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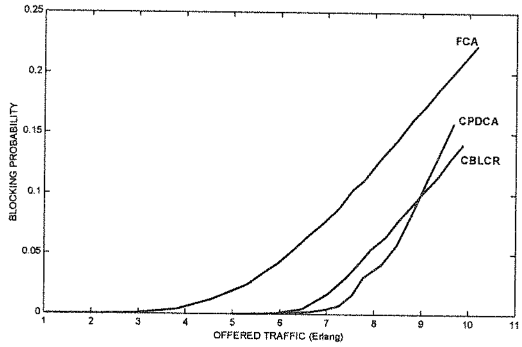

Figure (4)Average blocking probabilities of the CBLCR, uniform FCA and CPDCA versus offered traffic (Erlangs), in stationary Conditions (Without user's mobility effect).

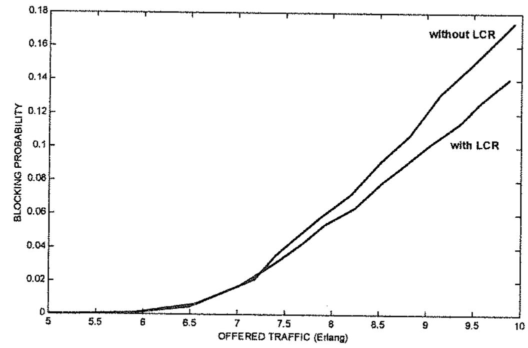

Figure (5) Average blocking probabilities of the proposed CBA scheme with and without locked-channel reassignment procedure in stationary conditions.

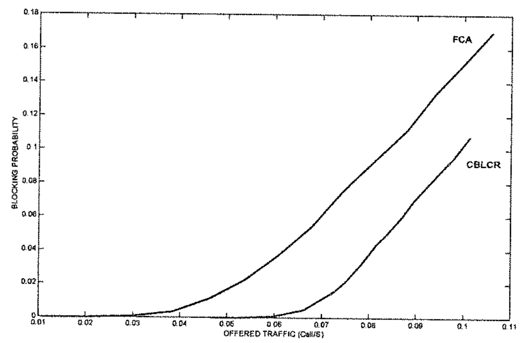

Figure (6) Average blocking probabilities of CBLCR and uniform FCA versus offered traffic (Calls/Sec) with user mobility effect.

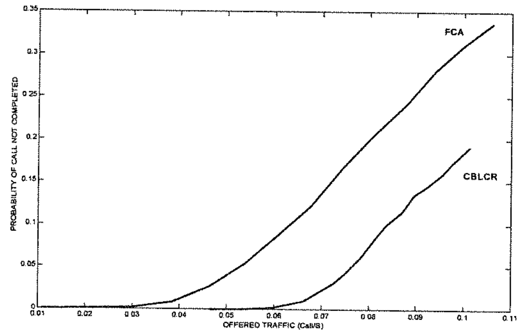

Figure (8) Average forced termination probabilities of CBLCR and uniform FCA versus offered traffic (Calls/Sec) with user mobility effect.

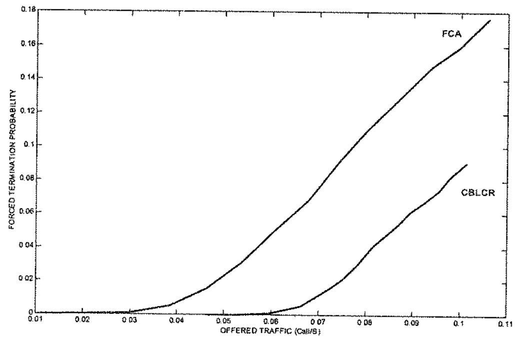

Figure (7) Average HO failure probabilities of CBLCR and uniform FCA versus offered traffic (Calls/Sec) with user mobility effect.

