Compact pattern dynamic channel allocation: Discrete-event modeling & performance simulation of an innovative approach

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Abstract

With limited frequency spectrum and a tremendous growth in the demand for mobile communication services, the problem of channel assignment becomes increasingly important. In this paper a novel traffic-adaptive non-uniform compact pattern assignment algorithm is presented, which can be exploited in a PCS cellular environment with highly mobile users. The proposed dynamic channel assignment scheme copes with the handoff originated call demands problem as well as focusing on reduction of the blocking probability of the new calls.

The simulation of a cellular communication system comprises both discrete and continuous time processes. In this research, computer simulation results on a 49-cell network model conducted in a different manner and environment comparing to previous studies indicate superior teletraffic performance of the proposed strategy over its predecessors. By using a discrete time step model traffic simulator based on discrete-event simulation notion, the effect of users' mobility on the grade of service is also come under study in this research.

Key Words
Mobile Communications, Network simulation, Discrete-event model, Channel Assignment

1. Introduction

Steady quantitative and qualitative growth of cellular systems in the last decade along with pertinent demands and expectations of wireless telephone users throughout the globe, caused an extensive study of various and different Channel Assignment (CA) strategies [1]. There are many features that can be used to classify CA techniques, but the most common basis is to compare CA techniques in terms of the manner which co-channel cells are separated. In this classification CA strategies are divided into Fixed CA (FCA), Dynamic CA (DCA) and combining the first two, Hybrid CA (HCA). In the traditional FCA strategy, the service area is partitioned into a number of cells and the same number of channels grouped as a set, is permanently assigned to each cell according to a predetermined reuse pattern [1-3]. The number of different sets of channels depends on the carrier-to-interference ratio (C/I) needed to guarantee an adequate service quality. The number of channels in each set depends on the predefined blocking probability of that cell. In Contrast to FCA, in DCA strategies there is no fixed relationship between the channels and the cells and every channel can be used in any cell in the network as long as the interference constrains are fulfilled. After successful or unsuccessful completion of each call, the assigned channel will be returned to a central pool [1, 4]. Due to their traffic adaptive nature, DCA strategies will play a dominant role in next generation of cellular mobile systems.

In this paper, we have proposed a heuristic DCA scheme, which uses the Compact Pattern (CP) concept as a foundation for dynamic allocation of logical (not merely physical) channels [5]. Our proposed scheme, which is a generalized and extended version of the original method, also utilizes the novel concept of channel restoration through which the teletraffic performance of the system is considerably promoted. In this research we have tried to evaluate the performance...
of our proposed scheme in a highly mobile micro-
cellular environment, where the performance of CA
strategy is severely affected by user's mobility. As
analytic models of mobile communication networks are
often not general or detailed enough to be a useful mean
for performance evaluation, this goal has been achieved
through making use of an innovative discrete time step
model network simulator, which essentially is founded
upon discrete-event modeling and simulation notion [6-8]. Discrete-event simulation is the modeling over time
of a system all of whose state changes occur at discrete
points of time. A discrete-event simulation proceeds by
producing a sequence of system snapshots, which
represent the evolution of system through time. A given
snapshot at a given time includes not only the system
state at that specific moment, but also the Future Event
List (FEL) of all activities currently in progress and
when each such activity will end, the status of all entities
and current membership of all sets, plus the current
values of cumulative statistics and counters that will be
used to calculate summary statistics at the end of
simulation. Numerical results derived from this
performance evaluation process indicate that the
proposed scheme outperforms some well-known and
efficient DCA schemes.

2. CA strategy description

CP-Based DCA with pattern restoration can be
divided into two phases: channel allocation and channel
releasing, reassignment and restoration.

2.1. Channel allocation

Assume the location of cells be represented by their
integer coordinates (i, j) in a two-dimensional array of
hexagonal cells. CP-based DCA differs from
conventional DCA strategies by trying to keep the co-
channel cells of any channel to a CP whenever possible.
A CP of a cellular network is defined as the channel
allocation pattern with minimum average distance
between co-channel cells [5]. In CP-based DCA with
channel restoration, channel allocation phase is in
charge of finding an optimal idle channel for the newly
arrived service demands. For enhancing CP-based DCA
with channel restoration teletraffic behavior when
handoff is taken into account, in this research a modified
cost function based on the idea propounded in [9] has
been utilized. This modified cost function selects the
best CP to which a channel should be assigned. The CP
that gives the largest reduction in the new call blocking
probability and the handoff arrival blocking probability
will be chosen. The cited cost function in cell (i, j) is
given by:

\[
R_{i,j}(n_y) = f(\lambda_{ij}, n_y) + f(\mu_{ij}, n_y)
\]

