Comparisons of Channel-Assignment Strategies in Cellular Mobile Telephone Systems

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Abstract—Two new channel-assignment strategies are proposed. They are the locally optimized dynamic assignment (LODA) strategy and the borrowing with directional channel-locking (BDCL) strategy. Their performance is compared with the fixed assignment (FA) strategy currently used on certain systems and the borrowing with channel ordering (BCO) strategy (the strategy that has given the lowest blocking probability in previous research). Computer simulations on a 49-cell network for both uniform and nonuniform traffic showed that the average call-blocking probability of the BDCL strategy is always the lowest. The LODA performance is comparable with BCO under nonuniform traffic conditions but is inferior under uniform traffic conditions.

I. INTRODUCTION

THE CELLULAR mobile telephone system has found important applications in metropolitan areas. Its frequency band has been allocated by the Federal Communications Commission (FCC) [1]-[4] to be on 824-849 MHz for transmission from mobiles and on 869-894 MHz for transmission from base stations. The channel spacing is 30 kHz. This frequency band can accommodate 832 duplex channels. Among them, 21 channels are reserved for call setup, and the rest are used for voice communications.

To satisfy the large demand of mobile telephone service, channels need to be reused in different noninterfering cells. How the channels are to be assigned for simultaneous use in different cells directly affects the throughput of such systems [1], [3], [5].

Several channel-assignment strategies have been suggested in the literature. In the fixed assignment (FA) strategy, a set of nominal channels is permanently assigned to each cell, and the same set of channels is reused some distance away. That distance is called the cochannel reuse distance and is usually assumed to be three cell units. Using the FA strategy, an arriving call can only be served by the nominally assigned channels. If all nominal channels are assigned, new cells are blocked. Most of the other strategies are variations of the FA strategy with different channel borrowing methods adopted.

We shall briefly review the "simple borrowing" strategy, the "hybrid assignment" strategy and the "borrowing with channel ordering" strategy in Section II. In Section III and IV we introduce two new strategies: the "locally optimized dynamic assignment" strategy and the "borrowing with directional channel locking" strategy. Finally, in Section V, the call-blocking probabilities of four representative strategies are compared by simulation on a 49-cell network.

II. THREE CHANNEL-BORROWING STRATEGIES

A. Simple Borrowing Strategy

In the simple borrowing (SB) strategy [5], a channel set is nominally assigned to each cell. When a call arrives in a cell, a nominal channel is assigned to serve the call. If all nominal channels are busy, a nominal channel of the neighboring cells is borrowed to serve the call if that borrowing does not interfere with existing calls. Otherwise, the call is blocked.

When a channel is borrowed, several other cells are prohibited from using that channel. To see this, consider Fig. 1, where cell P borrows channel x from cell A1 to serve a call. Cell A2 and cell A3, being the cochannel cells of A1, cannot use channel x because they are within the cochannel interference range of cell P. This kind of borrowing therefore carries a penalty. To minimize the blocking of later calls, the general rule is to borrow from the "richest" neighboring cell, i.e., the cell with the most unassigned channels.

B. Hybrid Assignment Strategy

The SB strategy gives lower blocking than the FA strategy under light and moderate traffic conditions. In heavy traffic conditions, however, channel borrowings may proliferate to such an extent that the channel usage efficiency drops drastically, causing a rapid increase in blocking probability. It was shown in [6] that the FA strategy performs better than the SB strategy in heavy traffic conditions.

Combining the advantages of the SB and FA strategies, a hybrid assignment (HA) strategy was proposed in [6]. In the HA strategy, the set of nominal channels assigned to each cell is divided into two subsets A and B. Subset A channels are used in the local cell only, while subset B channels can be lent to the neighboring cells. The ratio #A/#B (#A and #B denote the number of elements in subsets A and B, respectively) is set a priori. It was found that the optimum ratio depends on the traffic load.

C. Borrowing with Channel-Ordering Strategy

Elouedi and Singh [7] proposed an improved strategy which we shall call the "borrowing with channel-ordering" (BCO) strategy. It has two distinct features:

1) the #A/#B ratio automatically varies according to traf-
minimizing the channel reuse distance of \( c_i \). In other words, we want to pack the cells using \( c_i \) as compactly as possible so that the channel could again be reused in the closest possible range. This strategy therefore represent a locally optimized dynamic assignment strategy.

IV. Borrowing with Directional Channel-Locking Strategy

A. Motivation

In BCO strategy, a channel is suitable for borrowing only if it is simultaneously free in the three nearby cochannel cells. This requirement is too stringent as we shall see in the following two examples.