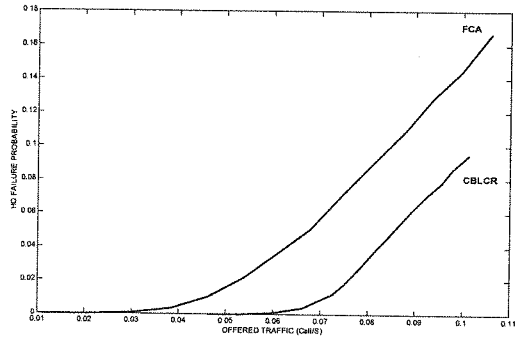

Figure (9) Average call not completed probabilities of CBLCR and uniform FCA versus offered traffic (Calls/Sec) with user mobility effect.

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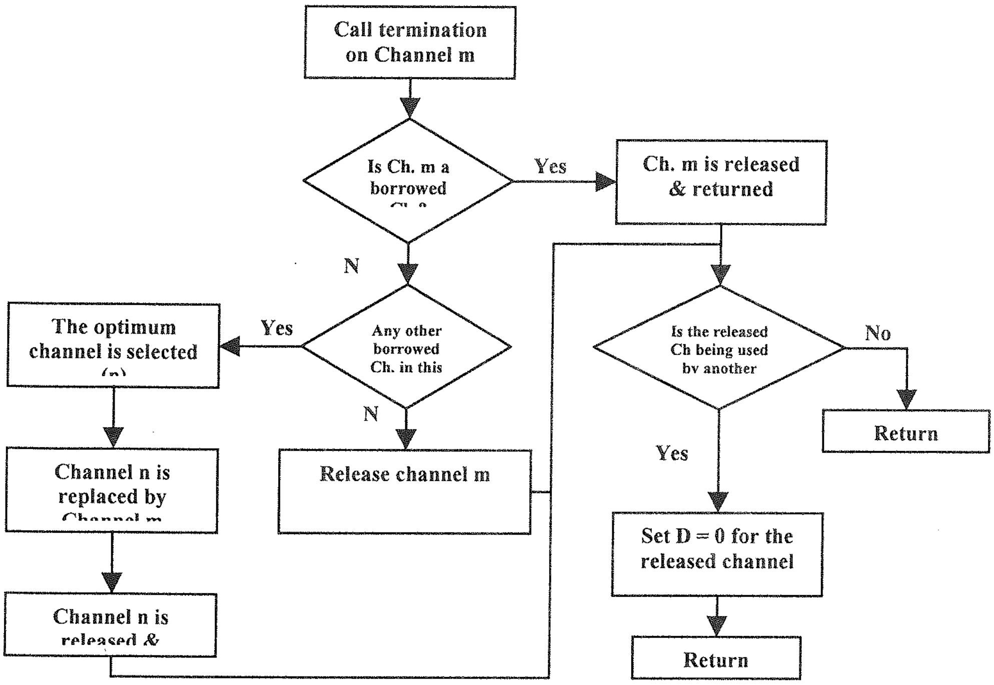


Figure (2) Flowchart of normal release and reallocation procedure.

