocation, but at the expense of exchange of status information between base stations large number of times [6]. In the signal strength measurement based scheme, a base station uses only local information, without a need to interact with other base stations in the system.

3.3 Comparison of FCA and DCA

We need to make a trade-off between the quality of service, complexity of algorithm implementation and spectrum utilisation efficiency. DCA strategies perform better than FCA under non-uniform traffic and light to moderate traffic intensity. However, FCA schemes perform better at high traffic loads with uniform traffic. The implementation complexity of DCA is higher than FCA. DCA schemes require heavy processing power. FCA is more suitable for centralised control system while DCA is applicable to decentralised control system. FCA is more suitable for large cell environment while DCA is suitable for micro-cellular environment. Also, FCA requires low signalling load whereas DCA requires moderate to heavy signalling load.

4. Hybrid Channel Allocation

Hybrid channel assignment (HCA) schemes are achieved by combining FCA and DCA techniques. In HCA scheme, the total available channels are divided into two sets as fixed and dynamic sets. The fixed set contains channels that are assigned to cells as in FCA schemes while any of the DCA schemes could be used for the dynamic set of channels. Many HCA schemes include channel re-ordering and call-queuing instead of call-blocking [6]. The ratio of fixed to dynamic channel is an important parameter that defines the performance of the system. This ratio is a function of traffic load and would vary over time.

Performance evaluation of different HCA schemes measured the probability of blocking as the load increases for different ratios of fixed to dynamic cells. For a given system with fixed to dynamic ratio of 3:1, the HCA gives a better grade of service that FCA for load increases up to 50 percent [6]. Simulation studies showed that system with most dynamic channels gives the lowest probability of queuing for load increased up to 15 percent of the base load where as loads over 40 percent, systems with no dynamic load gives the best performance [6]. From load of 32 to 40 percent, systems with low dynamic channel gives best performance.

5 Load Balancing scheme

An extension to the dynamic load balancing with selective borrowing scheme (LBSB) in discussed in [11]. In this scheme, a cell tries to borrow channels from adjacent cells before its nominal channel set is used up. Channels are borrowed and reassigned internally via intra-cellular handoffs.

In this scheme, cells are classified as either hot or cold based on demands from adjacent cells, a threshold parameter $h$ and its own channel demand. For example, a cell is labelled hot when its channel availability falls below $h$. This is an early indicator that the cell will fail to cope with the increasing volume of traffic in the future, resulting in exponentially increasing blocking probabilities. The channel availability of each cell is measured by its degree of coldness, which is the ratio of channels available to the total number of allocated channels in the cell.

Let $C =$ Number of allocated channels to the cell.
Degree of coldness,
\[ d_c = \frac{\text{Channels available}}{C} \]  (1)

A cell is hot if \( d_c < h \) where \( h \) is the threshold parameter. Typical values of \( h \) are 0.2, 0.25 etc., indicating that about 75% to 80% of the nominal channels are in use. For a network with \( N \) cells, the average network channel availability is given by,
\[
d_c^{\text{avg}} = \frac{1}{N} \sum_{i=1}^{N} d_c(i) \]  (2)

Fig 1. Cell network structure

A hotspot region can then be defined to consist of tessellated hot cells as in Fig 1. A ring is a group of cells that contain at least one hot cell. An arbitrary center cell is chosen and ring \( i \) ( \( i = 0, 1, 2, 3, \ldots \) ) is \( i \) number of rings away from the center cell. Ring 0 is unique since it contains the center cell and therefore the center cell by definition must be a hot. All other rings contain \( 6i \) cells as can be seen from hexagonal geometry. Cells can be either corner or non-corner cells. The First Peripheral Ring is defined as the first ring encountered which contains all cold cells.

For the generic case of a hot cell surrounded by hot cells, the individual cell demand is labelled \( X \) and is given by,
\[ X = C \left( d_c^{\text{avg}} - h \right) \]  (3)

This is the channel demand for a hot cell, and demands of other cell states would be modifications of \( X \). The demand of \( X \) for the hot cell is satisfied via channel borrowing. For a cell in ring \( i \), the number of channels which cells in ring \( i+1 \) can lend is denoted by \( l_{i+1} \), where
\[
l_{i+1} = \frac{3(i+1) + 1}{6(i+1)} X \]  (4)

The demand of each cell in the entire network is computed beforehand and a channel demand graph is constructed. Having accomplished that, the channel migration process begins with ring \( i \) handing off some calls to the borrowed channels from ring \( i+1 \). The handoffs free ring \( i \)'s nominal channel set allowing channels to be lent to cells in ring \( i-1 \). This is then repeated for each ring in the network until the center cell is reached.

