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Using Cultural Algorithm for the Fixed-Spectrum Frequency Assignment Problem

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Abstract: In this study the problem of the fixed-spectrum frequency assignment problem, where the objective is to minimize the cost due to the interference arising in a solution, is studied and solved using a cultural algorithm which is refined by a deterministic local search heuristic. Computational results, obtained for 8 well-known benchmarks problem, confirm the effectiveness of cultural algorithm.

Key words: Cultural algorithms, evolutionary programming, frequency assignment problem, interference minimisation

INTRODUCTION

The importance of the Frequency Assignment Problem (FAP) for efficient use of the radio spectrum and minimization of interference is now well recognized. The majority of the early work on this problem concentrated on the minimum span problem (Hale, 1981; Hurley *et al*., 1997). In this variation of the FAP, constraints are specified, which, if satisfied, should lead to acceptable interference. It is then necessary to minimize the spectrum used, measured as the difference between the greatest and smallest assigned frequencies. It is now increasingly recognized that the Fixed Spectrum Frequency Assignment Problem (FS-FAP) is of greater importance to network operators. In this variation of the FAP, the available spectrum to the operator is known in advance and is necessary to minimize some measure of interference. The constraints considered here are binary constraints, specifying the necessary frequency separation between given pairs of transmitters. There may be penalties (or weights) associated with the violation of each constraint. The objective can be to minimise the number of constraints violated or, as is increasingly done by operators, to minimise the sum of the weights associated with violated constraints.

The FAP is a generalization of the well known graph colouring problem (Hale, 1980), which is the problem of finding a coloring of a graph so that the number of used colors is minimized, subject to the constraints that each 2 adjacent vertices have 2 different colors: As such FAP is a NP-hard problem (Kunz, 1991; Mathar and Mattfeldt, 1993). Such problems require the use of extremely time-consuming algorithms to obtain exact solutions. It is, therefore, necessary to use more time-efficient algorithms that, however, cannot guarantee optimal solutions.

Different lower bounds on the optimal solution value for the frequency assignment problem have been proposed (Tcha *et al*., 1997; Montemanni *et al*., 2004). These techniques are useful both in assessing the quality of approximate solutions and in limiting the search for optimal assignments and are usually derived from graph-theoretic approaches, which adapt techniques originally developed for the coloring problem.

Exact algorithms have been proposed in Aardal *et al*. (1995) and Maniezzo and Montemanni (1999). Due to the NP-hardness of the problem, any exact optimization algorithm requires in the worst case an amount of time exponentially growing with the size of the instance. In order to obtain good solutions in a reasonable amount of time and due to the relevant actual importance of the FAP, much effort has been spent in studying heuristic algorithms. Different approaches have been used, including tabu search (Montemanni *et al*., 2003), simulated annealing (Duque-Anton *et al*., 1993), genetic algorithms (Crompton *et al*., 1994), neural networks (Kunz, 1991), dynamic programming (Shirazi and Amindavar, 2005) and ant colony optimisation (Alami and El Imrani, 2006a). This research reports about the results obtained applying to FS-FAP cultural algorithm which includes a local search. Cultural algorithm framework has proved successful in dealing with real problems optimization (Digalakis and Margaritis, 2002).

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THE FIXED-SPECTRUM FREQUENCY ASSIGNMENT PROBLEM (FS-FAP)

In this study, the most common variation of FS-FAP, referred to the minimum interference frequency assignment problem, is considered. A system of n cells is represented by n vectors $X = \{x_1, x_2, \ldots, x_n\}$. We assume that the channels are equally spaced in the frequency domain and are ordered from the low-frequency band to the high-frequency band with numbers 1, 2,…, m. We use an n×n nonnegative symmetric matrix C, called a compatibility matrix, to represent the Electromagnetic Compatibility Constraints (EMC). The EMC is composed of 3 constraints: The Co-Site Constraint (CSC): Each pair of frequencies assigned to a cell should have a minimal distance between frequencies; the Adjacent Channel Constraint (ACC): The adjacent frequencies in the frequency domain can not be assigned to adjacent cells simultaneously and the Co-Channel Constraint (CCC): For a certain pair of cells, the same frequency can not be used simultaneously.

Each diagonal element cii in C represents the CSC and the rest of the elements, cij (where i # j), represent the ACC or CCC. A demand vector R $\{r_1, r_2, \ldots, r_n\}$ describes the channel requirements for each cell. Each element ri in R represents the minimal number of channels to be assigned to cell xi.

The FS-FAP is specified by the triple (X, R, C), where X is a cell system, R is a requirement vector and C is a compatibility matrix. Let N = {1, 2,..., m} be a set of available channels and let Hi be the subset of N assigned to xi. The objective of FS-FAP is to find an assignment $H = \{H_1, H_2, \ldots, H_n\}$, which satisfies the following conditions:

$$|Hi| = ri, \text{ for } 1 \leq i \leq n \tag{1}$$

$$|h - h'| \geq cij, \text{ for all } h \in Hi,\ h' \in Hj, \text{ where } \leq 1 \leq i \leq n \text{ and } 1 \leq j \leq n,\ I \# j \tag{2}$$

$$|h - h'| \geq cii, \text{ for all } h, h' \in. Hi, \text{ where } h \# h' \tag{3}$$

Where |Hi| denotes the number of channels in the set of Hi. We call such an assignment an admissible assignment.