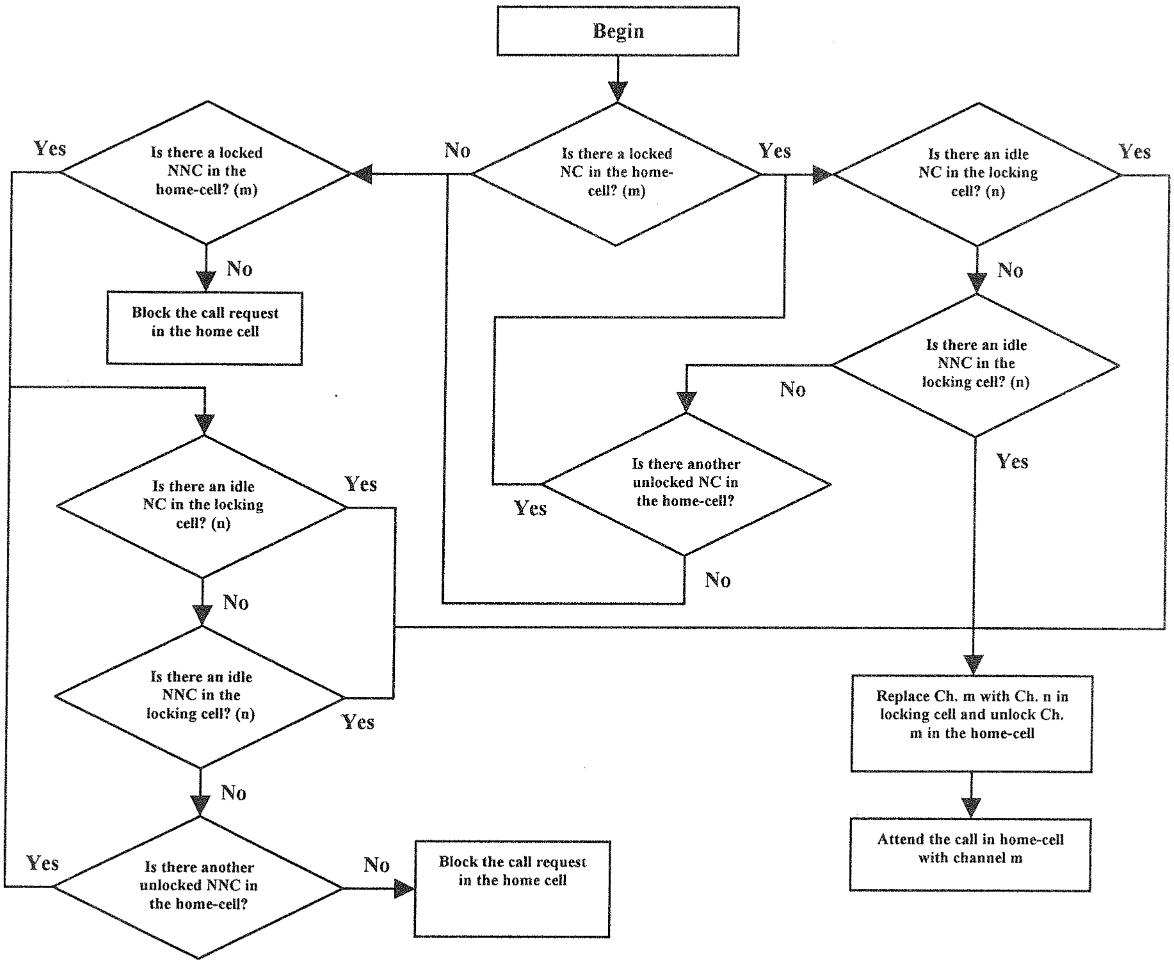


Figure (3) Flowchart of Locked-channel reassignment procedure.

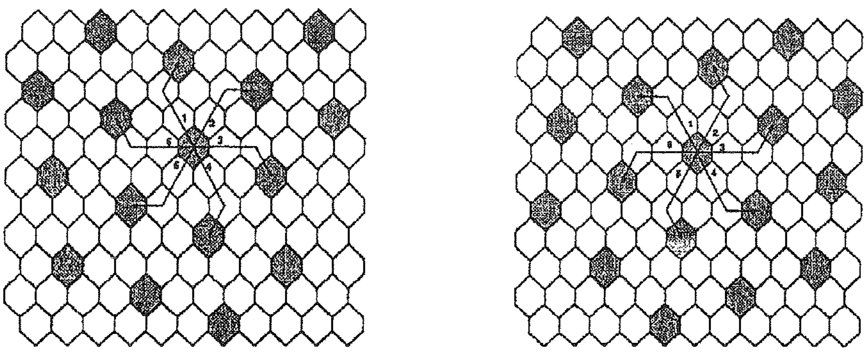
of Locked-channel reassignment procedure in improving teletraffic performance of the system is evident in this figure. Of course the price incurred by implementation of this procedure in real systems will be more complexity in network management operations and as a result more network management overhead. However, one should never forget reduction of the overhead resulting from CA activities, while maintaining enhanced bandwidth utilization of the entire cellular network is an important design goal of the cellular network system.

