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.

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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

Elnoubi 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-

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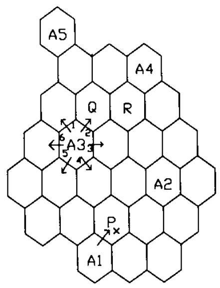

Fig. 1. Channel-borrowing and directional locking.

fic load;

2) all nominal channels are ordered such that the first channel has the highest priority to be assigned to the next local call, and the last channel is given the highest priority to be borrowed by the neighboring cells.

In the BCO strategy, after a channel is borrowed, it is locked in the cochannel cells within the channel reuse distance of the borrowing cell. Being locked means that the channel can neither be used to serve a call nor can it be borrowed. As shown in Fig. 1, channel x is nominally assigned to cochannel cells $A1$, $A2$, and $A3$. If cell P borrows channel x from neighbor $A1$, then channel x is locked in cells $A1$, $A2$, and $A3$, all of which are in P's interference range. It was found that, among all the channel assignment strategies described, the BCO strategy has the lowest call blocking under all traffic conditions [7].

III. Locally Optimized Dynamic Assignment Strategy

In the locally optimized dynamic assignment (LODA) strategy, the concept of nominal channels is not used. Instead, a particular cell having a call to serve evaluates the cost of using each candidate channel. The channel with the minimum cost is then assigned. The cost here is a measure of the future call blocking probability. Details of the LODA strategy are described below.

Given a cell P, let the nth tier cells of P be all those cells n hops (or cell units) away from $P (n = 1, 2, 3, \cdots)$. When a call arrives in cell s_m, the set of candidate channels for assignment $X(s_m)$ is the set of channels not being used in the first and the second tier cells of s_m. The cost for using channel c_j in $X(s_m)$ is established in three steps.

1) Calculate the usage frequency $U(c_i)$ of channel c_i, where $U(c_i)$ is defined as the number of third tier cells of s_m currently using channel c_i.

2) Find the set of channels for which the usage frequency U is maximum, and call it $C_{\max}$.

3) Let $D(s_m, s_n)$ be the distance between cells s_m and s_n, and $F(c_i)$ be the set of fourth and fifth tier cells of s_m currently using channel c_i. Then the cost of using c_i $(c_i \in C_{\max})$ is defined as

$$L(c_i) = \sum_{s_n \in F(c_i)} [D(s_m, s_n) - 3].$$

The channel with the minimum cost is assigned to serve the call in s_m. In the case of a tie, one of the minimum cost channels is assigned arbitrarily. Here, minimizing $L(c_i)$ means 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 interference 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)).

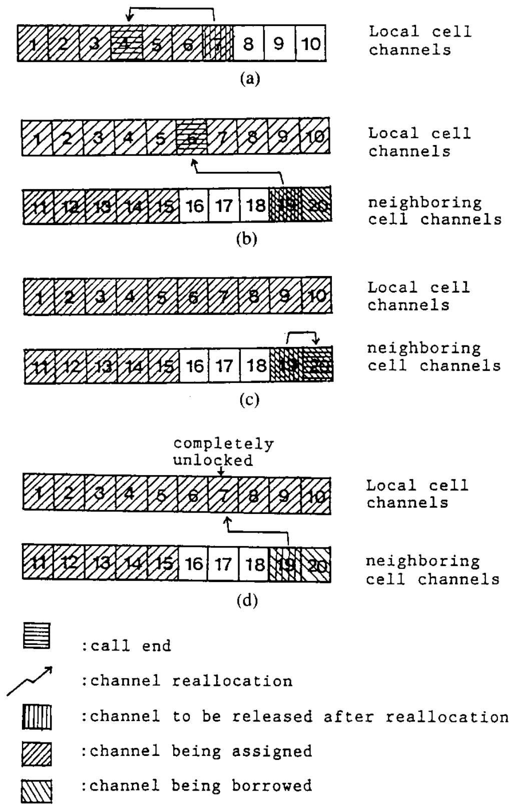

Fig. 2. Channel reallocation.

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 carrying on lower order borrowed channel is switched to this channel (Fig. 2(c)) [7].