The objective of the FS-FAP is to find an assignment that minimizes the total number of violations in an assignment. Formally we have:

$$\text{Min} \sum_{i=1}^{n}\sum_{a=1}^{m}\sum_{j=1}^{n}\sum_{b=1}^{m} p(i,a)e(i,a,j,b)p(j,b) \tag{4}$$

Where,

$$\varepsilon(i,a,j,b) = \begin{cases} 0 & \text{if the distance between channel a and b is greater or equal to } c_{ij} (|a-b| \geq c_{ij}), \\ 1 & \text{otherwise.} \end{cases}$$

$$\text{and } p(i,a) = \begin{cases} 1 & \text{if the channel a is assigned to the ith cell,} \\ 0 & \text{otherwise.} \end{cases}$$

ε(i, a, j, b) is set to 1 if the assignment of channel a to cell xi and channel b to cell xj violates the EMC.

HYBRID CULTURAL ALGORITHM

Cultural algorithm: Cultural Algorithms (CA) are techniques that add domain knowledge to evolutionary computation methods. They are based on the assumption that domain knowledge can be extracted during the evolutionary process, by means of the evaluation of each point generated (Reynolds, 1994). This process of extraction and use of the information has been shown to be very effective in decreasing computational cost while approximating global optima, in unconstrained, constrained, dynamic and real problem optimization (Chung and Reynolds, 1998; Becerra and Coello, 2004; Saleem, 2001; Alami and El Imrani, 2006b). Also, a recent study has proposed a new model in order to improve the performance of cultural algorithm in the context of multimodal optimization (Alami and El Imrani, 2007).

Cultural algorithms are made of two main components: The population space and the belief space (Reynolds, 1999). The population space consists of a set of possible solutions to the problem and can be modelled using any population based technique, e.g. evolutionary programming (Fogel, 1995). The belief space is the information repository in which the individuals can store their experiences for the other individuals to learn them indirectly. In cultural algorithms, the information acquired by an individual can be shared with the entire population. Both spaces (i.e., population space and belief space) are linked through a communication protocol, which states the rules about the individuals that can contribute to the belief space with its experiences (the acceptance function) and the way the belief space can influence to the new individuals (the influence function). Those interactions are depicted in Fig. 1.

The main idea behind this approach is to preserve beliefs that are socially accepted and discard unacceptable beliefs. Therefore, if a CA is applied for global optimization, then acceptable beliefs can be seen as constraints that direct the population at the micro-evolutionary level. These constraints can influence directly the search process, leading to an efficient optimization process.

Some versions of cultural algorithms have been built, with different choices for the implementation of the micro

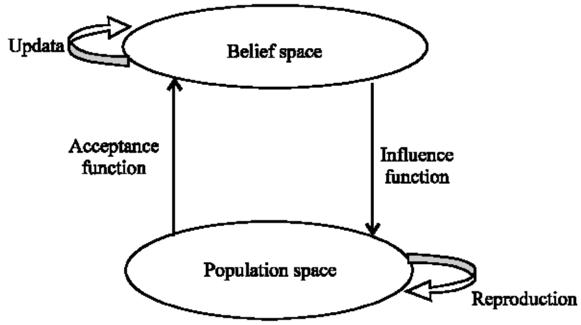

Fig. 1: Spaces of cultural algorithms

and macro levels (Reynolds and Zannoni, 1994; Zannoni and Reynolds, 1997). In this study, the population space is supported by an evolutionary programming system and the belief represents 2 types of knowledge: Situational knowledge which provides the exact point where the best individual of each generation was found and normative knowledge, which stores intervals for the decision variables of the problem that correspond to the regions where good results were found. The shell is called, Cultural Algorithm with Evolutionary Programming (CAEP). The pseudo code for the CAEP is given in the study. The bold characters indicate cultural algorithm components. The plain text gives the basic EP pseudo code:

1. Select an initial population of n candidate solutions, from a uniform distribution within the given domain for each parameter from 1 to p.
2. Assess the performance score of each parent solutions by a given objective function f.
3. Initialize the belief space with the given problem domain and candidate solutions.
4. Generate n new offspring solutions by applying a variation operator, V as modified by the influence function, Influence. Now there are 2n solutions in the population.
5. Assess the performance score of each offspring solutions by the given objective function
6. For each individual, select c competitors at random from the population of size 2n. Conduct pair wise competitions between the individual and the competitors.
7. Select the n solutions that have the greatest number of wins to be parents for the next generation.
8. Update the belief space by accepting individuals using the acceptance function.
9. Go back to step 4 unless the available execution time is exhausted or an acceptable solution has been discovered.

