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A two-phase knowledge based hyper-heuristic scheduling algorithm in cellular system

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ABSTRACT

In this paper, we investigate the resource scheduling assignment problem in cellular mobile networks by considering both the inter-cell interference and intra-cell interference simultaneously. The task of this problem is to find the minimum required bandwidth to satisfy channel demand from each cell without interference constraints violation. Different from existing works, a novel two-phase hyper-heuristic technique which integrates harmony search and a set of prior information based heuristics is proposed to solve it. We validate performance of our approach by integrating a local search procedure in the later iterations. The proposed algorithm is tested on a set of benchmark problems, and the results are compared with the best state-of-the-art approaches. The results show that the method proposed in this article works effectively on the benchmark problems and has better performance on most problems than the algorithms that are investigated.

1. Introduction

With the rapidly developing of mobile communication technology, more and more mobile users are inspired to complete a variety of operations over wireless networks. The rare and restricted spectrum resources cannot satisfy such tremendous channel demands from mobile users that the number of whom is increased quickly. It is extremely important to effectively utilize the spectrum resource to alleviate the shortage of wireless resources.

In cellular mobile networks, the coverage area of a network is divided into a set of hexagon cells. The entire available frequency spectrum is divided into a sequence of nonoverlapping spectrum bands and allocated to the mobile users inside the cells. In order to mitigate interference, the same channel can be assigned to different cells only if the distance between them is equal to or greater than the minimum reuse distance. Three constraints are mainly considered to be satisfied to avoid interference: (1) Cochannel constraint, the same channel cannot be assigned to different cells simultaneously if their distance is smaller than the minimum reuse distance; (2) Adjacent channel constraint, the adjacent channel cannot be assigned to adjacent cells simultaneously; (3) Cosite constraint, any pair of channels allocated to the same cell must be separated by a minimum channel separation distance. The task of the frequency assignment problem (FAP) in cellular mobile networks is defined as allocating channels to satisfy the demand from each cell with minimum spectrum band and meanwhile some frequency separate constraints must be satisfied to avoid interference.

The spectrum assignment problem in cellular mobile networks is a classical combinational optimization problem, and is equivalent to the classical graph coloring problem which is proven to be a NP-complete problem and difficult to find an optimal assignment in polynomial time [1]. A lot of research has been done to find optimal or near optimal channel scheduling schemes [2–16]. Most previous works solved this problem based on graph theory: transforming the frequency assignment problem to a graph coloring problem, and then applying some exact methods or heuristic methods to find an optimal solution. The frequency assignment in [2] is formulated into a graph coloring problem, and a randomized saturation degree heuristic which based on node ordering and randomization is used to solve this task. In this work, the cell with the largest number of colored neighbors is colored preferentially. The work in [4] reduces the channel assignment problem to a 3-CNF-SAT expression through polynomial reduction of a graph. Many other types of heuristic or meta-heuristic approaches also perform to find a best ordering for the cells or the calls which usually lead to good assignment results: simulated annealing [5], genetic algorithm [6–8], tabu search [9,10], neural network [11,12], and other heuristic methods [13,14].

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Hyper-heuristic based approach is designed to solve FAP problem in cellular radio networks rapidly [15,16]. Kendall and Mohamad [15] proposed a great deluge hyper-heuristic technique to find the near-optimal solutions. Four local search methods are acted as low level heuristics to improve the solution quality. The results are improved in [16] through applying four different acceptance criteria. In these methods, each low level heuristic defined could only perform a unique move from a current solution to generate a new solution. This is equivalent to the mutation operator in genetic algorithm.

In this paper, a novel two-phase knowledge based hyper-heuristic (TPKHH) approach is introduced to tackle the FAP problem with better solutions. It is obvious that cell ordering has a great influence on the result, so six influential cell evaluation methods are elected to act as low level heuristics to generate part of a feasible solution. Different from previous hyper-heuristic based approaches [15,16], the TPKHH operates on the heuristic space instead of solution space. Each low level heuristic performed is to choose one cell to construct part of a feasible solution, other than directly act as a local search operator on a feasible solution to get a totally new solution. In the proposed algorithm, a harmony search technique is invoked as a high level heuristic to search for a permutation of these low level heuristics for constructing frequency assignment scheme for the FAP problem.

