Aggressive Fuzzy Distributed Dynamic Channel Assignment Algorithm

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ABSTRACT: Constraint based channel assignment schemes often rely on crisp evaluations of radio-interference-constraints to determine if an open channel is feasible for assignment. Such approach has been popularly adopted to formulate fixed channel assignment (FCA) schemes, dynamic channel assignment (DCA) schemes, and more recently on distributed DCA (DDCA) schemes. DDCA schemes are localized DCA schemes where every cell site is responsible for channel assignments to calls generated within that cell. This paper is to introduce the Aggressive Fuzzy DDCA (AFDDCA) scheme in which feasibility evaluation of constraints is *soft*. The scheme is in the *polite* mode when perfectly feasible channel exists, and in *aggressive* mode otherwise. The aggressive policy is progressive. We will demonstrate that, when traffic is heavy, AFDDCA scheme can outperform globally optimal DCA in terms of spectral efficiency while voice quality degradation is surprisingly mild.

I. INTRODUCTION

In this paper, we will introduce a class of aggressive distributed dynamic channel assignment algorithms in general, and to consider the consequence of violating radio-interference constraints on throughput capacities as well as signal-to-interference (S/I) ratio in particular. Formulation of a channel assignment (CA) scheme in FDMA/TDMA based cellular mobile communication systems aims at maximizing throughput capacity subjected to contentment in S/I performance. Constraint based CA schemes are classes of optimization algorithms where S/I ratio are stated in a set of crisp channel separation constraints, which specify minimum channel separations between assigned channels within the same cell (*cosite constraints*) or between a pair of cells (*cochannel constraints* and *adjacent channel constraints*). The set of constraints defines the feasible solution space for channel assignments. The strategy is to search for the optimal channel assignment over the feasible solution space. Such approach has been popularly adopted in the formulation of fixed CA (FCA) schemes, dynamic CA (DCA) schemes, and more recently on distributed DCA (DDCA) schemes.

FCA schemes are constrained CA schemes based on the assumption that traffic density distribution of every cell within the network are fixed and known. Such an assumption, however, is not valid on microcellular networks in which traffic distributions can vary dynamically. In contrast to FCA schemes, DCA schemes are executed on a call-by-call basis. Upon receiving of a call, the central processor responsible for channel assignment will gather the running traffic rate as well as channel occupancy information from all cell sites for the computation of the optimal channel assignment. DCA schemes have been shown to outperform FCA schemes in throughput capacities under the condition of *non-uniform heavy* traffic [1-4]. Since DCA schemes are executed on the setting of centralized computation, the bulk of information exchange between the central controller with every cell site as well as the computational complexities can become inhibitively high as the network size grows. This necessitates the employment of DDCA schemes. In this scheme, every base station is a controller executing a DCA scheme for making channel assignment decisions to calls generated within that cell. Information exchanges is limited only to neighboring cells which can "significantly" interfere with the cell. The distributed nature enables DDCA schemes to self-adapt with spatial and temporal variations of traffic distributions. This feature makes possible DDCA schemes to be much more capable than DCA schemes to resolve congestion or *hot-cell* situations.

Given the feasible solution space defined by the set of constraints, globally optimal assignment strategy requires

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exhaustive search which is a *np* complete combinatorial searching problem. Researchers have spent much efforts on the establishment of suboptimal searching strategies in order to keep the complexity low. These efforts have brought forth many suboptimal DCA schemes with searching complexities ranging from low to very high. Sivarajan *et.al* of Caltech have formulated a number of DCA schemes of searching complexity ranges from very low to very high [3]. In general, throughput performance is oftenly proportional to the exhausiveness, and hence the complexity, of the searching scheme.