Most of the steps previously described are the same as in evolutionary programming (Fogel, 1995). The function accept (P(t)) accepts those individuals that can contribute with their knowledge to the belief space. The function update (B(t)) creates the new belief space with the beliefs of the accepted individuals. The idea is to add to the current knowledge the new knowledge acquired by the accepted individuals. The function generate (P(t)) used in evolutionary programming is modified so that it includes the influence of the belief space in the generation of offspring. Evolutionary Programming uses only mutation and the function influence (P(t)) indicates the most promising mutation direction. The remaining steps are the same used in evolutionary programming.

Implementation to FS-FAP: The FS-FAP operates only on integer values; then, it is possible to consider it as an Integer Programming (IP) problem. IP problems are more difficult to solve than linear programming problems involving fractional (continuous) values. The difficulty is that while the number of potential solutions is finite, no general method has been devised to narrow the search space to only feasible integer solutions. This effectively means that an IP algorithm must enumerate every possibility before identifying the optimal solution.

The aim of this study is the use of a CA for the FS-FAP and the modification of CAEP shell to support IP.

Population and belief space: The initial population consists of a set of solutions which represent frequency assignments. Each population member is made up of Rtot integer parameters, where Rtot is the total number of frequency request in the cellular system. The belief space also contained the same Rtot parameters as were present in the individuals. Each parameter in the belief space is represented by a bounded interval. Initially, these intervals are set to the theoretical maximum and minimum values. In addition to parameter ranges, the belief space also keeps track of a subset of the individuals, known as the elite set. The elite set represents the two individuals in the population with the best scores and is used to control the direction of change when the mutation operator is applied.

Acceptance function: This function is used to control which members of the population are allowed to impact the belief space. In this study, the following formula is used to elect the K appropriate individuals (Chung and Reynolds, 1998):

$$k = 0.2^{*} n + \text{integer}[(10/(g + 1)] \quad (5)$$

Where n is the population size and g is the current generation number. This effectively reduces the number of individuals influencing the belief space as the number of generation increases.

```
if x_{i,j} < E_i then // Direction of mutation is positive and step size is:
Size of belief interval * N(0,1)
x_{i,j} = Round (x_{i,j} + |size (I_i) * N (0, 1)|)
else if x_{i,j} > E_i // Direction of mutation is negative and step size is:
Size of belief interval * N(0,1)
x_{i,j} = Round (x_{i,j} - |size (I_i) * N (0, 1)|)
else // Direction decided randomly, step size will be a portion of
interval size.
x_{i,j} = Round (x_{i,j} + size (I_i * N (0, 1))
```

Fig. 2: The influence function principle

Influence function: This function is the link between the belief space and the population space. It is used to guide mutation operator. In Fig. 2, xi, j represents parameter i for the jth individual, Ei represents parameter i for the elite (i.e., the best solution in the population space), Round is an integer rounding function created for the FS-FAP problem, size(Ii) is the size of the belief interval for parameter i and N(0, 1) is a realization of a normal distribution with mean zero and standard deviation of 1.

Updating the belief space: The acceptance function involves taking the top K% (those with the best performances) and using them to update the belief space parameter ranges. Ranges are generalised (widened) or specialised (narrowed) based on the minimum and maximum values for each parameter within K% of the population. If a new best individual is found in the previous generation, the elite is updated.

Deterministic local search procedure: At each generation, a deterministic local search procedure is performed to the n individual. The basic idea is that each solution is taken to its local minimum by the application of a deterministic local optimization heuristic (Li, 1995). This heuristic consists in choosing, for each channel call of each cell that violates the electromagnetic constraints, a channel, if exists, that validates the EMC. The new optimized solutions are considered as the final solutions produced in the current generation.

RESULTS AND DISCUSSION

To test the performance of cultural algorithm, eight well-known benchmarks (Cheng *et al.*, 2005), are used in this study. For these benchmarks problem, the number of available channels allows us to obtain channel assignment solutions without interference.

Results obtained are compared with other results from Cheng *et al.* (2005), Funabiki and Takefuji (1992), Kim (1997) and Ngo and Li (1998). The algorithm is implemented in visual C++ language. This program is run on a PC with a Pentium 4 (3.2 GHz) CPU.

Table 1 summarizes the characteristics of these eight problems, together with all the demand vectors, Di (= ri) and the compatibility matrices, Ci. A demand vector specifies the number of channels that each site requires. The total number of frequency request in such problem is the sum of Di's elements.

For example, problem 1 specifies that there are 4 sites, with a total of 11 available channels. In addition, each site's channel demand is listed in D1, with electromagnetic compatibility constraints specified in C1. In this case, the total number of frequency request is the sum of D1's components (= 6 frequencies call) (Table 1 and Fig. 3).

In this study, results obtained for some of the benchmarks problem mentionned below are presented. Note that the parameters of the algorithm used in this study are the population size and the maximum number of generations.

Problem #1: This problem is simple to solve. The CAEP is applied using a population of 10 individuals evolving during 10 generations. Table 2 depicts channels assignment for each cell. From this table, these assignments validate all the electromagnetic compatibility constraints. Note that several solutions are obtained for this problem. These different solutions differ only in the frequency affectation to the three first cells; but for the fourth cell, the affectation shown in Table 2 is the single one that avoids the co-site interference.

