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Assignment of cells to switches in a cellular mobile network using a hybrid Hopfield network-genetic algorithm approach☆

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Abstract

Handoff and cabling cost management plays a key role in the design of cellular telecommunications networks. The efficient assignment of cells to switches in this type of networks is an NP-complete problem which cannot be solved efficiently unless P = NP. This paper presents a hybrid Hopfield network-genetic algorithm approach to the cell-to-switches assignment problem, in which a Hopfield network manages the problem's constraints, and a genetic algorithm searches for high quality solutions with the minimum possible cost in terms of handoff and cable displayed. We show, by means of computational experiments, the good performance of our approach to this problem.

Keywords: Cellular networks; Cell-to-switch assignment; Hopfield neural networks; Genetic algorithms

1. Introduction

In a cellular mobile telecommunications network, the area of coverage is often divided in hexagonal *cells*, normally hierarchically set to reduce link costs. The cells usually communicate through stationary base stations to *switches*, which route calls either to another base station or to a public switched telephone network [1,2,15,22].

Due to users' mobility, the signals between the mobile unit and the base station may become weaker while interference from neighboring cells increases [2,21]. *Handoffs* are used to avoid problems related to weak signals and interference during a call. A handoff occurs when mobile networks automatically transfer a call from a radio channel in one base station to another radio channel in an adjacent base station, as the user crosses into the adjacent base station's cell area.

If a handoff occurs between two cells associated to the same switch (cells A and B in Fig. 1 for example) it is called *simple handoff*. This type of handoff is relatively easy to perform, and does not involve any location update in the databases that record the position of the user [1,3]. Imagine now that a user moves from cell B to cell C. In this case, the process of handoff involves the execution of a complicated protocol between switches 1 and 2 (see Fig. 1). It involves, in addition, the updating of the location of the user in the position databases, and also, if the original switch (2 in this case) is the responsible for maintaining the billing information, it may not be able to remove itself from the connection. Note that the handoff process in the case of cells connected to different switches consume much more network resources than handoffs between cells connected to the same switch. Consequently, it is usually advantageous to connect cells which have a high frequency of handoffs between them to the same switch.

The cell-to-switch assignment problem (CTSAP) was introduced in [4], and further studied in [1]. These papers present some heuristic algorithms to solve the problem. Several other heuristics techniques have been applied to the CTSAP, such as tabu search [3,5], simulated annealing [2], genetic algorithms [6] and hybrid algorithms which mix genetic algorithms and local search heuristics [7,8].

In this paper we present a novel approach to the CTSAP based on a hybrid Hopfield network-genetic algorithm scheme. In our approach, the problem's constraints are managed by the

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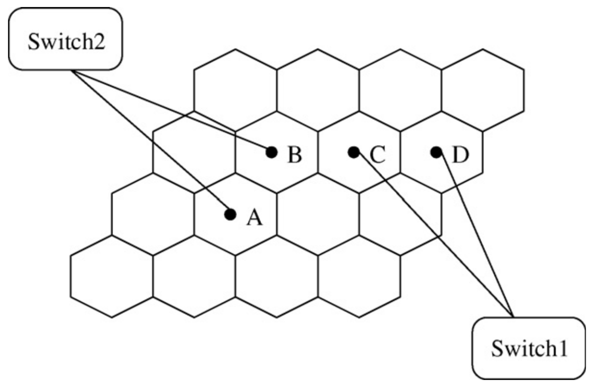

Fig. 1. An example of a simple handoff (from A to B or from C to D) and a complex handoff (from B to C).

Hopfield neural network (HNN), whereas the quality of the solution obtained is improved by a genetic algorithm (GA). The novelty of our approach is in the mix of a binary Hopfield network and a GA to form the hybrid HNN-GA. We propose two different GAs to be hybridized with the Hopfield network; a GA with binary encoding and an GA with integer encoding. The performance of this hybrid scheme, using the two GAs, has been tested in several test problems and compared with an existing GA [17] which manages the problem's constraints by a penalty function, and with a memetic algorithm formed by a GA and a tabu search (TS) heuristic [7]. The effectiveness of our algorithm has been shown by means of comprehensive experiments in several instances of the CTSAP. The results obtained in these experiments show that our method is significantly better (statistically) than previous approaches to the CTSAP.

