Available online at www.sciencedirect.com
ScienceDirect
Signal Processing 88 (2008) 1461–1476
SIGNAL PROCESSING
www.elsevier.com/locate/sigpro

An heuristic search technique for fixed frequency assignment in non-homogeneous demand systems

L.M. San José-Revuelta*

Dept. de Teoría de la Señal y Comunicaciones e I.T., E.T.S.I. Telecomunicación, Universidad de Valladolid, 47011 Valladolid, Spain

Received 6 October 2006; received in revised form 14 November 2007; accepted 11 December 2007
Available online 11 January 2008

Abstract

In this paper, an heuristic algorithm is applied to solve the problem of frequency reuse in cellular radiocommunication systems, where the main aim is to obtain a channel assignment free of interferences such that the resulting bandwidth is close to the minimum theoretical channel span required. Specifically, a genetic algorithm (GA) whose probabilities of mutation and crossover are on-line adjusted based on the diversity of the population is presented. This diversity is estimated by means of analyzing the individuals' fitness entropy. The resulting algorithm obtains accurate solutions, thus offering an interesting alternative to other global search techniques, such as simulated annealing, tabu search and neural networks, as well as to standard GAs. A complete selection of the most well-known benchmark instances has been used in order to evaluate the performance of the proposed procedure. Numerical simulations show that optimal bandwidth solutions are achieved within a reasonable computation time for all the problem instances tested.

Keywords: Micro-genetic algorithm (μ-GA); Channel assignment; Diversity control; Electromagnetic compatibility (EMC)

1. Introduction

There exist a continuously growing research activity in the field of mobile communications in order to develop sophisticated systems with increased network capacity and performance. Most of the problems that appear in complex modern systems are characterized by search spaces whose complexity increases exponentially with the size of the input, being, therefore, intractable for solutions using analytical or simple deterministic approaches [1,2]. Some of these problems belong to the class of NP-complete problems [3]. Evolutionary computation[1] (EC)-based techniques and, specifically, genetic algorithms (GAs), are based on the principle of natural selection and survival of the fittest, thus constituting an alternative method for finding solutions to these highly nonlinear problems with multimodal solutions' spaces. GAs efficiently combine explorative and exploitative search so as to avoid convergence to suboptimal solutions. Unlike the steepest descent approaches, GAs require no gradient calculation and are much less susceptible to local optima, since global search techniques avoid such traps by providing the ability to selectively

*Tel.: +34 983423660; fax: +34 983423667.
E-mail address: lsanjose@tel.uva.es

[1]At the end of the paper, an Appendix that shows the most frequently used acronyms and symbols of the paper has been included.

0165-1684/$ - see front matter
doi:10.1016/j.sigpro.2007.12.004

accept successive potential solutions even if they have a higher cost than the current solution [4]. Besides, GAs have already been proposed to solve specific NP-complete problems [5,6].

This paper focuses on the application of a low complexity genetic algorithm (μ-GA)—whose internal parameters are in-service adapted in order to control the diversity of the population—to solve the *channel assignment problem* (CAP) found in cellular radio systems. In this kind of systems, the frequency reuse by which the same channels are reused in different cells, becomes crucial [7]. Every cell is allocated a set of channels according to its expected traffic demand. The entire available spectrum is allocated to a cluster of cells arranged in shapes that allow for uniform reuse patterns. The channels must be located in such a way as to satisfy certain frequency separation constraints to avoid channel interference[2] using as small a bandwidth as possible. Considering this scenario, the CAP fits into the category of multimodal and NP-complete problems [1,3,8,9].

The fixed CAP has been extensively studied during the past decades. A comprehensive summary of the work done before 1980 can be found in [8]. When only the co-channel constraint (CCC) is considered, the CAP is equivalent to an NP-complete graph coloring problem [10]. In this simpler case, various graph-theoretic approaches have been proposed [8,10–12].

From the point of view of EC, some procedures based on neural networks (NNs) [13–16] and simulated annealing (SA) [17–19] have already been considered. The SA approach solves the drawback of easy convergence to local optima found in NNs, though its rate of convergence is rather slow, and a carefully designed cooling schedule is required. A comparison between SA and the tabu search (TS) methods shows that the TS algorithm is not only capable of matching, even outperforming SA, in locating the minimal number of frequencies for channel allocation, but it also constitutes a faster procedure [20]. On the other hand, several GA-based approaches have been applied to solve the CAP: For instance, in [21], Cuppini defined and used an asexual crossover and a special mutation. A disadvantage of such crossover is that it can easily destroy the structure of the current solution and, thus, make the algorithm harder to converge. In [22], Lai and Coghill represented the channel assignment solution as a string of channel numbers grouped in such a way that the traffic requirement is satisfied. The evolution is then proceeded via a *partially matched crossover* (PMX) *operator*—this type of crossover has also been used in [23]—and basic mutation. Two years later, Ngo and Li [24] suggested a GA that used the so-called *minimum separation encoding scheme*, where the number of 1's in each row of the binary assignment matrix corresponds to the number of channels allocated to the corresponding cell. To satisfy the demand requirement this number would normally be constant. Each chromosome is a binary string that represents the assignment matrix through a concatenation of its rows, and genetic operators are defined so as to preserve the number of 1's in each chromosome. Authors stated that this algorithm outperforms the NN-based approach described in [13].

Another closely related problem is the determination of a lower bound for the *span* (difference between the largest channel used and the smallest channel used) in channel assignment problems (CAPs). For instance, [25] formulates the CAP as a minimum cost set cover problem and proposes to solve it by the so-called *block depth-first search* (BDFS) heuristic search technique. This method is proved to guarantee an optimal solution when running with available computer memory without any time constraint and also to produce a high quality suboptimal solution when running under a time constraint. In [26], Smith et al. show how the most powerful results available for determining lower bounds for minimum span channel assignment problems can be adapted and simplified for cellular problems, and that the calculation of these bounds becomes feasible even for very large problems.

In this paper a diversity-guided μ-genetic algorithm (DGμGA) is developed and applied to solve the CAP. It offers low computational load and attains good quality solutions (optimal, minimum span, solutions) while maintaining satisfactory convergence properties. The probabilities of mutation and crossover of the GA are on-line adjusted by making use of an individuals' fitness dispersion measure based on the Shannon entropy (see Eq. (8) in Section 3.5). This way, the diversity of the population is monitored and controlled at every iteration of the algorithm and the obtained method offers the flexibility and robustness characteristic of GAs. The first one, *flexibility*, deals with the

[2]Electromagnetic compatibility (EMC) constraints.