Problem #2: Table 3 presents the channel assignment solution for problem #2. For this problem, the number of cells is 25 and the total number of frequency request in the cellular system is 167, while the available spectrum is 73.

The CAEP is performed using a population of 20 individuals which evolve for 10 generations. For this problem, the algorithm has converged at the first iteration (generation).

Table 2 shows the obtained solution includes channels that do not violate the electromagnetic compatibility constraints and use the total available spectrum [1…73]. Note that the channels affectation of each cell are not necessary ordered, e.g., for the 25th cell (8, 17, 4, 10, 1), this is can be explained by the stochastic feature of cultural algorithm.

Problem #3: This problem is more complicated than the previous one in term of the total number of channel request in the cellular system which is equal to 481 demands. In addition, the Co-Site Constraints (CSC), given by the diagonal elements of the compatibility matrix, are set to 5.

C_1 / D_1

				D_1
5	4	0	0	1
4	5	0	1	1
0	0	5	2	1
0	1	2	5	3

C_2 / D_2

																									D_2
2	1	1	0	1	0	1	1	1	1	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	10
1	2	1	0	1	0	1	1	0	1	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	11
1	1	2	1	1	1	1	1	1	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	9
0	0	1	2	0	0	1	1	1	1	1	1	1	0	0	0	0	0	0	0	0	0	1	1	1	5
1	1	1	0	2	0	0	0	0	0	1	1	1	1	1	1	0	0	0	0	0	0	0	0	0	9
0	0	1	0	0	2	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4
1	1	1	1	0	1	2	1	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	5
1	1	1	1	0	1	1	2	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	1	0	7
1	0	1	1	0	1	1	1	2	1	1	1	0	0	0	0	0	0	0	0	0	0	0	1	1	4
1	1	1	1	1	1	1	1	1	2	1	1	1	1	1	1	0	0	0	0	0	1	0	1	0	8
0	0	1	1	1	0	1	1	1	1	2	0	1	1	1	1	0	1	1	1	1	1	1	1	1	8
1	1	1	1	1	0	1	1	1	1	0	2	1	1	0	0	0	0	0	0	0	0	0	0	0	9
1	1	1	1	1	0	1	1	0	1	1	1	2	1	1	1	1	1	1	1	0	0	0	0	0	10
1	1	1	0	1	0	0	0	0	1	1	1	1	2	1	1	1	1	1	1	0	0	0	0	0	7
1	1	0	0	1	0	0	0	0	1	1	0	1	1	2	1	1	1	1	1	1	1	0	0	0	7
0	0	0	0	1	0	0	0	0	1	1	0	1	1	1	2	1	1	1	1	0	0	0	0	0	6
0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	2	1	1	0	0	0	0	0	0	4
0	0	0	0	0	0	0	0	0	0	1	0	1	1	1	1	1	2	1	1	0	0	0	0	0	5
0	0	0	0	0	0	0	0	0	0	1	0	1	1	1	1	1	1	2	1	1	1	1	0	0	5
0	0	0	0	0	0	0	0	0	0	1	0	1	1	1	1	0	1	1	2	1	1	1	0	0	7
0	0	0	0	0	0	0	0	0	0	1	0	0	0	1	0	0	0	1	1	2	1	1	0	0	6
0	0	0	0	0	0	0	0	0	1	1	0	0	0	1	0	0	0	1	1	1	2	1	1	1	4
0	0	0	1	0	0	0	0	0	0	1	0	0	0	0	0	0	0	1	1	1	1	2	1	1	5
0	0	0	1	0	0	0	1	1	1	1	0	0	0	0	0	0	0	0	0	0	1	1	2	1	7
0	0	0	1	0	0	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0	1	1	1	2	5