First, consider Fig. 1, and let cell \( P \) borrow channel \( x \) from cell \( A1 \). Then channel \( x \) is locked in cells \( A1 \), \( A2 \), and \( A3 \) according to the BCO strategy. Cell \( Q \), a neighbor of \( A3 \) therefore cannot borrow channel \( x \) from cell \( A3 \). However, since \( P \) and \( Q \) are three cell units apart, \( Q \) can use channel \( x \) without interfering the calls in cell \( P \).

Second, suppose channel \( x \) is locked in \( A1 \), \( A2 \), and \( A3 \) due to cell \( P \)'s borrowing of channel \( x \) from \( A1 \). Then cell \( R \) cannot borrow channel \( x \) from cell \( A4 \) because doing so would require channel \( x \) to be free in \( A4 \), \( A3 \), and \( A2 \) simultaneously. However, since cells \( R \) and \( P \) are three cell units apart, \( R \) can borrow channel \( x \) from \( A4 \) without interfering the calls in \( P \).

The above observations motivate us to design a new channel assignment strategy called borrowing with directional channel-locking (BDCL). In this new strategy, when a channel is borrowed, the locking of this channel in the cochannel cells is restricted only to those affected by this borrowing. Thus the number of channels available for borrowing is greater than that of the BCO strategy. To determine in which case a "locked" channel can be borrowed, "lock directions" are specified for each locked channel.

B. Directional Locking of Borrowed Channel

Consider Fig. 1, and let cell \( P \) borrow channel \( x \) from cell \( A1 \). Then channel \( x \) in cell \( A3 \) needs to be locked in directions 3, 4, and 5 only. Cells in directions 1, 2, and 6 are free to borrow channel \( x \) since their borrowing will not interfere the call in cell \( P \). Since cell \( Q \) is in direction 2 of \( A3 \), channel \( x \) is not locked to cell \( Q \). Whether channel \( x \) can be borrowed depends also on its locking conditions in \( A4 \) and \( A5 \) (the two nearby cochannel cells). If channel \( x \) is indeed locked in cells \( A4 \) and \( A5 \) but the cell locking channel \( x \) is beyond \( Q \)'s interference area, channel \( x \) could be borrowed.

C. Channel-Reallocation

To minimize channel borrowing, both the channel-ordering concept and channel-reallocation concept are adopted in the BDCL strategy. When a call terminates, a channel is reallocated when needed according to the following rules.

1) When a call on a nominal channel terminates and there is another call on a higher order nominal channel in the same cell, then the call in the higher order nominal channel is reallocated to the newly released lower order channel (Fig. 2(a)).
2) When a call on a nominal channel terminates and there is another call on a borrowed channel, the call on the borrowed channel is switched to the nominal channel. The borrowed channel is released (Fig. 2(b)).

3) When a call on a borrowed channel terminates and there is another call on a lower order borrowed channel, the call on the lower order borrowed channel is switched to the nominal channel (Fig. 2(c,d)).

4) When a channel is completely unlocked (i.e., unlocked in all six directions) by the termination of all calls in the interfering cell, any call on a borrowed channel or a higher order channel is immediately switched to the nominal channel (Fig. 2(d)).

The channel reallocation strategy can minimize the number of calls progressing on the borrowed channels. Rule 4 is essential because channel borrowing usually occurs under heavy traffic conditions. In Fig. 1, if cell P borrows a channel from cell A1, it is possible that in the next moment a call will arrive at cell A1 and no channel will be available for assignment. Cell A1 then has to borrow a channel from its neighbors. If most of the cells are under heavy traffic at the same times, borrowing one channel may induce multiple channel borrowings. Because of the penalty of channel locking when a channel is borrowed, the throughput will degrade. Rule 4 is aimed at reducing the amount of multiple channel borrowings.

D. Channel Status Table

The Mobile Telephone Service Office (MTSO) keeps a channel status table for assigning and releasing channels. The status table keeps the following information for each cell in the network:

- FC ordered list of free nominal channels,
- SC ordered list of nominal channels serving local calls,
- LC ordered list of nominal channels being locked, their locking directions and the cells responsible for their locking.

E. Channel Assignment Procedure

When a call arrives in a cell, say cell P, the following steps are executed.

1) If FC(P) is not vacant, assign the first channel in FC(P) to serve the call. Move that channel from FC(P) to SC(P).