4) When a channel is completely unlocked (i.e., unlocked in all six directions) by the termination of call(s) in the interfering cell, any call on a borrowed channel or a higher order channel is immediately switched to this 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 borrowing. 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 ($1 \leq x, y \leq 7$) 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

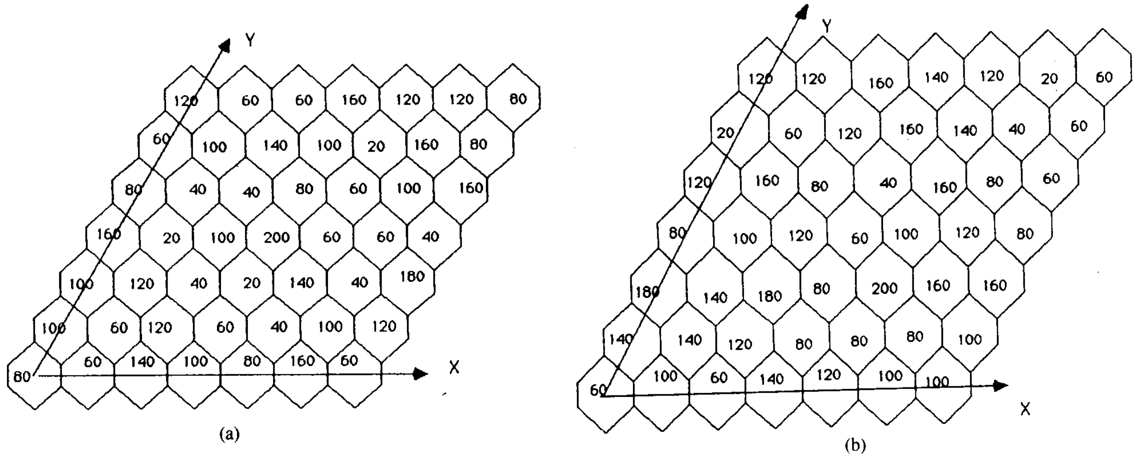

Fig. 3. Cellular system layout with two nonuniform traffic distributions. (a) Traffic distribution 1. (b) Traffic distribution 2.

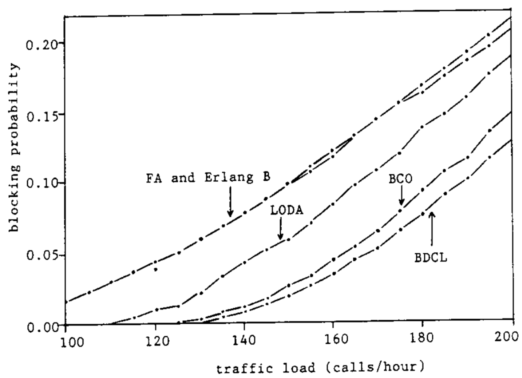

Fig. 4. Blocking comparison: uniform traffic.

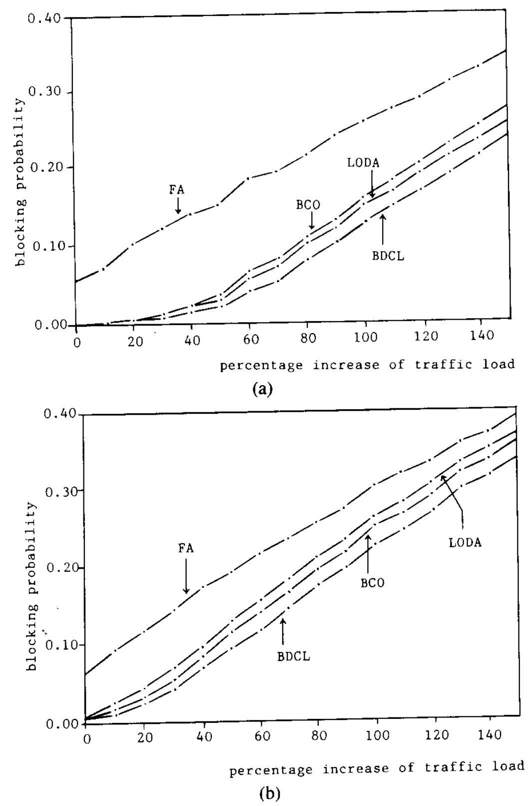

Fig. 5. Blocking comparisons: nonuniform traffic.

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 attempts 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, $\cdots$, 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.

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