C_3 / D_3

																					D_3
5	1	1	1	1	1	1	1	1	0	0	0	0	0	1	1	1	1	0	0	0	8
1	5	1	1	1	0	1	1	1	1	0	0	0	0	1	1	1	1	0	0	0	25
1	1	5	1	1	0	0	1	1	1	1	0	0	0	0	1	1	1	0	0	0	8
0	1	1	5	1	0	0	0	1	1	1	1	0	0	0	0	1	1	0	0	0	8
0	0	1	1	5	0	0	0	0	1	1	1	0	0	0	0	0	1	0	0	0	8
1	0	0	0	0	5	1	1	0	0	0	0	1	1	1	0	0	0	0	0	0	15
1	1	0	0	0	1	5	1	1	0	0	0	1	1	1	1	0	0	1	0	0	18
1	1	1	0	0	1	1	5	1	1	0	0	0	1	1	1	1	0	1	1	0	52
1	1	1	1	0	0	1	1	5	1	1	1	0	0	1	1	1	1	1	1	1	77
0	1	1	1	1	0	0	1	1	5	1	1	0	0	0	1	1	1	0	1	1	28
0	0	1	1	1	0	0	0	1	1	5	1	0	0	0	0	1	1	0	0	1	13
0	0	0	1	1	0	0	0	0	1	1	5	0	0	0	0	0	1	0	0	0	15
0	0	0	0	0	1	1	0	0	0	0	0	5	1	1	0	0	0	0	0	0	31
1	0	0	0	0	1	1	1	0	0	0	0	1	5	1	1	0	0	1	0	0	15
1	1	0	0	0	1	1	1	1	0	0	0	1	1	5	1	1	0	1	1	0	36
1	1	1	0	0	0	1	1	1	1	0	0	0	1	1	5	1	1	1	1	1	57
0	1	1	1	0	0	0	1	1	1	1	0	0	0	1	1	5	1	1	1	1	28
0	0	1	1	1	0	0	0	1	1	1	1	0	0	0	1	1	5	0	1	1	8
0	0	0	0	0	0	1	1	1	0	0	0	0	1	1	1	1	0	5	1	1	10
0	0	0	0	0	0	0	1	1	1	0	0	0	0	1	1	1	1	1	5	1	13
0	0	0	0	0	0	0	0	1	1	1	0	0	0	0	1	1	1	1	1	5	8

C_4 / D_4

																					D_4
7	1	1	0	0	1	1	1	1	0	0	0	0	1	1	1	1	1	0	0	0	5
1	7	1	1	0	0	1	1	1	1	0	0	0	0	1	1	1	1	0	0	0	5
1	1	7	1	1	0	0	1	1	1	1	0	0	0	0	1	1	1	0	0	0	5
0	1	1	7	1	0	0	0	1	1	1	1	0	0	0	0	1	1	0	0	0	8
0	0	1	1	7	0	0	0	0	1	1	1	0	0	0	0	0	1	0	0	0	12
1	0	0	0	0	7	1	1	0	0	0	0	1	1	1	0	0	0	0	0	0	25
1	1	0	0	0	1	7	1	1	0	0	0	1	1	1	1	0	0	1	0	0	30
1	1	1	0	0	1	1	7	1	1	0	0	0	1	1	1	1	0	1	1	0	25
1	1	1	1	1	0	1	1	7	1	1	0	0	0	1	1	1	1	1	1	1	30
0	1	1	1	1	0	0	1	1	7	1	1	0	0	0	1	1	1	0	0	1	40
0	0	1	1	1	0	0	0	1	1	7	1	0	0	0	0	1	1	0	0	1	40
0	0	0	1	1	0	0	0	0	1	1	7	0	0	0	0	0	1	0	0	0	45
0	0	0	0	0	1	1	0	0	0	0	0	7	1	1	0	0	0	0	0	0	20
1	0	0	0	0	1	1	1	0	0	0	0	0	7	1	1	0	0	1	0	0	30
1	0	0	0	0	1	1	1	1	0	0	0	1	1	7	1	1	0	1	1	0	25
1	1	1	0	0	0	1	1	1	1	0	0	0	1	1	7	1	1	1	1	1	15
0	1	1	0	0	0	0	1	1	1	1	0	0	0	1	1	7	1	1	1	1	15
0	0	1	1	1	0	0	0	1	1	1	1	0	0	0	1	1	7	0	1	1	30
0	0	0	0	0	0	1	1	1	0	0	0	0	1	1	1	1	0	7	1	1	20
0	0	0	0	0	0	0	1	1	1	0	0	0	0	1	1	1	1	1	7	1	10
0	0	0	0	0	0	0	0	1	1	1	0	0	0	0	1	1	1	1	1	7	25

C_5

7	2	1	0	0	1	2	2	1	0	0	0	0	1	1	1	0	0	0	0	0
2	7	2	1	0	0	1	2	2	1	0	0	0	0	1	1	1	0	0	0	0
1	2	7	2	1	0	0	1	2	2	1	0	0	0	0	1	1	1	0	0	0
0	1	2	7	2	0	0	0	1	2	2	1	0	0	0	0	1	1	0	0	0
0	0	1	2	7	0	0	0	0	1	2	2	0	0	0	0	0	1	0	0	0
1	0	0	0	0	7	2	1	0	0	0	0	2	2	1	0	0	0	0	0	0
2	1	0	0	0	2	7	2	1	0	0	0	1	2	2	1	0	0	1	0	0
2	2	1	0	0	1	2	7	2	1	0	0	0	1	2	2	1	0	1	1	0
1	2	2	1	0	0	1	2	7	2	1	0	0	0	1	2	2	1	1	1	1
0	1	2	2	1	0	0	1	2	7	2	1	0	0	0	1	2	2	0	1	1
0	0	1	2	2	0	0	0	1	2	7	2	0	0	0	0	0	2	0	0	1
0	0	0	1	2	0	0	0	0	1	2	7	0	0	0	0	0	1	0	0	0
0	0	0	0	0	2	1	0	0	0	0	0	7	2	1	0	0	0	0	0	0
1	0	0	0	0	2	2	1	0	0	0	0	2	7	2	1	0	0	1	0	0
1	1	0	0	0	1	2	2	1	0	0	0	1	2	7	2	1	0	2	1	0
1	1	1	0	0	0	1	2	2	1	0	0	0	1	2	7	2	1	2	2	1
0	1	1	1	0	0	0	1	2	2	1	1	0	0	1	2	7	2	1	2	2
0	0	1	1	1	0	0	0	1	2	2	1	0	0	0	1	2	7	0	1	2
0	0	0	0	0	0	1	1	1	0	0	0	0	1	2	2	1	0	7	2	1
0	0	0	0	0	0	0	1	1	1	0	0	0	0	1	2	2	1	2	7	2
0	0	0	0	0	0	0	0	1	1	1	0	0	0	0	1	2	2	1	2	7

