# Aggressive Fuzzy Distributed Dynamic Channel Assignment for PCS

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*Abstract*— **In this paper, two variants of the aggressive fuzzy distributed dynamic channel assignment (AFDDCA) schemes, namely, the *Aggressive Simple Fuzzy Distributed Dynamic Channel Assignment* (AFS-DDCA) scheme and the *Aggressive Maxavail Fuzzy Distributed Dynamic Channel Assignment* (AFMA-DDCA) scheme, are introduced. The respective crisp counterparts of the two schemes are the *Simple* and the *Maxavail* schemes formulated by McEliece and Siverajan of Caltech. The crisp and the fuzzy versions of both schemes are identical in formulation and complexity, except: (1) Fuzzified constraints are used in the fuzzy schemes while crisp constraints are used in the crisp schemes. (2) The fuzzy schemes automatically enter aggressive mode when all perfectly feasible channels are not available. Under this scenario, *slightly* less feasible channels are activated for assignment. The aggressive feature can be interpreted as a soft constraint violation. Fuzzifying constraints effectively enlarge the feasible solution space and hence can increase throughput performance with simple search schemes. We will show through simulations that both AFDDCA variants surpass their crisp counterparts in throughput performance. Quality degradation due to constraint violation is mild. Hence, the Grade of Service (GOS) is better than that of many DCA algorithms based on complex search schemes.**

## I. INTRODUCTION

The frequency band allocated by Federal Communication Commission (FCC) for mobile telephone systems is on 824-849MHz for uplink transmission, and is on 869-894MHz for downlink transmission. In Frequency Division Multiple Access/Time Division Multiple Access (FDMA/TDMA) systems, these bands are divided into a number of narrow band channels to form duplex pairs with sufficient bandwidth.

A novel concept behind cellular communication systems is the frequency reuse principle. Under this principle, various channel assignment (CA) algorithms are formulated for spectral management. A good CA algorithm is required to maximize throughput performance while link quality is guaranteed to satisfy some minimum requirements. As the cell sizes of PCS are shrinking down to the order of few hundred meters, CA algorithms for PCS may have good chance to encounter rather drastic changes in traffic patterns, both *temporally* and *spatially*. Clearly, conventional fixed channel assignment (FCA) schemes, whose performance is at best when traffic pattern is statistically static, will not function well under such circumstances. Indeed, Dynamic Channel Assignment (DCA) schemes, whose assignment schemes follow changes of traffic patterns, have been demonstrated to outperform FCA schemes in throughput performance in the scenario of spatially non-uniform traffic patterns. Like FCA schemes, CA decision making in DCA schemes is centralized. This can be a major factor to hinder DCA schemes be useful for PCS as the complexity of DCA schemes can become prohibitively high when sizes of PCS are large. More recently, distributed DCA (DDCA) schemes, where CA decision making is distributed at every cell site, have been proposed. Clearly, the complexity of DDCA algorithms is invariant to PCS sizes. Since every base station is capable in making CA decision, DDCA algorithms can adapt with dynamic traffic, and can resolve cellular traffic congestion in a timely manner.

In [11], Chih-Lin I. and P. Chao of AT&T Bell Lab formulated a DDCA scheme referred to as the *Local Pack Dynamic Channel Assignment Scheme* (LPDCA). With this scheme, each base station maintains an Augmented Channel Occupancy (ACO) table containing channel occupancy information in the host cell and all the neighboring cells that can notably interfere with the host cell. The LPDCA is shown to have good adaptability to spatial and temporal variations of traffic pattern. The *Aggressive Fuzzy Distributed Dynamic Channel Assignment* (AFDDCA) formulated by the authors [13], [14] is a modification of the LPDCA scheme. In particular, data registered on the ACO table is transformed to a soft feasibility index in (0,1). Channel with unity feasibility index is absolutely assignable. Likewise, channel with zero feasibility index is absolutely not- assignable. Channels with intermediate feasibility indices are assignable when the algorithm operates in *aggressive* mode: when traffic within the cell is very high, or when perfectly assignable channel does not exist. The throughput performance of AFDDCA is shown to surpass many highly complex DCA schemes, including the most exhaustive DCA schemes. Signal-to-Interference ratio (SIR) degradation in AFDDCA, due to the relaxation of *worst case* constraints is surprisingly mild.