2) If all the nominal channels are busy, the MTSO searches through all the neighboring cells of P to identify all the free channels as well as all the "locked" channels but with cell P in the nonlocking direction. Call this set of channels X. If X is empty, block the call.

3) Select the channels in X which are either a) free in their two nearby cochannel cells, or b) being locked but the minimum distance between cell P and the locking cells is at least three cell units apart. Call the set of selected channels Y. If Y is empty, block the call.

4) The MTSO assigns the particular channel in Y which is the last ordered channel from the cell with the maximum number of free channels. Denote the assigned channel as channel X.

5) With channel x assigned, the three nearby cochannel cells will lock channel x in the appropriate directions. Move channel x from the FC list to the LC lists of the three cells. Cell P is also recorded in LC to indicate that it is responsible for locking channel x.

F. Channel Release Procedure

When a call on channel x of cell P terminates, the channel reallocation procedure described earlier is performed. After that, the channel status table is updated as follows.

1) If channel x is not a borrowed channel, it is moved from SC(P) to FC(P).

2) a) If channel x is borrowed from cell N, the locking of channel x is removed from the LC lists of cell N and its two nearby cochannel cells A2 and A3.

   b) After cell N gets back channel x, it performs the channel reallocation procedure and update the status table accordingly.

   c) If a channel is completely unlocked after the directional unlocking of channel x in cells A1 or A2, apply the usual channel reallocation procedure and update the channel status table.

V. PERFORMANCE COMPARISONS

The simulated cellular system contains 49 hexagonal cells shown in Fig. 3. Two integer variables x and y (1 ≤ x, y ≤ 7) are used to describe the cell locations. All cells are assigned with ten nominal channels. The channel reuse distance in the system is assumed to be three cell units. The arrival of calls follows a Poisson process and the call duration is exponentially
distributed with a mean of 3 min. As shown in [7], the SB strategy and the HA strategy always give a higher blocking probability than the BCO strategy. Their performance will therefore not be shown in our comparison.

First, consider the case when all cells in the network have the same arrival rate. Fig. 4 shows the average cell blocking rate of the FA, the BDCL, the LODA and the BCO strategies as a function of traffic load (calls/hour). Also shown is the Erlang B formula, which, as it should, agrees with the FA blocking result from simulation. From Fig. 4, we see that, in general, the BDCL strategy gives the lowest blocking probability, followed by the BCO, the LODA, and the FA strategies. It is interesting to note that the LODA does not perform better than BCO under uniform traffic conditions. The reason is that LODA gives only the short term optimized assignment. On the other hand, the BCO and BDCL strategies use the nominal cell, the channel order and the channel reallocation concepts always attempt to keep average channel reuse distance minimum. Under moderate traffic conditions (150 calls/h) the blocking probabilities are two, three, six, and ten percent for the BDCL, BCO, LODA, and FA strategies respectively; whereas under heavy traffic conditions (200 calls/h), the blocking probabilities are 12.5, 14.5, 18.5, and 21.5 percent respectively.

Fig. 3(a) shows a case for nonuniform traffic load. The numbers in the cells represent the Poisson arrival rates (calls/h) in the respective cells. They range from 20 to 200 calls/h. Fig. 5(a) shows the blocking probabilities of the four channel assignment strategies as the traffic rates in Fig. 3(a) are increased by 10, 20, . . . , 150 percent over the base load. Here the BDCL strategy again gives the lowest blocking probability. The blocking probability of the LODA is lower than the BCO strategy. At the base load, the FA strategy has a blocking probability of five percent whereas the other three strategies have negligible blocking. At very heavy traffic conditions (150
percent above the base load) the blocking probability are 24, 26, 27.7, and 34.7 percent for the BDCL, LODA, BCO, and FA strategies, respectively. Fig. 5(b) compares the blocking probabilities for the nonuniform traffic load shown in Fig. 3(b). For this case, we found that BCO gives lower blocking than LODA, whereas the BDCL strategy still gives the lowest blocking probability.

VI. CONCLUSION

We have surveyed four conventional channel-assignment strategies and proposed two new ones. Most of the dynamic assignment type strategies are based on the channel-borrowing concept. Our study shows that with the use of channel-ordering and directional channel locking concepts, the newly proposed BOCL strategy can give a lower blocking probability than all the other proposed strategies under both uniform and nonuniform traffic conditions. It is interesting to note that its performance is even better than the LODA strategy, indicating that a limited freedom on a spatially optimized assignment pattern is better than the successively optimized assignment method.

REFERENCES


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