Fig. 3: Constraint matrices and demand vectors

Table 1: Specifications of the eight benchmark problems used

Problem #	No. of cells	No. of channels	Compatibility matrix (C)	Demand vector (D)
1	4	11	C1	D1
2	25	73	C2	D2
3	21	381	C3	D3
4	21	533	C4	D3
5	21	533	C5	D3
6	21	221	C3	D4
7	21	309	C4	D4
8	21	309	C5	D4

Table 2: Channel assignment solution for problem #1

Cells #	---------------------Channel aassignment--------------------		
1	3		
2	10		
3	8		
4	1	6	11

For this problem, the population size used is set to 30 and the maximum of generations is 20. Table 4 depicts the obtained solution which does not violate the electromagnetic compatibility matrix.

Table 4 shows that the 9th cell, with the highest request of channels, uses the entire available spectrum without violating the electromagnetic constraints. In fact, the difficulty of this problem is that for this cell, channels affectation represented in Table 3 represents the single solution to avoid the co-site constraints; the other constraints (Adjacent Channel Constraint (ACC) and the Co-Channel Constraint (CCC)) must be validated by the remainder cells.

Problem #6: The remainders problems have in common a similar demand vector D4 and differ only in the constraints matrix and the number of channels available.

Using a population of 30 individuals and 20 as a maximum number of generations, the final solution provided by CAEP is depicted in Table 5.

Problem #8: For this system of 21 cells, the available spectrum is [1… 309], the total number of channels request is 470 and the co-site constraints is 7.

Table 6 displays the solution obtained using 40 individuals which are evolved during 20 generations.

Table 3: Channel assignment solution for problem #2

Cells #	Channels assignment										
1	37	73	2	4	6	8	10	12	14	16	
2	21	23	49	51	53	25	55	57	32	59	61
3	48	52	54	56	58	60	62	64	43		
4	2	37	19	25	32						
5	45	65	18	20	22	24	26	28	30		
6	4	6	8	10							
7	70	65	18	20	26						
8	45	24	50	17	22	28	30				
9	11	3	5	7							
10	47	67	69	27	29	31	33	35			
11	53	51	55	61	57	42	49	59			
12	63	68	71	34	36	38	40	42	44		
13	46	39	41	1	3	5	7	9	11	13	
14	15	17	19	50	66	70	72				
15	34	48	52	54	56	36	38				
16	23	2	10	21	25	32					
17	22	12	18	4							
18	37	8	29	14	20						
19	27	40	30	33	35						
20	6	22	24	16	31	4	26				
21	1	17	5	14	12	7					
22	32	19	2	25							
23	3	9	28	13	20						
24	16	14	18	21	6	12	23				
25	8	17	4	10	1						

Table 4: Channel assignment solution for problem #3

Cells#	Channels assignment																							
1	128	2	7	12	17	22	27	32																
2	188	3	8	13	18	23	28	38	43	48	53	58	63	68	73	78	83	88	93	98	103	108	113	118
3	123	4	9	14	19	24	29	34																
4	62	2	7	12	17	22	27	32																
5	41	1	6	11	16	21	26	31																
6	80	1	6	11	16	21	26	31	36	41	46	51	56	61	66									
7	123	4	9	14	19	24	29	34	39	44	49	54	59	64	69	74	79	84						
8	285	5	10	15	20	42	47	52	57	62	67	72	77	82	87	92	97	102	107	112	117	122	127	132
	137	142	147	152	157	162	167	172	177	182	187	192	197	202	207	212	217	222	227	232	237	242	247	252
	257	262	267	272																				
9	1	6	11	16	21	26	31	36	41	46	51	56	61	66	71	76	81	86	91	96	101	106	111	116
	121	126	131	136	141	146	151	156	161	166	171	176	181	186	191	196	201	206	211	216	221	226	231	236
	241	246	251	256	261	266	271	276	281	286	291	296	301	306	311	316	321	326	331	336	341	346	351	356
	361	366	371	376	381																			
10	37	44	49	54	59	64	69	74	79	84	89	94	99	104	109	114	119	124	129	134	139	144	149	154
	159	164	169	174																				
11	68	3	8	13	18	23	28	33	38	43	48	53	58											
12	80	4	9	14	19	24	29	34	39	45	50	55	60	65	70									
13	157	2	7	12	17	22	27	32	37	42	47	52	57	62	67	72	77	82	87	92	97	102	107	112
	117	122	127	132	137	142	147																	
14	33	3	8	13	18	23	28	38	53	58	63	68	73	78	83									
15	89	208	213	218	223	228	233	238	243	248	253	258	263	268	273	94	99	104	109	114	119	124	129	134
	139	144	149	154	159	164	169	174	179	184	189	194												
16	302	307	25	30	35	40	45	50	55	60	65	70	75	80	85	90	95	100	105	110	115	120	125	130
	135	140	145	150	155	160	165	170	175	180	185	190	195	200	205	210	215	220	225	230	235	240	245	250
	255	260	265	270	275	312	280	287	292															
17	193	128	133	138	143	148	153	158	163	168	173	178	183	198	203	209	214	219	224	229	234	239	244	249
	254	259	264	269																				
18	67	5	10	15	20	42	47	52																
19	88	2	7	12	17	22	27	32	37	43														
20	48	3	8	13	18	23	28	33	38	53	58	63	68											
21	57	4	9	14	19	24	29	34																