(1)

Where \( \lambda_{ij} \) is the new call arrival rate and \( \mu_{ij} \) is the new
handoff arrival rate in cell (i, j), \( n_y \) is the current number
of allocated channels in this cell and the function \( f(a, b) \)
is defined as:

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

(2)

The CP \((Y_1, \text{or } Y_2)\) that gives the largest reduction in
above-mentioned cost function is obtained by the
following decision rule:

\[
\sum_{(i,j) \in Y_1} R_{i,j}(n_y) - \sum_{(i,j) \in Y_2} R_{i,j}(n_y + 1)
\]

(3)

Channels are assigned to each cell on a CP basis
according to initial FCA scheme. A non-compact
channel with a minimum cost function is chosen to
attend a newly arrived call request according to the
following steps, only if no appropriate compact channel
has been remained in the central pool to be assigned to
newly arrived call demand:
I) A search will be conducted for all the channels which
are idle in the first and second tier of cells encircling cell
(i, j) (set M). Any member of this set can be used in cell
(i, j). If M is empty the call will be blocked.
II) For selecting the optimal  channel between members
of M, one of the non-compact members of M will be
chosen which is being used by the largest number of
channels in the system.
III) If M does not contain any non-compact channel, an
incomplete compact channel (one that has not been fully
utilized by all the cells of its corresponding CP), which
gives the minimum reduction in the new call blocking
probability and the handoff arrival blocking probability,
will be chosen.

This procedure is further illustrated by the flowchart
of Fig. 1.

2.2. Channel releasing and restoration

When a call is terminated (either naturally or
forcefully) and channel x is released in cell (i, j), CP-
based DCA with pattern restoration may release another
active channel y in this cell, according to different rules,
and reassign channel x to the call on channel y. This
operation is used to restore the CPs and hence maintain
the lowest possible reuse distance between co-channels.
When channel \( x \) is released, channel releasing and restoration phase performs the following steps in the local cells:

I-Pattern of channel \( x \) will be restored. By pattern restoration we mean possible change from non-compact pattern to a CP or pattern-less status (In the case that no other cell in the system uses channel \( y \)).

II-The call on an active non-compact channel \( y \), if there exists one, will be switched to compact channel \( x \) and channel \( y \) will be released in cell \( (i, j) \) and its pattern will be restored.

III-If no active non-compact channel exists in the local cell, a compact channel \( y \) that is active in smallest number of cells will be found and if this number is smaller than that of compact channel \( x \), the call on channel \( y \) will be switched to channel \( x \). Afterwards, channel \( y \) will be subjected to pattern restoration procedure.

Hence, if a non-compact channel is due to be released, first the possibility of restoration to a CP will be investigated for this channel and afterwards the reassignment process will be accomplished by executing afore-mentioned steps. By utilizing this approach, a two-way change from CPs to non-compact pattern and vice versa can take place (channel restoration), which will improve teletraffic performance of the CA scheme especially in heavy traffic conditions. As the traffic rate increases, the randomness of call initiation will gradually destroy the CPs and the number of non-compact channels will rise. This will cause an increase in average reuse distance and therefore channel utilization will decrease. Step II can minimize the number of calls holding the non-compact channels and restore CPs. Step III intends to pack the ongoing calls, so that newly arrived calls can more readily be accepted.

3. Simulation and numerical results

3.1. Discrete-event network simulation and traffic generation

To simulate a PCS network as realistically as possible, an initiative discrete time step model traffic simulator based on discrete-event simulation principles was developed for this research [7, 8]. The simulation environment consists of a wraparound cellular topology [6, 10] with 49 hexagonal cells arranged in a 7*7 array. The reuse pattern in simulation is seven. The mechanism for advancing simulation time and guaranteeing that all events occur in correct chronological order is based on the FEL. FEL contains all event notices for events that have been scheduled to occur at a future time. Scheduling a future event means that at the instant an activity begins, its duration is somehow derived (usually according to a given pdf) and the end-activity event, together with its event time, is placed on the FEL. After the system snapshot at simulation time \( t_1 \) has been updated, the simulation clock is advanced to simulation time \( t_2 \) and the event associated with this moment in the FEL will be executed. At the time \( t_2 \), new future events may or may not be generated (randomly, with probabilities \( p_i \) and \( 1 - p_i \)), but if any are, they are scheduled by creating event notices and putting them in their proper position on the FEL. This process repeats until the simulation is over. Fig. 2 depicts the flowchart of the driver section of simulation program, which is in charge of event-scheduling and was codified using Visual C.

