MINIMIZATION OF MOBILE-NETWORK CHANNEL INTERFERENCE USING PARTICLE SWARM OPTIMIZATION

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ABSTRACT

The global increase in the demand for mobile communication services has raised the need for efficient channel assignment within the limited available bandwidth available to wireless network operators hence one of the most important challenges faced by these operator is that of efficiently assigning available channels such that the utilization of available bandwidth is maximized while minimizing interference from neighborhood channels, and at the same time satisfying as many call demands as possible. This problem is known to belong to a class of very difficult combinatorial optimization problems such that the difficulty of finding a good solution increases exponentially with an increase in the number of cell to be assigned. In this paper, the particle swarm optimization algorithm is used to solve the stated channel assignment problem, using the Philadelphia Benchmark Network as a test case. The results presented in this paper show that channel utilization can be significantly improved with lower channel interference, when compared to comparative solutions reported in literature, and should result into significant gains for network operators.
Keywords: *PSO, Channel Assignment, Network Optimization, Mobile Communications*

INTRODUCTION

As the demand for and the number of services offered by cellular networks increase, efficient allocation of the limited frequency bandwidth, for the purpose of increasing channel utilization, is a challenge in any cellular communication platform. Channel utilization is improved by the method of frequency re-use, which involves the use of the same frequency or channels simultaneously in separate cells subject to the base transceiver station (BTS) distance also called the re-use distance (Kendal and Mohammed, 2004b). Optimal channel assignment requires an adherence to a specified reuse distance so as to minimize electromagnetic interference among communicating channels, and at the same time servicing as many calls as possible; the foregoing is known as the Channel Assignment Problem (CAP) (Kendal and Mohammed, 2004a).

The channel assignment problem can be categorized into three, namely; the Fixed Channel Assignment, Dynamic Channel Assignment and Hybrid Channel Assignment (which is a combination of fixed and dynamic channel assignment) (Katzela and Naghshineh, 1996). In fixed channel assignment, the channels are permanently assigned to base stations based on predetermined traffic demand and interference constraints, therefore it does not adapt to changes in demand or interference constraints, and the assignment strategy is updated from time to time as demand profile changes.

In the dynamic assignment case, all available channels are placed into a central pool and are dynamically assigned upon request by a base station. Once a call is completed, the channel is returned to the pool and can be used by other base stations. Dynamic assignment provides flexibility and traffic adaptability at the cost of higher system complexity and computational overhead. Under heavy traffic conditions, dynamic strategies tend to become less efficient because of the computational time required to complete the assignment (Katzela and Naghshineh, 1996), and since heavier traffic is expected in the future, the fixed assignment schemes is preferred because of its higher efficiency (Kendall and Mohamad, 2004a).

There are two possible objectives to fixed assignment problem defined as follows:

i. **The Minimum Span - Channel Assignment Problem (MS-CAP):** In this case the cell station number and compatibility matrix are fixed, while the task is to minimize the number of consecutive channels assigned for a given traffic demand. The MS-CAP attempts to maximize the number of assigned channels while minimizing electromagnetic interference.

ii. **The Minimum Interference - Channel Assignment Problem (MI-CAP):** In this case the number of radio channels, cell station number, traffic demand and compatibility matrix are fixed, while the task is to minimize the severity of electromagnetic interference.

The CAP is a practical but NP-hard optimization problem that has been studied by a number of authors; finding an acceptable solution using classical optimization methods requires an amount of time that grows exponentially with the number of the cells to be assigned. Other approaches that have been used in solving this problem include Heuristics approach (Thavarajah and Lam, 1999; Vittorio and Antonella, 2000), graph coloring approach (Comellas and Ozon, 1995), adaptive local search approach (Kendall and Mohamad, 2004a), and other hyper-heuristics approaches (Kendall and Mohamad, 2004b), genetic algorithm (Lipo et al, 2002) and hybrid ant colony (Peng-Yeng and Shan-Cheng, 2007) have also been used.