Clearly, regardless of how thorough a searching strategy is implemented, the throughput performance is limited by the feasible solution space, which is defined by the set of channel separation constraints. Since radio interference can vary greatly from cell to cell, a normal practice is to set the constraints based on the worst case assumptions of mobile location and propagation conditions [4]. The conservative assumptions can result in large capacity penalties. Based on this observation, investigations are initiated to study the effects of violating a subset of constraints on throughput as well as S/I performances. Violation of constraints can be taken as an aggressive strategy. The investigations have resulted in a new class of DDCA algorithms which we shall refer to as the Fuzzy Distributed Dynamic Channel Assignment (FDDCA) algorithms [7]. The algorithm is adopted from I & Chao's LP-DDCA scheme [5]. In particular, the FDDCA scheme makes use of fuzzy logic to compute the *feasibility* of every free channel. The feasibility of a channel is a fuzzy truth value in [0,1] based on a collective evaluation of the compliance/violation level to each constraint if the channel is to be assigned. Here, a feasibility of unity implies absolutely assignable, and zero implies absolutely unassignable. The FDDCA algorithm operates on a progressive-aggressive mode. In particular, cells whose traffic rates exceed a certain threshold are permit to become aggressive. In this mode, channels of lower feasibility are automatically activated for assignment when channels of higher feasibility run out. Simple assignment scheme, in which channels of identical feasibility are randomly picked for assignment, is used.

The FDDCA strategy takes into account of the following items:

- Channel separation constraints are *soft* constraints. Clearly, if the separation between two channels are too close, interference among themselves is heavy. As channel separation gets farther, or the physical separation between the two cells are farther apart, interference will be decreased proportionally. Determination of constraint compliance/violation with crisp thresholding is certainly not appropriate. Thus, compliance/ violation of the two constraints should be more adequately represented by fuzzy truth values.
- In certain circumstances, users may prefer throughput over slight degradation in voice quality. Thus, when there is a high traffic rate in a particular site, it may be possible to *soft-violate* certain constraints given that certain grade of voice quality.

Extensive simulations are used to evaluate both the throughput and S/I performance of FDDCA algorithm. Reference [7] has documented the effects of violating at most one constraint by at most one channel distance. Such violations are permitted in cells that are hot. The aggressive strategy results in a considerable gain in throughput capacities with surprisingly mild S/I degradation.

In this paper, we modify the FDDCA algorithm such that every cell automatically enters the aggressive mode when no channel is fully feasible. Also, even a more aggressive mode is used: violation of up to three constraints, each of at most one channel separation, is permitted. The modified algorithm is referred to as the Aggressive-FDDCA (AFDDCA) algorithm. Simulation results demonstrate that throughput performance is improved even further while additional S/I degradation is marginal.

In the following, we will briefly review the FDDCA scheme. The performance of the AFDDCA scheme with will be documented in order.

2. FDDCA ALGORITHM

2.1 Distributed database

At each base station, an augmented channel occupancy (ACO) table is maintained. The format of an ACO table is shown in Table I. The entries of the table are the current channel occupancy status of every interfering neighbor cells as well as the host cell, i_0. Each row holds the channel occupancy information of an interfering cell. The M columns represent the M channels. An **'X'** mark in the ijth entry implies the jth channel at the ith cell is occupied. There are $n_o < N$ interfering base stations in the ACO, where N is the total number of base stations in the network.

Table I. ACO table at site i_0

	Channel			
Site	1	2	...	*M*
i_0		X		
i_1	X			X
...		X		
i_{no}	X			X

2.2 Fuzzy parameters

Physical parameters are mapped onto membership functions characterizing fuzzy concepts. The membership values, or the truth value, are fed to the *antecedent* section of the fuzzy rules. Inference logic is used to compute the truth value of the *consequent* of the rule after the overall truthness of the antecedent section is evaluated. In this paper, we will use the direct product of membership values as the evaluation method of the overall truthness of the antecedent section, and the MAX-product rule as the inferencing method. Details of fuzzy inferencing are given in [10].