In Contrast to traditional approach in hexagonal cellular geometry formulation [10], orthogonal coordinate system has been used in this research for positioning users throughout service area. With this choice of coordinate system the mobility modeling becomes more tractable. In this system and with the cellular array configuration that we have utilized, the coordinates of the cell centre is given by:

\[
\begin{align*}
  x &= (3k - \frac{1}{2})R \\
  y &= (2m-1)(\frac{\sqrt{3}}{2})R
\end{align*}
\]

where \( m \) and \( n \) are row and column numbers of the cell in cellular array and \( R \) is the cell radius. In the case of \( n \) being an odd number, the coordinates will be:

\[
\begin{align*}
  x &= (3k - 2)R \\
  y &= (2m)(\frac{\sqrt{3}}{2})R
\end{align*}
\]

The system snapshots are updated regularly every 10 seconds. A two-dimensional random walk process describes the mobility behavior 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: [11]

\[
f_{v}(v) = \begin{cases} 
  \frac{1}{0.6V_p} & 0.7V_p \leq v \leq 1.3V_p \\
  0 & \text{otherwise}
\end{cases}
\]

The initial velocity of a mobile unit is considered to be a random variable with truncated Gaussian distribution between \( V_{\text{MAX}} \) and \( V_{\text{MIN}} \). Also when a mobile changes direction, it is presumed its new angle of
direction \( \theta \) to be correlated to the previous one \( \theta_p \), with following pdf:

\[
f_{\theta}(\theta) = \begin{cases} 
1 & 0.75\theta_p \leq \theta \leq 1.25\theta_p \\
0.5\theta_p & \theta < 0.75\theta_p \\
0 & \theta > 1.25\theta_p 
\end{cases}
\]

(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, which means call requests are uniformly distributed throughout service area 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.

3.2. Performance evaluation

First of all we begin with investigating the effect of channel restoration on blocking probability of CP-based DCA when system is in stationary condition i.e. the mobility effect is relinquished. For this purpose the average blocking probabilities of CP-based DCA without pattern restoration, CP-based DCA with pattern restoration (M-CPDCA) and uniform FCA with seven-cell reuse pattern are plotted in Fig. 3 as a function of average offered traffic in Erlangs. It is observed that M-CPDCA always offers the lowest blocking probability over the whole range of traffic under consideration. At average blocking probability of 2%, the FCA has a capacity of about 5.1 Erlangs and M-CPDCA gives about 7.7 Erlangs, which represents a 51% more traffic-carrying capacity for M-CPDCA over FCA.

In the case of taking into account mobility effect, blocking probability alone will not provide sufficient information for evaluating the performance of CA schemes. Fig. 4 to 6 respectively depict average blocking probability, handoff failure probability and probability that a call is not completed (either by blocking or by forced termination due to handoff failure) of CP-based DCA with channel restoration and uniform FCA as a function of average offered traffic in call per seconds. In both cases handover process is implemented through making use of a simple non-prioritized handover strategy. The set of figures confirms M-CPDCA superiority in adapting itself to the user mobility over FCA in a PCS cellular environment. As a numerical example, for average handoff failure and call not completed probabilities of 2%, M-CPDCA can respectively carry about 58% and 63% more offered traffic (Calls/Sec) comparing to uniform FCA with seven-cell reuse pattern.

4. Conclusion

A modified extension of CP-based DCA has been proposed in this paper, which bases its channel assignment management over handoff originated traffic as well as new call demand arrivals. Simulation results based on using a discrete time step model traffic simulator specifically developed for this research designate superior capability of the proposed CA scheme in working as a non-prioritized handoff strategy in a PCS environment. Also by utilizing the concept of pattern restoration, the teletraffic performance of the cited scheme has been further enhanced.

5. References

Figure 1: Flowchart of channel allocation phase
Figure 2: Flowchart of driver section of the simulation program
Figure 3: Average blocking probabilities of CP-based DCA without pattern restoration, CP-based DCA with pattern restoration (M-CPDCA) and uniform FCA versus offered traffic (Erlangs), in stationary conditions.

Figure 4: Average blocking probabilities of CP-based DCA with pattern restoration (M-CPDCA) and uniform FCA versus offered traffic (Call/Sec) with user mobility effect.

Figure 5: Average HO failure probabilities of CP-based DCA with pattern restoration (M-CPDCA) and uniform FCA versus offered traffic (Call/Sec) with user mobility effect.

Figure 6: Average call not completed probabilities of CP-based DCA with pattern restoration (M-CPDCA) and uniform FCA versus offered traffic (Call/Sec) with user mobility effect.