In this paper we will present two variants of the AFDDCA algorithms. Namely, the *Aggressive Fuzzy Simple DDCA* (AFS-DDCA) and the *Aggressive Fuzzy Maxavail DDCA* (AFMA-DDCA). The terms *Simple* and *Maxavail* is used to indicated the assignment strategy employed. These two assignment strategies are borrowed from the *Simple* and *Maxavail* algorithms formulated by K. Sivarajan, R. McEliece, and J. Ketchum of Caltech [10]. The two schemes are chosen due to their low complexity. The *Simple* scheme always allocates the first found feasible channel in the search. The AFS-DDCA searches for the absolutely feasible channels first. If such channels exist, the first found channel will be assigned. Otherwise, intermediate feasible channels will be activated and the search/allocation procedure is repeated. On the other hand, the *Maxavail* scheme operates on the *maximizing channel availability* principle. With this principle, the scheme first searches over all absolutely feasible channels and compute the change of availability of feasibile channels if each of such channel is assigned. The channel resulting with the least change will be assigned. The AFMA-DDCA first of all activates all channels whose feasibility indices surpass a certain threshold, the *Maxavail* search scheme is then used to compute the loss in the total number of feasible channels if each of the absolute or intermediate feasible channel is assigned. The channel resulting with the least change is allocated. Procedure is repeated with lower values of threshold until a feasible channel is found or the threshold becomes lower than the allowable minimum. Clearly, the AFS-DDCA is identical in complexity to

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the *Simple* scheme, and so is the AFMA-DDCA to the *Maxavail* scheme. We will show that the throughput performance of the fuzzy algorithms surpass that of their crisp counterparts, while S/I degradation is mild.

We will first elaborate the formulation of the feasibility of a channel over fuzzified constraints. The formulation as well as the performance of the two fuzzy algorithms in contrasted with their crisp counterparts will be given in order.

## II. ALGORITHMS

The notation used in this section are,
$i$: the cell where the call arrives
$k$: the cell from which the interference originates
$E_i$: the set of cells such that $c_{ik} > 0$
$\{f_j, j = 1, ..., M\}$: the set of channels available to the network

As presented in [13], [14], we replace the crisp compatibility constraints in the compatibility matrix with *feasibility* functions. Values of feasibility are functions of frequency separation between any two channels in concern and vary from '0' to '1'. The form of function we have chosen is depicted in Fig. 1. $c_{ik}$ is the worst case channel separation for the pair of cells $(i, k)$ in concern. $f_j$ is the channel to be considered for assignment and $f_l$ is the channel being used in any of the cells included in the ACO table. We design the feasibility function, $u_{i,k}(f_j, f_l)$, such that when compatibility constraint is relaxed by one channel distance from its worst case value, the feasibiliy index reduces from '1' to '0.5'. Further reduction by one channel brings it to '0'. The compatibility matrix in this case is an $NXN$ matrix where the entry at $i$th row and $k$th column is a feasibility function with parameter $c_{ik}$.

We define the *overall feasibility* of a channel to be the product of feasibilities considering each channel being used in the host cell as well as interfering neighbors.

$$u_i(f_j) = \prod_{k \in E_i} \prod_{j - c_{ik} < l < j + c_{ik}} u_{i,k}(f_j, f_l) \qquad (1)$$

We limit the constraint relaxation to one channel distance at most by not choosing any channel with feasibility index '0'. However an assignment can result in more than one pair of channels with constraint relaxation. An overall feasibility index of '0.5' means there is only one such pair and a value of '0.25' means two such pairs and so on. The extent to which we are to allow relaxation, depends on how this effects the quality in terms of cumulative distribution of SIR for offered links. The performance of an algorithm based on this criteria depends on how good is it in improving throughput while keeping the quality degradation within the tolerable limit. We explain below two versions of AFDDCA algorithms named AFS-DDCA and AFM-DDCA algorithms.