We now proceed to elaborate the fuzzy concepts of *hotness* and *feasibility*. In the simplest form, hotness is defined as the ratio of offered traffic in a given cell to the average offered traffic per cell. When the ratio is larger than unity, the cell is said to be a *hot* cell. Since the importance of DCA strategy arises in the case of non-uniform heavy traffic, hotness parameters are used to depict the distribution of traffic in different cells. We first define the following notations to be used later:

ρ_i : the offered traffic in cell *i*,
λ_i : the call arrival rate in cell *i*, and
$1/\mu$: the mean call duration,

These parameters hold the relationship given by $\rho_i = \lambda_i / \mu$. We then proceed to define the concurrent *feasibility* of the channel f_k in the *i*th site, and the channel f_l in the *j*th site, as a membership function $\Im_{ij}$ of the spectral distance between two channels.

$$u_{ij}(f_k, f_l) = \Im_{ij}(|f_k - f_l|) \tag{2.1}$$

for $i,j = 1,2,\ldots,N$, where N is the total number of cells in the network, and $k,l = 1,2,\ldots,M$, where M is the number of channels. With (2.1), we define the fuzzy compatibility matrix consisting of a set of fuzzy membership functions:

$$\begin{bmatrix} \Im_{11} & \Im_{12} & \ldots & \Im_{1N} \\ \Im_{21} & \Im_{22} & \ldots & \Im_{2N} \\ \vdots & \vdots & & \vdots \\ \Im_{N1} & \Im_{N2} & \ldots & \Im_{NN} \end{bmatrix} \tag{2.2}$$

Feasibility measure for the case of fuzzy logic can be viewed as a softening of that of crisp logic. The feasibility curve for fuzzy logic can take on any shape as long as the shape is meaningful to be interpreted. Choosing the right membership function is vital in obtaining good performance. A typical curve is shown in Figure 2. With these definitions, we now proceed to elaborate the FDDCA algorithm.

2.3 FDDCA algorithm

On the arrival of a call request in the site i_o :

for each channel, f_k: $k = 1,2,\ldots,M$,

for each channel, f_l : $l = 1,2,\ldots,M$,

if f_l *is being used in any of the site,* i_n *, in the ACO table, including* i_o*, compute* $|f_k - f_l|$.

compute the corresponding feasibility index, $u_{i_o,i_n}(f_k, f_l)$*, with the use of fuzzy separation matrix.*

for each channel, f_k : $k=1,2,\ldots,M$, *compute the overall feasibility index using the product rule*:

$$u_{i_o}(f_k) = \prod_{n=0}^{n_o} \prod_{l=1}^{M} u_{i_o,i_n}(f_k, f_l)$$

where n_o *is the number of interfering base stations in the ACO table*

select the channel f_k *with the highest feasibility index.*

feed the feasibility index and the hotness index to the fuzzy decision maker.

In the first phase of our simulations, we defined a hotness index proportional to ρ_i for each cell. The set of control rules used in decision making is as follows:

***R*1**: if *feasibility* LOW , then BLOCK
***R*2**: if *feasibility* HIGH, then HONOR
***R*3**: if *feasibility* MEDIUM and *hotness* LOW, then BLOCK
***R*4**: if *feasibility* MEDIUM *AND hotness* HIGH, then HONOR

We will describe the selection of membership functions for some particular example in the next section. As a result of setting the hotness of some of the cells as HIGH, those cells were allowed to violate constraints (*aggressive* assignment) when they run out of channels in compliance with worst case constraints It was found that the best performance was achieved when all the cells were allowed to be aggressive. Hence in the second phase of our simulations, we extended our studies to how the performance increases with *increased number of violations* with *all the cells* carrying out *aggressive* assignment. In AFDDCA, up to three constraints are allowed to be violated, each is violated by at most one channel separation.