Performance of our proposed approach is evaluated by some certain well-known benchmark problems, commonly known as Philadelphia benchmarks, which defined a 21-node cellular network; Finland benchmarks from Helsinki, which defined a 25-node cellular network. Besides these, we also consider larger benchmark instances which composed 55-node cellular network. All those benchmark problems are widely used in the literature [3]. Although these benchmarks have been extensively studied by many researchers, it is believed that the state-of-the-art results can still be improved, which is very crucial and necessary for spectrum saving. The experiment result demonstrates that most of the best known results can be enhanced by the proposed algorithm. For the FAP problem, more frequency resource is capable of being saved.

The rest of the paper is organized as follows: Section 2 gives the formulation of the frequency assignment problem. Section 3 presents a brief introduction of the harmony search algorithm and the hyper-heuristic. Section 4 presents the proposed two-phase knowledge based hyper-heuristic algorithm. Section 5 proposes the benchmark problems and simulation results. Finally, section 6 gives the concluding remarks.

2. Problem formulation

A hexagonal cellular network is illustrated in Fig. 1.

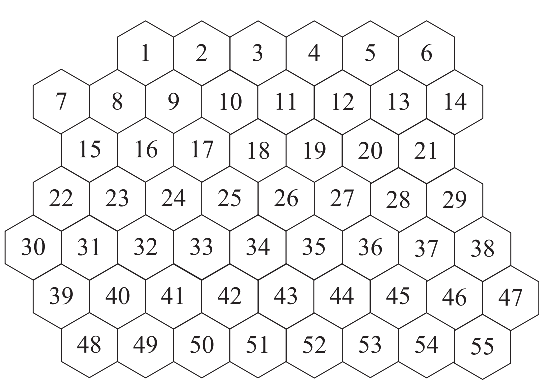

Fig. 1. A cellular network with 55 cells.

The basic frequency assignment problem in cellular network is described by the following components:

(1) A set of N distinct cells, which numbered as $1, 2, \ldots, N$.
(2) A demand vector $D = \{d_1, d_2, \ldots d_i, \ldots, d_N\} (1 \leqslant i \leqslant N)$: where d_i indicates the channel requirement of cell i.
(3) A symmetric compatibility matrix $C = \{c_{ij}\}_{N*N}$: where c_{ij} indicates the minimum channel separation distance between cell i and cell j.
(4) A channel assignment matrix $F = \{f_{ij}\}_{M*N}$: where $f_{ij} = 1$ denotes channel f_i is assigned to cell j, and $f_{ij} = 0$, otherwise.
(5) A set of frequency separation constraints defined as:

$$|f_k - f_l| \geqslant c_{ij}, \text{ for all } i, j, k, l, \text{ except for } (i = j, k = l);$$

where f_k is assigned to cell i, and f_l is assigned to cell j.

Given these conditions, the task of the frequency assignment problem (FAP) in cellular network aims to find a frequency assignment scheme with the minimum required system bandwidth to satisfy both the channel demand and interference constraints, i.e.:

Given: N, D, C

$$\text{Minimize } F = \{f_{ij}\}_{M_{Min}*N} \tag{1}$$

$$\text{s.t.} \sum_{m=1}^{M} f_{mi} = d_i \tag{2}$$

$$|f_k - f_l| \geqslant c_{ij}, \text{ for all } i, j, k, l, \text{ except } (i = j, k = l) \tag{3}$$

3. Preliminaries

In this section, firstly, a brief introduction of hyper-heuristic is provided. Then, harmony search is detailed explained which is used as the high level heuristic in the proposed algorithm.

3.1. Hyper-heuristics

Hyper-heuristics are novel heuristic methods and have attracted significant research attention in these years. In [17], Burke defined hyper-heuristics as: "*An automated methodology for selecting or generating heuristics to solve hard computational search problems.*" An overview of hyper-heuristics and classification is given in [18], and a generic framework of hyper-heuristic is provided in [19].

There are two main parts in the hyper-heuristics framework, the high level heuristic and the low level heuristics. Unlike meta-heuristics, the high level heuristic operates in the searching space which composed of multiple low level heuristics, without knowledge of the problem domain. In the problem solving process, the high level heuristic will decide which low level heuristic to apply at each decision point or to generate a new heuristic by the basic components. It is problem independent. So it is appropriate to apply to different problem domain with little adjustment.

The low level heuristics are composed of a sequence of heuristics, specifically designed or existed. Each low level heuristic (LLH) is commonly independent of the problem, and during the searching process, competes with each other to improve or generate a new solution for the original problem through selection, mutation, or learning operator. They search in the solution space directly.

A variety of hyper-heuristic approaches using different high level heuristics, together with a sequence of low level heuristics have been successfully applied to many combinatorial optimization problems, i.e., production scheduling [20], educational timetabling [21], vehicle routing [22] and so on.