The rest of the paper is structured as follows: in the next section, we provide a formal definition of the CTSAP. Section 3 provides a detailed overview of the most important existing approaches, whereas in Section 4 we describe the proposed Hopfield network-genetic algorithm approach. In Section 5 we present our experimental results and analyze the performance our algorithm. Finally, Section 6 concludes the paper with some remarks.

2. Problem definition

Consider a cellular mobile network with n cells and m switches, all located in known coordinates. Let c_{ik} be the amortized cost of cabling per unit time between cell i and switch k. Following Merchant and Sengupta [1], a handoff cost h_{ij} is incurred per unit time when cell i and j are assigned to different switches, and no handoff cost is considered when they are assigned to the same switch. Let λ_i be the number of calls handled by cell i per unit time, and M_k be the call handling capacity of switch k.

The problem's variables are defined as follows: let $\mathbf{X}$ be an $n \times m$ binary matrix, in which the element x_{ik} is 1 if cell i is assigned to switch k, and 0 otherwise; z_{ijk} is 1 if cells i and j are both assigned to switch k and 0 otherwise; y_{ij} is defined as 1 if cells i and j are assigned together to any switch and 0 otherwise. The CTSAP is then defined as follows:

find $\mathbf{X}$ which minimizes

$$Z = \sum_{i=1}^{n}\sum_{k=1}^{m} c_{ik}x_{ik} + \sum_{i=1}^{n}\sum_{j=1}^{n} h_{ij}(1-y_{ij}), \tag{1}$$

subject to:

$$\sum_{k=1}^{m} x_{ik} = 1 \quad \forall i, \tag{2}$$

$$\sum_{i=1}^{n} \lambda_i x_{ik} \leq M_k \quad \forall k, \tag{3}$$

$$z_{ijk} = x_{ik}x_{jk} \quad \forall i, j, k, \tag{4}$$

$$y_{ij} = \sum_{k=1}^{m} z_{ijk} \quad \forall i, j. \tag{5}$$

The objective function to be minimized (Eq. (1)) comprises the amortized cost of cabling between the cells and the switches and the handoff cost associated with handoffs between cells connected to different switches. Constraints 2 ensure that every cell is assigned to one and only one switch. Constraints 3 ensure that the switch capacities (M_k) are not exceeded. The nonlinear constraints 4 capture the appropriate values for z_{ijk} ($z_{ijk} = 1$ if and only if $x_{ik} = x_{jk} = 1$), whereas constraints 5 capture the correct values of variable y_{ij} ($y_{ij} = 1$ if $z_{ijk} = 1$ for any switch k).

We can obtain a more compact problem definition by substituting Eq. (4) in (5), to get the equivalent expression $y_{ij} = \sum_{k=1}^{m} x_{ik}x_{jk}$, which can be substituted into the objective function. The CTSAP can be stated then as:

find $\mathbf{X}$ which minimizes

$$Z = \sum_{i=1}^{n}\sum_{k=1}^{m} c_{ik}x_{ik} + \sum_{i=1}^{n}\sum_{j=1}^{n} h_{ij} - \sum_{i=1}^{n}\sum_{j=1}^{n}\sum_{k=1}^{m} h_{ij}x_{ik}x_{jk}, \tag{6}$$

subject to:

$$\sum_{i=1}^{m} x_{ik} = 1 \quad \forall i, \tag{7}$$

$$\sum_{i=1}^{n} \lambda_i x_{ik} \leq M_k \quad \forall k. \tag{8}$$

3. Previous approaches

The CTSAP was introduced by Merchant and Sengupta in [4]. The same authors studied the problem further in [1]. These papers presented a valid linear integer programming formulation for the CTSAP. In these articles is also suggested that exact approaches failed even with relatively small CTSAP instances, and a heuristic algorithm which provide better results than exact approaches for large CTSAP instances is proposed.

The formulation introduced in [1] was extended by Menon and Gupta in [2]. In this paper the authors also presented a hybrid heuristic which integrates ideas from