3. SIMULATIONS AND RESULTS

3.1 Simulation Environment

The simulation assumed exponentially distributed inter-arrival time (Poisson arrival) and call holding time. A call request arrives to the cell i with a probability p_i. Hence the offered traffic in the ith cell is equal to $\rho_i = p_i \rho$, where ρ is the total traffic in the entire system. Blocked calls are assumed to be cleared. In order to assess the cumulative distribution of signal to interference ratio (S/I), within each cell 192 uniformly distributed user positions are considered. The distribution of call generation within a cell was assumed to be uniform. The received signal (interference) power was taken to be proportional to $1/d^4$, where d is the distance between the base station and the mobile unit. Non-cochannel interference was weighted by a factor <1.0. Computation of S/I was carried out considering all users in the system at steady state.

The system simulation program generates an exponentially distributed random number with a pre-determined *mean* to decide upon the next call arrival time. Generation of random number for the call holding time is similar. An infinite population is assumed and thereby the arrival rate remains constant. When there is a call arrival, it is *assigned* to a particular site with the probability as mentioned above paragraph. Next the channel assignment routine is called. At each increment of the clock, on going calls are checked for any departure. If there is any departure, tied frequencies are released. (More details can be found in [3]. A different approach to system simulation is adopted in some other literature [6]).

3.2 The simulation and results

The example is adopted from [3], where N=21 and M=96 with non-uniform Spatial Distribution of traffic. The cell arrangement for the example is as in Figure 1. The worst case channel separations (same as the crisp separations under conventional method) are, five for cosite, two for first tier cells, and one for second and third tier cells. For instance, $c_{77} = 5$, $c_{71} = c_{78} = 2$, $c_{72} = c_{79} = c_{73} = 1$. In FDDCA strategy, these values are softened, as depicted in Figure 2. In first phase of the simulation the hotness was considered to be HIGH if it is greater than a threshold, T, as a result of which base stations at certain cells carry out aggressive policy if they run out of channels under polite policy. Figures 3 and 4 show the performance of the FDDCA algorithm with such settings. The blocking performance of FDDCA's with four different constraints are computed and contrasted with the results corresponding to the DCA algorithms, namely FCA, SIMPLE, MAXAVAIL, and CALBOUND, presented in [3]. The simulation conditions are same as that in [3]. The mean inter-arrival time was set at 180/ρ seconds, and mean call duration is 180 seconds. Careful examination reveals that when a cell exhausts the channels with crisp logic, the FDDCA allows those hot sites to softly violate only one of the three electromagnetic (EM) constraints by at most one channel separation. (see [7] by the same authors for details). Clearly, this soft violation scheme is activated only when the traffic is heavy.

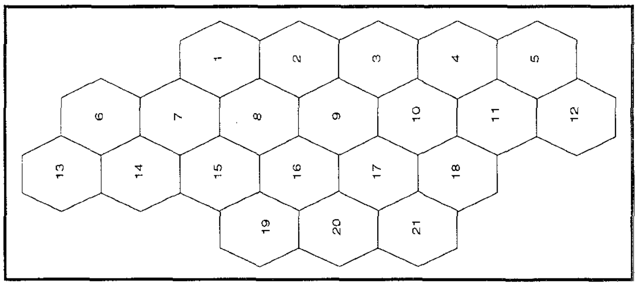

Figure 1. The cell system in the example.

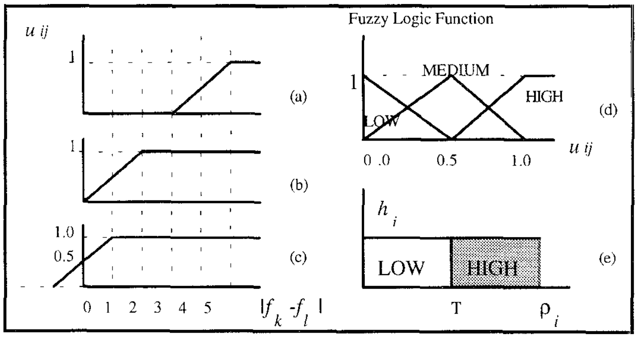

Fig. 2. Fuzzy channel separation functions, and logic functions for the example. (a), (b), and (c) give the usability index functions for C_{ij}=5, C_{ij}=2, *and* C_{ij}=1 respectively.(d) curves for logic levels LOW, MEDIUM, and HIGH as functions of u_{ij}.(e)hotness index.