In this study, the particle swarm optimization (PSO) algorithm is used to solve the Minimum Interference - Channel Assignment Problem (MI-CAP). To test the effectiveness of the proposed solution, the Philadelphia Benchmark instance, which has become a standard case-study for CAP problems in literature was used as a test case; this way the solutions obtained in this work were compared to similar solutions in literature.

The objective of MI-CAP is to assign active calls channels within a given span of frequency spectrum such that electromagnetic interference is minimized, thereby improving the quality of service (QoS) the customers and financial returns on investment for the operator subject to the following constraints:

i. **Co-channel constraint:** The same frequency channel cannot be assigned to certain pairs of radio cells simultaneously;

ii. **Adjacent channel constraint:** Adjacent frequency channels cannot be assigned simultaneously;

iii. **Co-site constraint:** Assigned channels within the same radio cell must meet a minimal frequency separation distance from each other.

Thus, for a given network with *N* cells and *m* radio channels, with d_i given as the number of radio channels that should be assigned in cell *i* and the compatibility matrix C_{ij} which shows the adjacent channel constraint (or frequency separation) between cell *i* and cell *j*. For a call emanating from channel *k* of cell *i*, the frequency separation between it and any other channel *m* in an adjacent cell *j* must satisfy the constraint

$$\left| f_{ik} - f_{jm} \right| \geq C_{ij} \qquad \text{……………………1}$$

If *i* = *j*, then we have a co-site constraint. Therefore the optimization problem is to

Minimize

$$\left| f_{ik} - f_{jm} \right| < C_{ij} \qquad \text{……………………2}$$

Subject to

$$1 \leq i, j \leq N \quad \text{and} \quad 1 \leq k, m \leq d_i$$

Particle Swarm Optimization (PSO): The steps involved in implementing the particle swarm optimization (PSO) algorithm can be summarized as:

i Initialize PSO parameters, and *P* particles (also called particles or solution candidates);
ii Determine the fitness of each particle;
iii Update a particle's personal best, *pbest* and the overall (or global) best particle *gbest*;
iv Update velocities (*v*) and positions (particles);
v Terminate on convergence or at end of iteration;
vi Go to step 2

The *P* particles together with their velocities may be initialized randomly or based on an expert input, the latter results in a faster convergence. In this study, the initial population was generated using the method recommendation by Kennedy and Eberhart (1995). The *pbest* is updated by comparing the current *pbest* of a particle with that of its previous *pbest*, and retaining the better of the two values; while the best of all the *pbests* in any generation is selected as the *gbest.* Velocities and positions are updated using the PSO equations in 3 and 4 respectively.

$$v_n^{i+1} = \omega \cdot v_n^i + c_1 \cdot r_1^i \cdot (\hat{p}_n^i - p_n^i) + c_2 \cdot r_2^i \cdot (\hat{p}_g^i - p_n^i) \qquad \text{……………………3}$$

$$p_n^{i+1} = v_n^{i+1} + p_n^i \qquad \text{……………………4}$$

Where ω, c_1 and c_2 are the PSO parameters to be initialized, while r_1 and r_2 are normalized unit random numbers and *i* is the iteration counter. Also $\hat{p}_n$ *pbest* for the n^{th} particle and $\hat{p}_g$ is the *gbest*.

Fitness Measure: The fitness in step 2 of the PSO algorithm connects the PSO to the problem space, and it determines how well a particle solves the optimization problem. In this study, the amount of interference in the assigned channels is used as the fitness measure. This interference can be measured by the frequency separation f_s in the assigned channels. The interference can be obtained from the number of instances where co-channel or adjacent channel frequency separation satisfies the condition

$$\left| f_{ik} - f_{jm} \right| \leq C_{ij} \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 5$$

Each instance of interference is assigned a numerical value 1, while instances without interference are assigned a 0 value; interference beyond the second layer is not considered. The fitness is then the overall sum of all interferences in any channel assignment pattern represented by particle p_i in P, and the particle with the least interference value has the best fitness.