For assessing the performance of the proposed scheme in a highly mobile environment, three other performance indexes have been evaluated in addition to average blocking probability. These three metrics are handoff failure probability (the probability that a handoff call finds all channels busy on its arrival at its target cell), probability of forced termination (the probability that a call that was originally accepted by the system is interrupted during its process due to handoff failure) and probability of call not completed (the probability that a call is not finished either by blocking, for a new call attempt, or forced termination, for a handoff call). Fig. 6 to 9 respectively show average blocking probability, hand-off failure probability, probability of forced termination and unfinished call probability of CBLCR in comparison to uniform FCA. In both cases handover process is implemented through making use of a simple non-prioritized handover strategy. Capability of CBLCR for performing in a highly mobile environment such as PCS is evident from these results. At average handoff failure and call not completed probabilities of 2% it can respectively carry about 47% and 51% more offered traffic (Calls/Sec) comparing to uniform FCA with seven-cell reuse pattern. Further investigations based on reported results [11, 15, 16] indicate that CBLCR can effectively and impressively compete with well known existing CBA schemes such as BDCL and CPMCB, both which utilize more complicated decision making processes (especially BDCL) for their CA operations and therefore inflict additional network management complexity upon the system. Also one should consider the facts that interference constrains will never be violated in CBLCR and the maximum number of channel reallocations is at most one.

5-Conclusion

Channel borrowing is a significant design strategy in a mobile cellular communication system that affects the performance of the network and proper utilization of the network bandwidth. The main objective of CBA schemes is to distribute load as evenly as possible among neighboring cells.

In this paper a new CBA scheme called CBLCR, has been proposed and its performance has been extensively evaluated by means of an initiative cellular network simulator, which has been developed aiming to simulate a mobile communication environment as realistically as possible. The proposed scheme exploits CP concept and efficient release and reallocation techniques. Numerical results denote its capability and fitness for being used in high capacity cellular systems and utilizing a high level of spectrum efficiency.



(b)

Figure (1) Compact patterns assigned (a) Clockwise (Y_1) (b) Anti-clockwise (Y_2).

one in the neighboring cells of the local cell (a NNC of the local cell) and tries to unlock it in a manner similar to step I, so that the local cell can borrow it and assign it to the newly arrived call request.

The above-cited procedure has been illustrated in flowchart of Fig. 3.

4-Numerical results

To simulate a PCS network as realistically as possible, an initiative discrete time step model traffic simulator [17-19] was developed for this research, which uses a wraparound cellular topology (toroidal universe) consisting of 49 hexagonal cells. In this kind of simulators, the cellular system is only studied at specific (regularly spaced) time instants. Between time instants many mobile units may have moved, new calls may have been created and others may have been terminated. In general, the whole system changes between each time instant.

The reuse pattern in simulation is seven. A two-dimensional random walk process describes the mobility behaviour of mobile units in the simulation environment. We presume a mobile to change its velocity at random intervals. At each velocity update, the new velocity v will be correlated to the previous one V_p with a pdf given by: [20]

$$f_V(v) = \begin{cases} \dfrac{1}{0.6V_p} & 0.7V_p \le v \le 1.3V_p \\ 0 \end{cases} \tag{6}$$

The initial velocity of a mobile unit is considered to be a random variable with truncated Gaussian distribution between V_{MAX} and V_{MIN}.

Also when a mobile changes direction, it is presumed its new angle of direction θ to be correlated to the previous one θ_p, with following pdf:

$$f_\theta(\theta) = \begin{cases} \dfrac{1}{0.5\theta_p} & 0.75\theta_p \le \theta \le 1.25\theta_p \\ 0 \end{cases} \tag{7}$$

The initial direction of a mobile unit is considered to be a random variable with uniform distribution in the range $(0, 2\pi)$.