The end result would be a balanced network with all cells having almost equal traffic loads and hence a reduced blocking probability.

5.1 Enhancements to this scheme

We have made some enhancement to load balancing scheme in [11] as follows:

- \textit{Channel demand, }\( X \)

Assuming the initial network had an average degree of coldness, which was above the threshold parameter. If a particular cell \( i \) started off as being heavily loaded or having a huge difference between its channel availability and the average network channel availability, then the computed demand \( X \) would be insufficient to alleviate the traffic load.

For example:

For a network consisting of 36 cells, let us assume that cells 1 to 36 had 18 channels available on average and the total channels allocated to each cell was 100. Now, if the threshold parameter \( h \) is 0.16, let us compute the demand \( X \).

\[
d_c^{\text{avg}} = \frac{18}{100} = 0.18 \]

From (3)
\[ X = 100 \times (0.18 - 0.16) \]
\[ = 2 \text{ channels.} \]

Now if, the center cell, cell 0 had only 2 channels available (other cells may have more than 20 channels available resulting in an average of 18 channels available) to begin with, the load balancing algorithm will try to lend \( X=2 \) channels. This gives cell 0 a total of 4 channels after balancing. However, it results in cell 0 having a degree of coldness of 0.04, which is still much less than \( h \) ! The algorithm has failed to bring the cell to the cold safe state after load balancing.
• Demand in a complete hotspot coordinate system

The use of the coordinate system for a complete hotspot was found to generate an unequal traffic demand among cells in a particular array. The problem affects the row of non-corner cells in a particular array, which have values of increasing j.

For example:
Consider a network with 4 rings. A cell array in ring 4 would have cells with coordinates $C_{4,0}$ to $C_{4,3}$. The amount of channels borrowed using the equation in [11] Lemma 1 for non-corner cells results in the following:

<table>
<thead>
<tr>
<th>Channels borrowed</th>
<th>$C_{4,1}$</th>
<th>$C_{4,2}$</th>
<th>$C_{4,3}$</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$7/8 \ h_{i+1}$</td>
<td>$5/8 \ h_{i+1}$</td>
<td>$3/8 \ h_{i+1}$</td>
</tr>
</tbody>
</table>

This represents an unequal borrowing trend, resulting in a network that has unbalanced rates of borrowing within the cell arrays of all the rings. The situation is magnified as the number of rings in the network are increased. However, the effect will only be noticed in particular cells that have their channels heavily borrowed from adjacent cells and channel availability close to the threshold parameter.

The performance of our scheme was investigated with different traffic loads with varying parameters. We were interested in looking at the blocking probabilities resulting from different call arrival rates. The trend of blocking probabilities with various threshold parameters $h$ was also examined. The duration of the simulation was varied to test the performance of the scheme in steady state.

In a simulation, a network of two rings was configured and a threshold parameter of $h=0.18$ was chosen. The computed average degree of coldness for the network was approximately 0.19. The duration of the simulation was set to $t=60$ iterations. The results are shown in Fig. 2.

The graph demonstrates that channel assignment with load balancing is capable of handling the incoming traffic and performs brilliantly with very low blocking probability. The increased traffic loads only result in a marginal increase in blocking probability.

Fig 2 : Average Blocking Probability for different call arrival rates

6. Conclusion

In this paper, we have reviewed the main characteristics of various channel assignment schemes in mobile communication system. A more comprehensive review is discussed in [6]. A lot of research has been done in the area of centralised, decentralised, adaptive and power control based channel allocation schemes. The main criteria used to compare the performance of cellular system under different assumption are probability of call blocking, probability of forced call termination, total carried traffic and delay in channel assignment. The emerging new technologies of microcellular networks and wireless access broadband networks will introduce new set of constraints in the resource and channel allocation problems.

7. References