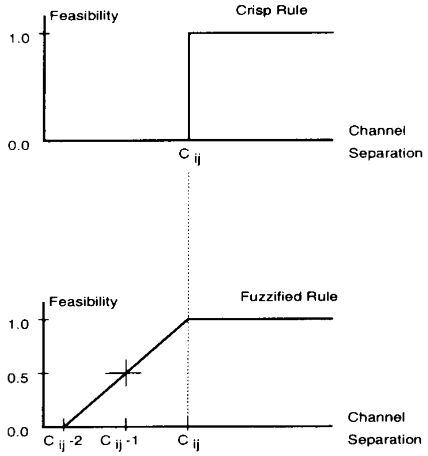

Fig. 1. Feasibility index as a function of channel separation

The two AFDDCA algorithms are briefly explained below with their crisp rule based counterparts. Pseudo codes are given in Appendix A.

- **Simple:**
  On the arrival of a call request, search for a *feasible* channel from the set of channels, starting from first channel $f_1$, in the ascending order. Assign the first feasible channel found. Return "call blocked" signal if no feasible channel found. A feasible channel is one for which there are no occupied channels at any site in the ACO table (including the host site) which violate the constraits.

- **Maxavail:**
  On the arrival of a call request, search for *feasible* channels from the set of channels. For each feasible channel, compute the reduction in number of feasible channels available to the system that would result due to the assignment of the particular channel in concern. Select the channel which minimizes such reduction. In other words the channel which could 'maximize the number of channels available to the system for successive assignments' is chosen. Definition of a feasible channel is same as that for "simple" algorithm.

- **AFS-DDCA:**
  A predefined value of overall feasibility is used as the threshold. As explained in the previous section, this threshold decides to what extent the algorithm will relax the worst case compatibility constraints. On the arrival of a call request, all the channels are checked for their feasibility indices. The channel with largest value is chosen. When there is a tally, the channel with smallest channel number is chosen. The feasibility index of the chosen channel is compared against the threshold. If the value is larger than threshold, the call request is honoured, else blocked.

- **AFMA-DDCA:**
  The Distributed database at each cell in this case contains information regard to the occupied channels and feasibility indices for each channel in each site. Each channel is checked for its feasibility index. Channels with feasibility indices larger than the predefined threshold are in turn checked for their effect in reducing the number of feasible channels available for successive assignments. The channel which minimizes such reduction (maximizes the availability) is assigned. If no feasible channels are found with the previous 'threshold', then it is reduced to a lower value. Above procedure is repeated until a feasible channel is found or the threshold becomes lower than the minimum allowable value. If non of the channels have feasibility index larger than threshold, the call is blocked.

A generic flow chart of AFDDCA algorithm is given in Fig. 2.

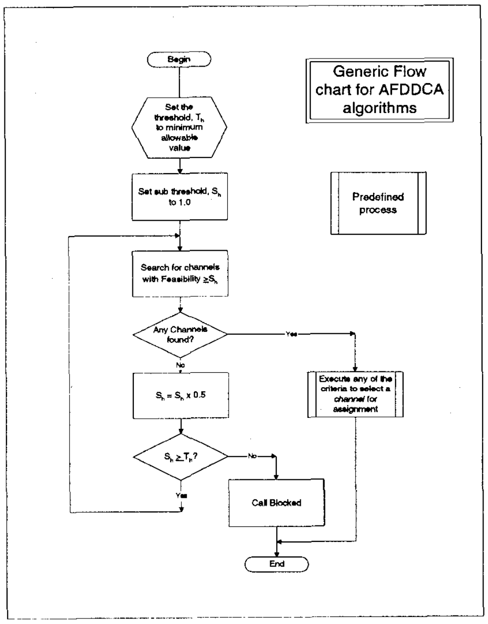

Fig. 2. Flow chart for AFDDCA algorithms

## III. SIMULATION

The example network, traffic model and the propagation models used in the simulation are as described below.