In the second phase of our simulations softer rules were applied to permit base stations to assign channels more aggressively. To our amazement the resulting quality degradation are very small compared to the gain in throughput performance. In Figure 3, the blocking performance of AFDDCA with violation of one constraints, and with violation of two/three constraints, are compared with that of MAXAVAIL and CALBOUND strategies presented in [3]. Figure 4 shows the variations of the cumulative distribution function of the S/I with different levels of aggressiveness. It can be seen that quality degradation in terms of S/I ratio is relatively small compared to the gain in throughput performance in terms of blocking probability. We have simulated many cases to achieve parameter variations. Consistent results were found: soft violations of constraints result in degradation mostly when the S/I ratio is good to very good. The S/I degradation is insignificant at the lower end of the S/I distribution curve.

4. CONCLUSION

In this paper, we have presented a fuzzy logic based aggressive distributive DCA scheme referred to as the aggressive fuzzy distributed DCA (AFDDCA) algorithm. Fuzzy logic is employed to infer usability of every free channel for assignments. Aggressiveness is incorporated into the algorithm. We have demonstrated that aggressiveness can alternatively be implemented with a control violation of channel separation constraints. Simulation results show that gentle violation of constraints can yield considerable gain in throughput capacities while degradation in S/I performance is slight. The FDDCA scheme has demonstrated to achieve good throughput performance in scenarios of non-uniform heavy traffic. The result may also imply that channel separation constraints in most CA schemes are too conservative.

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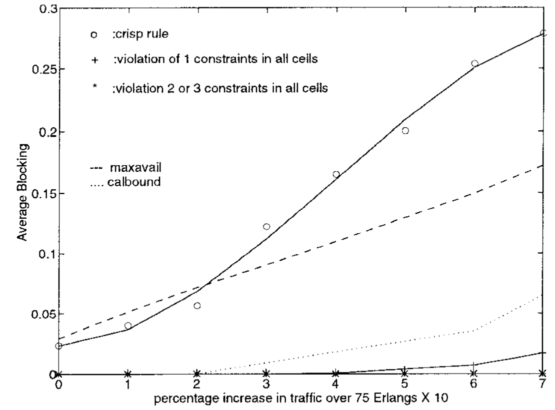

Figure 3 Average Blocking vs. percentage increase in traffic for MAXAVAIL, CALBOUND, and AFDDCA algorithms.

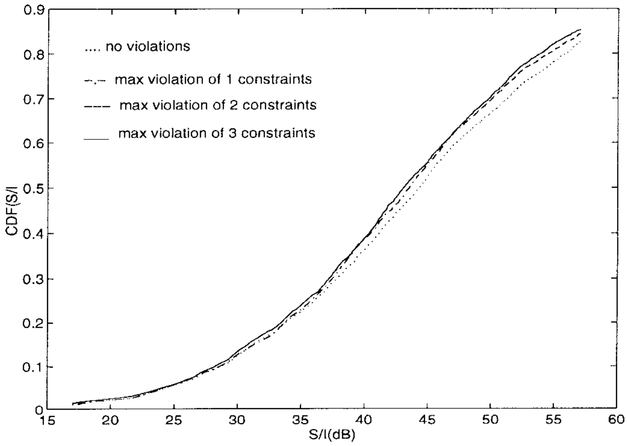

Figure 4 Cumulative Distribution of S/I at steady state when total traffic $\rho = 120.0$ Erlangs. Interference factors are 1.0, 0.1, 0.01, 0.001, 0.0001, and 0 for channels with separations 0, 1, 2, 3, 4, and 5 respectively.