In this case, the highest frequencies request is required by the 12th cell. The only solution that does not violate the co-site constraints is given in Table 5 and must use the total spectrum to avoid interferences.

Comparisons with other techniques: Table 7 presents comparisons of the simulation results obtained using CAEP and other methods reported in the literature (Cheng *et al.*, 2005; Funabiki and Takefuji, 1992;

Table 5: Channel assignment solution for problem #6

Cells #	Channels assignment																								
1	21	54	1	6	11																				
2	24	50	2	7	14																				
3	64	69	3	9	15																				
4	37	42	4	10	49	17	22	27																	
5	74	52	59	67	2	7	12	19	24	29	34	39													
6	136	121	2	7	126	13	18	23	28	33	38	43	48	53	58	63	68	73	78	83	88	93	98	103	108
7	97	64	3	8	15	20	25	30	35	40	45	51	56	69	74	79	84	89	102	109	118	123	128	133	138
	143	148	153	158	163																				
8	137	77	4	10	17	22	27	32	37	42	47	52	57	62	67	72	82	87	92	142	147	104	112	117	122
9	191	186	5	12	26	31	36	41	46	71	76	81	86	91	96	101	106	111	116	121	126	131	136	141	146
	151	156	161	166	171																				
10	198	203	208	8	13	18	23	28	33	38	43	48	53	58	63	68	73	78	83	88	93	98	103	108	113
	118	123	128	133	138	143	148	153	158	163	168	173	178	183	188										
11	14	20	25	30	220	45	50	55	60	65	70	75	80	85	90	95	100	105	110	115	120	125	130	135	140
	145	150	155	160	165	170	175	180	185	190	195	200	205	210	215										
12	1	6	11	16	21	26	31	36	41	46	51	56	61	66	71	76	81	86	91	96	101	106	111	116	121
	126	131	136	141	146	151	156	161	166	171	176	181	186	191	196	201	206	211	216	221					
13	99	104	1	6	11	16	21	26	31	36	41	46	52	57	62	67	72	77	82	87					
14	175	180	5	12	19	24	50	55	60	65	70	75	80	85	90	95	100	105	110	115	120	125	130	135	140
	145	150	155	160	165																				
15	189	107	9	59	66	194	199	204	209	214	219	113	119	124	129	134	139	144	149	154	159	164	169	174	179
16	152	61	132	29	34	39	44	49	157	162	167	172	181	190	195										
17	94	99	1	6	11	16	21	51	56	176	182	187	192	197	202										
18	62	77	82	35	40	87	47	189	54	194	199	72	204	209	92	214	219	104	112	117	122	127	137	142	147
	154	159	164	169	174																				
19	98	103	2	7	13	18	23	28	33	38	43	48	53	58	63	68	73	78	83	88					
20	120	110	3	14	19	24	30	45	50	55	60	65	70	75	80	85	90	95	100	105					
21	144	97	4	9	15	22	27	32	37	42	52	57	64	69	74	79	84	89	102	107	114	119	124	129	134