Sequential Random Numbers and Repetition of Hotspot Cell Channels: The sequential random numbers used to loop through the *m* channels in *i-th* cell was generated using Kwan and Tak-Shing (2000) method.

$$SRN_i = rand\left[1, 1+a, 1+2a, \cdots, a(m_1 - 1)\right] \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 6$$

Where N is the number of cells in the network,

m_i is the number of radio channels in cell i

a is the co-channel separation distance.

Philadelphia Benchmark Instance and Simulation: The Philadelphia benchmark consists of 21 (hexagonal) cells in a cellular phone network in Philadelphia. The network structure is shown in Figure 1, while problem specification with three sets (referred to Cases I, II and III) whose demand traffic, co-site and channel separation between adjacent cells are given as rows d_1, d_2 and d_3 respectively on Tables 1 and 2. The parameters of the PSO are presented on Table 3.

The results obtained were compared to that Genetic Algorithm (GA) and Simulated Annealing (SA) (Thavarajah, and Lam, 1999), where the study used the genetic algorithm, simulated annealing, local search and heuristic technique to solve the same problem.

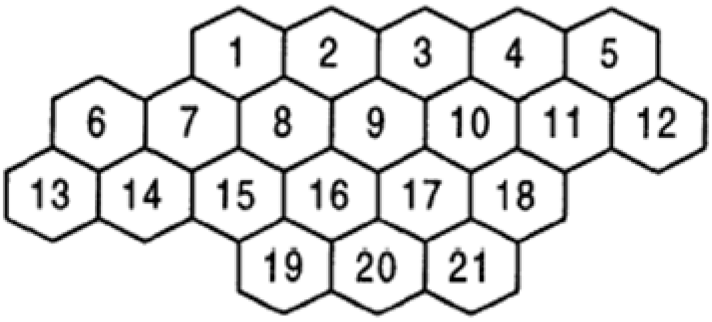

Figure 1: Philadelphia Benchmark with 21 (hexagonal) Cell Structure

Table 1: Network Specification with Cell Demand Data

Cell No		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
No. of required channels	d_1	8	25	8	8	8	15	18	52	77	28	13	15	31	15	36	57	28	8	10	13	8
	d_2	5	5	5	8	12	25	30	25	30	40	40	45	20	30	25	15	15	20	20	20	25
	d_3	10	11	9	5	9	4	5	7	4	8	8	9	10	7	7	6	4	5	5	7	6

Table 2: Problem Specifications

Problem Instance	Co-channel Seperation	Adjacent Channel Separation
d_1	5	1
d_2	5	1
d_3	5	2

Table 3: PSO Parameter

Parameter	value
C1	0.25
C2	0.67
ω	0.127
No of Particles	20
fitness	No of interferences
Iteration limit	150

The results obtained were compared to that genetic algorithm (GA) and Simulated Annealing (SA) in (Thavarajah, and Lam, 1999), where the authors used the GA, simulated annealing, local search and heuristic technique to solve the same problem.