### A. Network Model:

- **Topology:**Two dimentional regular hexagonal grid with 144 cells (12X12) as shown in Fig. 2.
- **User locations:**192 uniformly distributed user locations in each cell. There can be more than one users at a particular location. An access attempt in a paricular cell orginates from any of these user positions with equal probability.
- **Worst case compatibility constraints:**Cosite - '5',first ring of buffer cells - '2',second ring of buffer cells - '1', and '0' otherwise.

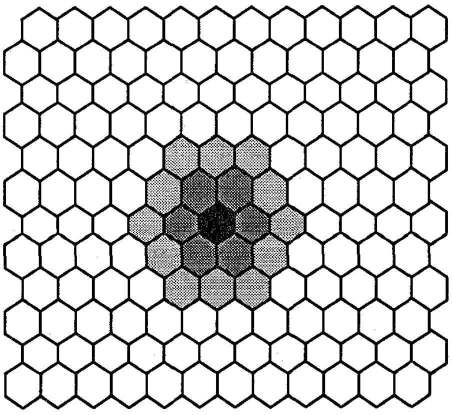

Fig. 3. Simulated Network

TABLE I
NOTATINOS AND FORMULAE FOR THE TRAFFIC SIMULATIN

| PARAMETER/FORMULA | DESCRIPTION |
|---|---|
| $\lambda_i, i = 1, \ldots, N$ | mean access attempt rate at port $i$ |
| $\lambda_T = \sum_{i=1}^{N} \lambda_i$ | mean access attempt rate for the whole network |
| $\mu^{-1}$ | mean call holding time |
| $\rho_i = \lambda_i/\mu; i = 1, \ldots, N$ | offered traffic in erlangs for cell $i$ |
| $\rho_T = \lambda_T/\mu$ | offered traffic in erlangs for whole network |
| $m_i$, $m$ | number of active users for cell $i$ and network |
| $m_i/m$ | the probability for a given departure to be in cell $i$ |
| $(\lambda_T + m\mu)^{-1}$ | mean inter-event time for the network |
| $P_a = \frac{\lambda_T}{\lambda_T + m\mu}$ | probability that the event is an access attempt |
| $P_a = \frac{\rho_T}{\rho_T + m}$ | probability that the event is a departure |

Base stations placed at the center of each cell maintain ACO tables consisting of channel occupancy information for interfering neighbors. As demonstrated in Fig. 2, the ACO table for the cell painted black, for instance, contains the channel occupancy information for the 19 shaded cells.

The number of channels available to the system was taken to be 70.

### B. *Traffic Model*

Each port is considered to be a finite server blocked-calls-cleared (BCC) service. The size of the server varies with time. Large User pools are assumed so that the arrival is a Poisson process. Exponentially distributed service time is assumed. Two different traffic situations were considered.

- **Uniform static traffic:**
  Every cell has equal traffic *i.e.*, $\rho_i = \rho \ \forall i$.
- **Dynamic traffic** The traffic in every cell undergoes a random walk between a lower and upper limit independently with a predefined increment/decrement. Traffic distribution is static over a time period before changing to another state. A typical traffic pattern in a cell during simulation is shown in Fig. 3.

Table I summarises the involved parameters and formulas.

### C. *Propagation Model*

We consider a model applicable for ports placed outdoors in residential areas [2]. The average received power is considered to decrease with distance $d$ as $d^{-4}$. Assessment of performance was carried out using *down link* SIR. This quantity for a user

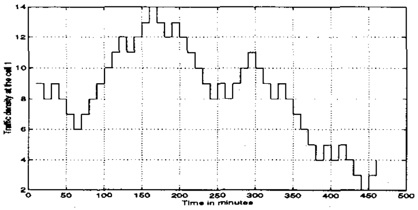

Fig. 4. Typical traffic pattern generated and used in simulation

getting access to a port (base station) $u$, in decibels, is given by,

$$\text{SIR} = 10log_{10} \frac{d_u^{-4}}{\sum_{p=0}^{c_{uv}-1} [\alpha_p \sum_{v \in E_p, v \neq u} d_v^{-4}]} \tag{2}$$