The traffic distribution throughout the service area is assumed to be uniform and to reflect the PCS environment; the total number of channels has been chosen to be 70. Finally the call duration pdf used in the simulation was a truncated Gaussian with a mode of 90 seconds, minimum call duration of 30 seconds and maximum call duration of 600 seconds. The actual mean of the truncated distribution is 103.5 seconds.

In deriving numerical results, we start with static blocking behavior. Fig. 4 compares the blocking performance of CBLCR with 7-cell reuse pattern uniform FCA and CPDCA [1] in stationary conditions. At average blocking probability of 0.02, the FCA has a capacity of about 5.1 Erlangs and our proposed scheme gives about 7.3 Erlangs, which represents a 43% more traffic-carrying capacity for the proposed scheme over FCA. CPDCA is an efficient DCA scheme, which outperforms most of existing DCA schemes. As it can be observed in Fig. 4, CPDCA possesses a slightly higher traffic carrying capacity in low and moderate traffic loads comparing to CBLCR, but this tide changes in higher traffic loads in favor of CBLCR due to efficient reassignment techniques. Also in CBLCR all the co-channel cells do have minimum separations, therefore it does not violate the interference constrains.

Stationary condition performances of our proposed CBA scheme with and without the presence of Locked-channel reassignment procedure have been compared in Fig. 5. The role

$$W_m = \sum_{(i,j)\in Y_m} R_{i,j}(n_{ij}) \quad (5)$$

Y_m is the CP allocated to m-th idle channel in the donor cell. In order to calculate this expression, it will be assumed that the corresponding channel is locked in the near co-channels of the acceptor cell. The selected channel is the one that minimizes Eqn. (5).

3-Release & reallocation procedures

Release and reallocation operations have been used in two different sections of our proposed CA scheme. Either of these two sections will be activated through calling its corresponding function and uses its own method for performing release and reallocation procedures.

3-1-Normal release & reallocation

When a call is terminated either permanently or locally (due to user's border crossing) in the home-cell and channel m is released in the local cell, CBLCR may release another active channel n according to following algorithm and switch its ongoing call to channel m.

I) if m is a borrowed channel in local cell, it will be released and returned back to its donor cell. Releasing m also means that it must be unlocked in the near co-channels of the acceptor cell. Afterwards, if no other cell in the system uses channel m, by setting *D [m]* = 0 (pattern-less state) it waits for another initial optimum CP assignment in its next allocation to a call demand.

II) if m turns out to be a NC in the local cell, a search will be conducted for finding a borrowed channel (n) in this cell. If more than one borrowed channel exists in the local cell, an optimal algorithm based on a cost function will determine the optimum borrowed channel to be released. Afterwards channel n will be released and returned back to its donor cell and its ongoing call will be switched to channel m. If no other cell in the system uses channel n, it will be returned to the central pool by setting D [m] = 0.

III) in the case of m being a NC and no borrowed channel being present in the local cell, m will be released and if it turns out to be idle throughout the system, channel m will be returned to the central pool.

Step II ensures efficient channel utilization. In order to determine the best borrowed channel candidate to be replaced by newly freed channel m, a cost function analogous to Eqn. (5) has been utilized. The best choice borrowed channel is the one that maximizes the cost function. Flowchart of Fig. 2 depicts the implementation of this procedure.

3-2-Locked-channel reassignment procedure

One of the major drawbacks of CBA schemes is the problem with locked channels due to channel borrowing, which has a disastrous effect on channel utilization efficiency especially under heavy traffic loads. This procedure specifically addresses the afore-mentioned problem.

If no free NC channel is found in cell (i, j) and this cell fails to borrow a channel from its neighboring cells, where a call demand arrives, this procedure will search for a locked channel in the local cell (NC) or in its neighbors that can be assigned to the newly arrived call request through the following one-channel reallocation procedure.