RESULTS AND DISCUSSION

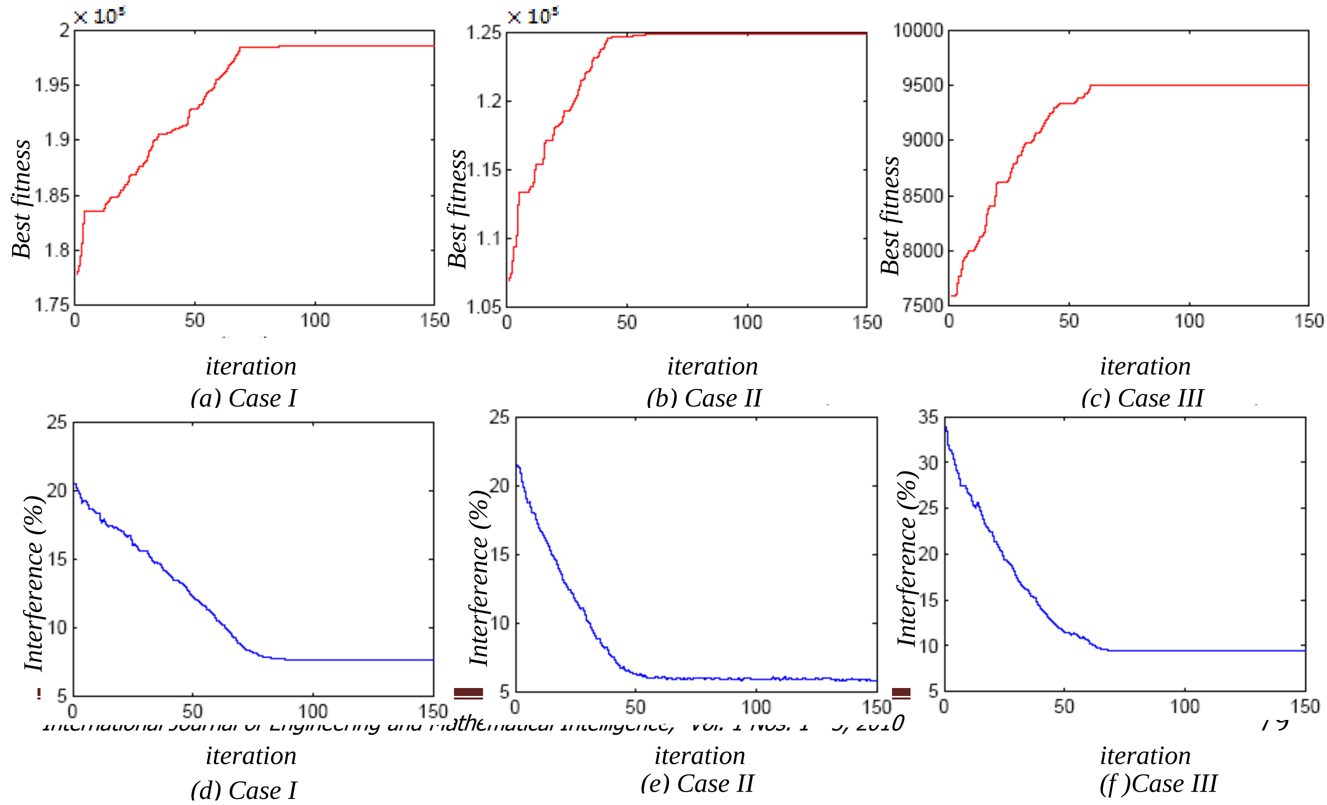

Figure 2: Simulation Results for Cases I, II and III

Figures 2(a), 2(b) and 2(c) show the trend of the most-fit solution (best particle) as iteration progressed for cases 1, 2 and 3, while Figures 2(d), 2(e) and 2(f) show the how the percentage of interference in the allocated channels decreased to less than 10% in all cases in less than 100 iteration steps.

Table 4: Comparison of GA, SA [2] and PSO

Case No.	Available Channels	Genetic Algorithm [2]		Simulated Annealing [2]		PSO (This Paper)	
		Channels Assigned (%)	Error in Assigned (%)	Channels Assigned (%)	Error in Assigned (%)	Channels Assigned (%)	Error in Assigned (%)
1	381	64.4	0	28.1	0	100	8%
2	221	55.3	0	26.3	0	100	6%
3	71	50.1	0	38.3	0	100	10%

CONCLUSION

In this study, the particle swarm optimization (PSO) algorithm was used to solve the Minimum Interference-Channel Assignment Problem (MI-CAP). To test the effectiveness of the proposed solution, the Philadelphia Benchmark instance, which has become a standard case-study for CAP problems was used as a test case. The solutions obtained were compared with similar solutions in literature. Particle Swarm Optimization (PSO) to minimize interference of the channel assignment problem was presented, showing that all available channels were assigned, about 90% of which are interference-free, and this allows maximum bandwidth utilization while allowing the remaining to be used for non-critical traffic such as voice and small message service (SMS).

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