where,

$E_p$:the set of ports using channels with channel separation $p$ relative to the channel used by $u$
$d_k$:the distance between the user in concern and port $k$ (host, $u$ or the interferer, $v$)
$c_{uv}$:the worst case channel separation for the port pair $u, v$
$\alpha_p$:the weighting factor for interference caused by channel with separation $p$. This is an attenuation factor ($< 1.0$) which represents the attenuation by the receiver filter for interference received on the frequencies at a channel distace $p$. $\alpha_p$=0.1, 0.01, 0.001, and 0.0001, for p=1,2,3, and 4 respectively. For $p > 4$, the factor was set to be 0.0.

## IV. RESULTS

The performance of different algorihms are compared in terms of Blocking Probability, Signal Quality and Grade of Service. Grade of Servic Parameter (GOS) is defined in terms of blocking probability, $P_B$, and outage probability, *i.e* probability of *bad links* as,

$$\text{GOS} = P_B + (1 - P_B)Pr\{\text{SIR} < Target\} \tag{3}$$

Target SIR was taken to be 18 dB. Simulation results are given in Fig. 4-11 and Table II. Performance of the network with uniform static traffic is given in Fig. 4-9. Fig. 10,11 and Table II give the performance of the system under dynamic traffic. Simulations for AFDDCA algorithms were carried out for 'threshold' settings of '0.5' and '0.25' corresponding to maximum number of relaxation of '1' and '2' constraints respectively. The results are shown with that of conventional "Simple" and "Maxavail" algorithms. Note that the AFDDCA algorithms with 'threshold' setting '1.0' correspond to these algorithms.

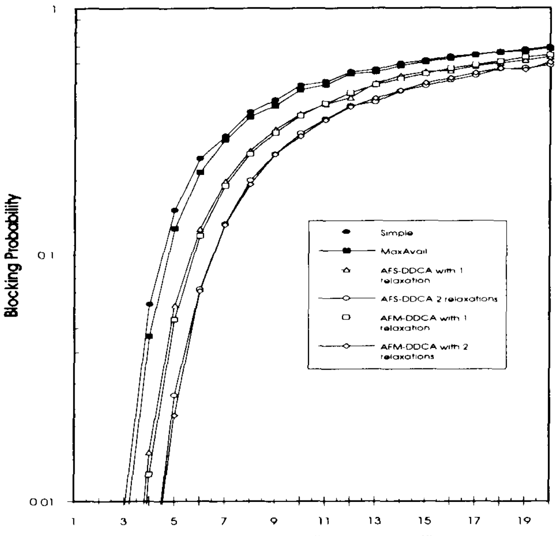

Fig. 5. Throughput with uniform static traffic

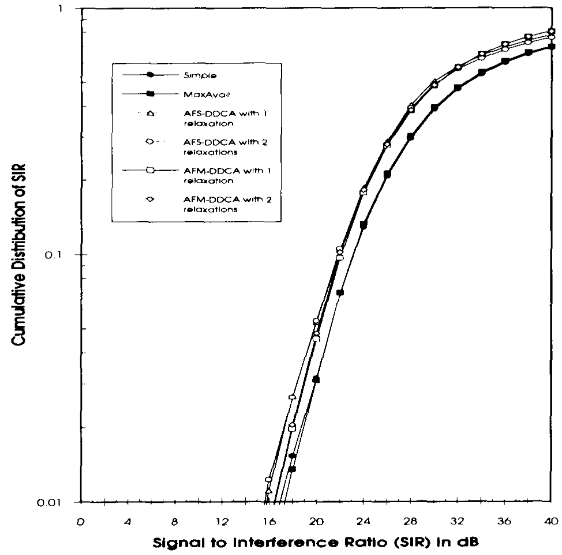

Fig. 6. Quality with uniform static traffic

With uniform static traffic distribution, AFDDCA algorithms result in improved throughput performance with the increase in the amount of relaxation (Fig. 4,5). For this traffic situation AFM-DDCA algorithm results in better throughput than AFS-DDCA algorithm in both the cases. Quality curves are shown in Fig. 6,7 for a traffic density value of 4.0 erlangs per cell. This is more or less the traffic density at which blocking rate is within the acceptable value of 1%. At this traffic density value, and with one constraint relaxation, the degradation is within the acceptable limit for both AFDDCA algorithms. With two such relaxations AFS-DDCA algorithm show only slight degradation in quality though AFM-DDCA algorithm is not so. However, it is found from GOS curves in Fig. 8,9 that the overall perfor-