I) a search will be conducted for unassigned but locked NCs in the local cell. The procedure tries to unlock one of these NCs (m) by first finding an idle NC in the locking cell (n) and afterwards switching the ongoing call from channel m to channel n in the locking cell. If the search for an idle NC in the locking cell turns out to be abortive, the procedure looks for an idle channel in neighboring cells (Non-Nominal Channel or NNC) of the locking cell for borrowing and replacing channel m.

II) in case of finding no unassigned but locked NC in the local cell, the procedure searches for

Originally, CP-based CAs were aimed at minimizing the overall blocking probability of the cellular mobile systems. For defining the blocking measure, if A_{ij} is the traffic in Erlangs to cell (i, j), arrival process is assumed to be Poisson and n_{ij} is the current number of allocated channels in this cell, the blocking probability in cell (i, j) will be given by the Erlang-B formula as:

$$P(A_{ij}, n_{ij}) = \left[\sum_{k=0}^{n_{ij}} \frac{A_{ij}^{k}}{k!}\right]^{-1} \cdot \frac{A_{ij}^{n_{ij}}}{n_{ij}!} \quad (1)$$

and the blocking rate in cell (i, j) will be $A_{ij} \cdot P(A_{ij}, n_{ij})$.

In CBLCR, function CP (i, j) decides on which CP to be initially assigned to a channel. As for CP channel allocation, there are two types of CPs to be chosen for each cell in a cluster, Y_1 and Y_2 [15, 16]. Assume λ_{ij} to be the new local call arrival rate and μ_{ij} to be the new hand-off arrival rate in cell (i, j). Function CP (i, j) chooses the optimum CP according to the following decision rule, which gives the largest reduction in overall blocking rate:

$$\sum_{(i,j)\in Y_1} R_{i,j}(n_{ij}) - \sum_{(i,j)\in Y_1} R_{i,j}(n_{ij}+1) \rangle^{Y_1} \langle_{Y_2} \sum_{(i,j)\in Y_2} R_{i,j}(n_{ij}) - \sum_{(i,j)\in Y_2} R_{i,j}(n_{ij}+1) \quad (2)$$

Where:

$$R_{i,j}(n_{ij}) = f(\lambda_{ij}, n_{ij}) + f(\mu_{ij}, n_{ij}) \quad (3)$$

The function *f (a, b)* is defined as:

$$f(a,b) = a\left[\sum_{k=0}^{b} \frac{a^{k}}{k!}\right]^{-1} \frac{a^{b}}{b!} \quad (4)$$

In this manner CBLCR bases its decision making process for channel assignment not only on local call request arrival traffic, but also on handoff originated call demands.

2-Channel borrowing procedure

When no appropriate idle CP channel is available in the local cell, an idle channel will be borrowed from the richest neighboring cell (i.e. cell with the largest number of free NCs) [11] by calling the function CBA (i, j). Two conditions should be met, if channel m can be borrowed from one of the six neighboring cells:

1-Channel must be free in the home-cell.

2-Co-channels of the borrowed channel within reuse distance of the acceptor cell (near co-channels) must be free.

After successful completion of borrowing procedure, channel m will be locked in donor cell as well as the near co-channels to avoid co-channel interference. If more than one free channel were found in the donor cell, an optimal channel allocation algorithm will be used in order to borrow a channel for the new call demand in the acceptor cell. The cost function used for this decision-making task is defined by following expression:

```
if (D [m] > 0)
                    if (Ch-Status [m][i][j] = -1 &
                            C [D [m]][i][j] = 1  &
                            Ch-Lock [m][i][j] = 0)
                            /*Assign NC m to call demand*/
                            Ch-Status [m][i][j] = User No.;
                            Ch-Lock [m][i][j] = 1;
}
/* Initial non-uniform assignment of CPs */
for (m = 1 to M)
{
if (D [m] = 0)
                    D [m] = CP (i, j);
                    Ch-Status [m][i][j] = User No.;
                    Ch-Lock [m][i][j] = 1;
}
/* CBA, if no free NC was found */
Ch-No = CBA (i, j);
if (1 =< Ch-No =< M)
          Ch-Status [m][i][j] = User No.;
          /* Borrowed Channel will be locked in donor cell and near co-channels */
          else
          /* Locked-Channel Reallocation procedure */
          Ch-No = LCR (i, j);
          if (1 =< Ch-No =< M)
                    Ch-Status [m][i][j] = User No.;
                    / *Necessary locking and/or releasing operation */
          else
                    The call is blocked
```