Table 6: Channel assignment solution for problem #8

Cells #	Channels assignment																								
1	48	6	13	20	27																				
2	1	8	15	24	31																				
3	70	77	42	49	56																				
4	23	30	90	97	104	118	2	9																	
5	174	181	188	32	111	18	4	11	25	62	69	76													
6	201	157	194	166	173	183	1	9	16	23	30	37	44	51	58	65	72	79	86	93	100	107	118	125	132
7	139	146	153	160	239	251	3	11	18	25	32	39	46	53	60	67	74	81	88	95	102	109	116	181	188
	196	203	210	217	224																				
8	29	230	22	57	36	43	50	64	71	78	85	92	99	112	119	129	162	169	176	237	287	244	253	260	267
9	173	180	187	264	271	257	250	5	12	19	26	33	40	47	54	61	68	75	82	89	96	103	110	117	124
	131	138	145	152	159																				
10	37	289	7	14	296	303	44	51	58	65	72	79	86	93	100	114	121	128	135	142	149	156	163	170	177
	184	191	198	205	212	268	275	282																	
11	270	277	284	291	20	298	305	27	39	46	53	60	67	74	81	88	95	102	109	116	123	130	137	144	151
	158	165	172	179	186	242	249	256																	
12	1	8	15	22	29	36	43	50	57	64	71	78	85	92	99	106	113	120	127	134	141	148	155	162	169
	176	183	190	197	204	260	267	274	281	288	295	302	309												
13	122	129	136	143	150	103	4	12	19	26	33	40	47	54	61	68	75	82	89	96					
14	226	191	198	205	212	219	7	14	21	28	35	42	49	56	63	70	77	84	91	98	105	113	120	127	
	134	141	148	155	163	170																			
15	249	123	137	144	151	158	165	172	179	186	193	200	207	214	221	228	235	242	256	263	270	277	284	291	298
16	274	246	126	133	140	182	2	9	16	190	197	204	211	218	225										
17	175	278	285	292	194	201	21	28	63	208	215	222	106	229	236										
18	294	287	189	132	139	125	196	3	10	17	24	203	34	41	48	55	210	217	224	231	238	245	252	259	266
	273	280	146	153	160																				
19	114	121	128	135	142	149	6	13	20	27	34	41	48	55	62	72	79	86	93	100					
20	109	116	130	161	147	154	4	11	18	25	32	39	46	53	60	67	74	81	88	95					
21	164	171	178	185	192	199	1	8	15	30	43	50	57	69	76	83	90	97	104	111	118	127	134	141	150

Kim, 1997; Ngo and Li, 1998). To acquire the average number of iterations and the convergence rates and to allow comparisons with the other methods, one hundred simulation runs were performed.

Table 7 shows that the implementation of CAEP to the eight benchmarks problem is useful. In fact, CAEP achieves 100% of convergence for all these problems. Moreover, the number of iteration required by CAEP to

Table 7: Results comparison between CAEP and other methods

Methods	Problem#	1	2	3	4	5	6	7	8
CAEP	# of iteration	1	2	2	2	2.25	2.75	3.52	4
	Convergence rate %	100	100	100	100	100	100	100	100
Result from (Cheng *et al*., 2005)	# of iteration	1	5	3	1	5	8.6	4	5
	Convergence rate %	100	100	100	100	100	100	100	100
Results from (Funabiki and Takefuji, 1992)	# of iteration	212	294.0	147.8	117.5	100.3	234.8	85.6	305.6
	Convergence rate %	100	9	93	100	100	79	100	24
Results from (Kim, 1997)	# of iteration	NA	279.9	67.4	64.2	126.8	62.4	127.7	151.9
	Convergence rate %	NA	62	99	100	98	97	99	52
Results from (Ngo and Li, 1998)	# of iteration	1	26382	NA	NA	NA	63152	NA	79502
	Convergence rate %	100	100	NA	NA	NA	92	NA	80

converge to the best channel assignment solution is less than this required by the other methods, except in the problem #4, CAEP converges at the second iteration, while the method reported in Cheng *et al*. (2005) converges at the first iteration and this is the only particular case.

It is obvious that the use of CAEP for FS-FAP is more efficient than other techniques both in terms of convergence rate and number of iteration required to convergence. This is can be explain by the fact that hybrid CAEP uses 2 main strategies to achieve the best solution quickly. First, it uses a belief space which can be seen as constraints that direct the evolution of individuals (solutions), leading to an efficient optimisation process. On the second hand, the algorithm implements a local search method in order to improve the performance of CAEP in term of the quality of the obtained solution.

CONCLUSION

In this study, the fixed spectrum frequency assignment problem is studied. The objective of this study is to minimize the total interference of an assignment plan. Due to the NP-hardness of this problem, any exact optimization algorithm requires in the worst case an amount of time exponentially growing with the size of the instance. For this reason, the heuristic methods are more suitable for this case. These heuristics attempt to identify an acceptable solution in a reasonable amount of time.

For that reason, a hybrid cultural algorithm is used to solve the frequency assignment problem. This algorithm implements a deterministic local search procedure within cultural algorithm paradigm. The hybridization of a local search procedure, based on enumerative method and cultural algorithm allows exploiting both determinist feature of the local search in finding the exact solution and stochastic feature of cultural algorithm to reduce the time of computation required to convergence. In fact, if cultural algorithm is applied for global optimization, then acceptable beliefs can be seen as constraints that direct the population at the micro-evolutionary level. These constraints can influence directly the search process, leading to an efficient optimization process.

This algorithm is performed to eight well-known benchmarks problem. Simulation results obtained show that this method outperforms the other algorithms both in terms of convergence rate and the number of iteration or generation required to achieve the best solution. The main reason of these performances is that this method implements a cultural algorithm to find a suitable solution in a reasonable computation time and a local search to improve the quality of identified solution.

In conclusion, for cellular systems with high number of cells, this algorithm can be efficiently applied to find the exact solution in an acceptable time of computation.

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