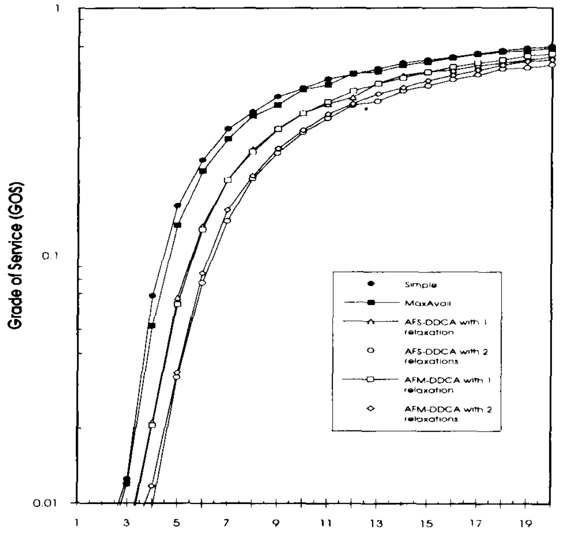

Fig. 7. Grade of Service with uniform static traffic

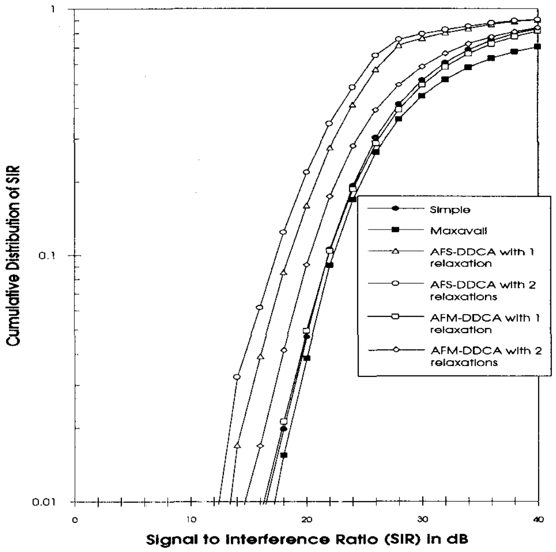

Fig. 8. Quality with one relaxation for dynamic traffic

TABLE II

Blocking Prabability and GOS with dynamic traffic.

| Algorithm | Blocking Pr. | GOS |
|---|---|---|
| AFM-DDCA, 2 relaxations | 0.312 | 0.340 |
| AFS-DDCA, 2 relaxations | 0.336 | 0.359 |
| AFM-DDCA, 1 relaxation | 0.376 | 0.387 |
| AFS-DDCA, 1 relaxation | 0.400 | 0.421 |
| Maxavail | 0.482 | 0.485 |
| Simple | 0.497 | 0.501 |

mance of both algorithms are better with two relaxations than with one relaxation at higher traffic density values.

With dynamic traffic, the throughput performance behave in a similar manner to situation with uniform static traffic. But the behaviour of the two algorithms in case of link quality is opposite to that in the above case. However the GOS still behave in a manner similar to the previous case.

## V. CONCLUSIONS

AFDDCA algorithms is a novel strategy towards efficient utilization of rare spectrum. It addresses the possibility to squeeze out the capacity wasted in the design of conventional compatibility parameters. Further, under circumstances when the 'call admission' with slight degradation in quality is acceptable, this class of algorithms is an attractive mean and has the capability to improve the overall service quality tremendously. Note that the computational complexities of the AFDDCA algorithms presented are more or less similar to their crisp rule based counter part but result in considerable performance gain.

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