To further illustrate this algorithm, A few variable names should be defined. Total number of channels in the system is M and the m-th CP is represented by the 3D array *C [m][i][j]*.

$$C_{ij}(m)=\begin{cases}1 & \text{if cell } (i,j) \text{ belongs to the } m-th \text{ CP}\\ 0 & \text{otherwise}\end{cases}$$

Array *Ch-Status [m][i][j]* denotes the occupancy state of channel m in cell (i, j) and it is equal to the number of that using this channel in cell (i, j) in case of being occupied.

$$Ch-Status_{ij}(m)=\begin{cases}User's\ No. & \text{if channel } m \text{ is being used in cell } (i,j)\\ 0 & \text{otherwise}\end{cases}$$

One-dimensional array D [m] indicates the CP that has been allocated to channel m and its equality to zero means channel m has not been assigned to any cell yet. In other words $D = [d_1\ d_2 \ldots d_M]$, where:

$$D(m)=\begin{cases}n & \text{channel } m \text{ is assigned according to } n-th \text{ CP}\\ -1 & \text{channel } m \text{ is assigned in a non-compact manner}\\ 0 & \text{channel } m \text{ is not yet assigned to any call}\end{cases}$$

Ch-Lock [m][i][j] expresses locked or unlocked state of channel m in cell (i, j).

$$Ch-Lock_{ij}(m)=\begin{cases}1 & \text{if channel } m \text{ is being locked in cell } (i,j)\\ 0 & \text{otherwise}\end{cases}$$

between complexity and usage of the system. At the cost of complexity, the capacity of Personal Communication System (PCS) can be increased, by utilizing the channel more efficiently.

In pure FCA, a different approach to create a more dynamic environment is the so-called Channel Borrowing Assignment (CBA) schemes [11-13]. In CBA, all available channels in the system are assigned to cells as NCs as in FCA. However, channels can be borrowed from neighboring cells according to some algorithm as long as the co-channel interference constrains are satisfied. One major advantage of CBA schemes over DCAs is that they do not require system-wide information. Borrowing can be performed in two different ways:
1-the frequency is inhibited in the original cell and now is transmitted by the overloaded cell.
2-the resource is kept by the original owner but is transmitted at a higher power level to provide coverage also for (part of) the requesting cell.

Some of the well-known CBA schemes such as BCO, BDCL and CPMCB do not solely rely on channel borrowing concept and use channel reassignment and ordering techniques for improvement of their blocking performance [1, 11].

In this paper a new CBA scheme based on Compact Pattern (CP) concept for initial non-uniform allocation of NCs to cells [14, 15] has been proposed and termed as CBLCR (Channel Borrowing with Locked-Channel Reassignment). To select the optimum channel for borrowing in a highly mobile micro-cellular environment, this scheme uses a cost function that not only considers the traffic load due to new call demand arrivals in the cells, but also takes into account the hand-off originated call demand traffic. Also initiative channel reallocation techniques have been utilized to further enhance teletraffic performance of CBLCR. To evaluate the performance of the proposed method in the presence of users' mobility, a discrete time step model cellular traffic simulator has been developed and exploited for extracting numerical results. The corner-stone of this research has been laid upon principles of CA in first and second generations cellular systems (FDMA/TDMA), but our proposed CA scheme can also be implemented in third generation mobile systems as long as the multiple access schemes allows it. For example, this scheme could be realized with the hybrid TDMA/CDMA system proposed for UMTS. Having this extension in mind, the shared resource is considered to be a logical channel throughout this research.

1-General strategy of CBLCR

Let us assume the location of cells is represented by their integer coordinates (i, j) in a two-dimensional array of hexagonal cells. A CP-based CA always tries to keep the co-channel cells of any channel to a CP whenever possible. Co-channel cells are cells, which can use the same set of frequency channels without violating the co-channel interference constraints. A compact pattern of a cellular network is defined as the channel allocation pattern with minimum average distance between co-channel cells [14]. Since the traffic distribution in real cellular mobile systems is more often non-uniform, CP concept provides a systematical approach for non-uniform assignment of channels. A cellular system with CPs can be laid out by using two shift parameters i and j ($i \geq j$). For a seven-cell reuse pattern i=2 and j=1. Fig. 1 shows the procedure of obtaining the co-channel cells of a CP. The two turning directions give rise to two CPs. As the reference cell can take position in any one of the seven cells within a cluster, a seven-cell reuse pattern will give a total of fourteen different CPs.

At the beginning all channels are kept in the central pool. When a call demand arrives at cell (i, j), a free channel is selected and then allocated to the new call demand according to the following algorithm:

```
/* Local assignment of NCs in home-cells */
for (m = 1 to M)
{
```

A Novel High Capacity Channel Borrowing Assignment Scheme Suitable for PCS Environments

V. Tabataba Vakili
Associate Professor

A. Aziminejad
Ph. D. Student

Department of Electrical Engineering,
Iran University of Science & Technology (IUST)

Abstract

Frequency planning in cellular systems becomes more and more critical as cell dimensions decrease. In this paper a new channel borrowing assignment scheme based on compact patterns is presented. Channel Borrowing with Locked-Channel Reassignment (CBLCR) allows the borrowing of resources in an adaptive way depending on the traffic conditions. By using efficient techniques in inter-cell and intera-cell reallocation phase of the proposed scheme, its teletraffic performance has been further improved. CBLCR does not require system-wide information and all it needs is information about the local cell and its interfering cells.

Whereas a main objective of this research has fundamentally been to study the effect of user's mobility on performance of channel assignment strategies in a microcellular scenario, an innovative simulation environment using discrete time step model traffic simulator notion has been developed and exploited for extracting as realistic as possible results regarding teletraffic performance of the proposed scheme in highly mobile environments.

Key Words

Mobile Communications, Channel Borrowing Assignment, Compact Pattern, Teletraffic Performance

Introduction

Channel Assignment (CA) plays a key role in mobile communication systems, where we had witnessed an explosive growth in past few years. The main objectives and technical challenges in future trends of the universal mobile telecommunication systems (UMTS's) are to provide higher spectral efficiency than existing systems and to have resource flexibility to accommodate multiple networks and traffic types within a given frequency band. The rising traffic demand in cited systems at an unpredictable rate has caused the radio spectrum to be treated as the most precious resource in mobile communications. To maximize its effective use, a lot of effort has been put in enhancing system level capabilities [1-4].

Older systems such as GSM use a Fixed CA (FCA) scheme, where the allocated cellular spectrum is divided into N channel sets and N neighboring cells are grouped into a cluster. Each cell in a cluster is then permanently assigned one of the N channel sets as its Nominal Channel (NC) set and the same channel set is reused in the corresponding cell in every cluster [5-7].

On the other side, Dynamic CA (DCA) techniques have been proposed that allocate resources "on demand" under either centralized or distributed control [5, 8-10]. Each of these two opposite approaches has their own advantages and disadvantages. FCA schemes are static but easy to handle, DCAs are highly adaptive but require transceivers capable to perform fast selection of the channel to use and a high signaling complexity. However, as the users' congestion grows, the cost of service becomes a major concern, in which efficiency of bandwidth utilization plays a critical role. When this is paramount, a trade-off must be made