Computers & Industrial Engineering 60 (2011) 566–575

Contents lists available at ScienceDirect

Computers & Industrial Engineering

journal homepage: www.elsevier.com/locate/caie

Discrete particle swarm optimization based on estimation of distribution for terminal assignment problems ☆

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ARTICLE INFO

Article history:
Received 28 June 2008
Received in revised form 4 August 2009
Accepted 21 December 2010
Available online 30 December 2010

Keywords:
Discrete particle swarm optimization
Estimation of distribution
Terminal assignment problem
Task assignment problem
Combinatorial optimization

ABSTRACT

Terminal assignment problem (TEAP) is to determine minimum cost links to form a network by connecting a given set of terminals to a given collection of concentrators. This paper presents a novel discrete particle swarm optimization (PSO) based on estimation of distribution (EDA), named DPSO-EDA, for TEAP. EDAs sample new solutions from a probability model which characterizes the distribution of promising solutions in the search space at each generation. The DPSO-EDA incorporates the global statistical information collected from personal best solutions of all particles into the PSO, and therefore each particle has comprehensive learning and search ability. In the DPSO-EDA, a modified constraint handling method based on Hopfield neural network (HNN) is also introduced to fit nicely into the framework of the PSO and thus utilize the merit of the PSO. The DPSO-EDA adopts the asynchronous updating scheme. Further, the DPSO-EDA is applied to a problem directly related to TEAP, the task assignment problem (TAAP), in order to show that the DPSO-EDA can be generalized to other related combinatorial optimization problems. Simulation results on several problem instances show that the DPSO-EDA is better than previous methods.

1. Introduction

The fast development of network infrastructures and cellular networks, the popularity of personal computers, and the advances in networking technology have boosted the demand for data communications and telecommunications services dramatically. In this situation, the reliability and quality of telecommunication service networks are critical in designing networks, which meets the performance parameters. A large variety of combinatorial optimization problems (COPs) have arisen not only in the design, but also in the management of communication networks (Abuali, Schoenefeld, & Wainwright, 1994; Alba & Chicano, 2006; Brudaru, 2003; Kampstra, van der Mei, & Eiben, in preparation; Khuri & Chiu, 1997). These COPs, arising from hardware design, data transmission and network design of the telecommunication field, require the application of effective optimization techniques for tackling them. One of these problems in the telecommunication network design is terminal assignment problem (TEAP) (Alba & Chicano, 2006; Kampstra et al., in preparation).

The TEAP is to determine minimum cost links to form a network by connecting a given set of terminals to a given collection of concentrators. In this problem, the terminals have a known requirement of capacity and this requirement varies from one terminal to another. Each concentrator has an associated maximum capacity which limits the number of terminals it can handle. The capacity of all concentrators is also known. The TEAP is a NP-complete COP (Abuali et al., 1994; Alba & Chicano, 2006; Brudaru, 2003; Kampstra et al., in preparation; Khuri & Chiu, 1997).

Abuali et al. (1994) proposed a greedy algorithm and a hybrid greedy-genetic algorithm (GA) for solving the TEAP. Khuri and Chiu (1997) proposed two GAs, a simple GA and a group GA with a penalty function, for the TEAP. Their results suggest that the GAs work well with this problem and outperform the greedy algorithm. Brudaru (2003) also proposed a hybrid group GA for the TEAP.

Previous algorithms on the TEAP only consider the situation in which the cost of assigning a single terminal to a given concentrator is known before running the algorithms. When one of the objectives of the TEAP is to balance the assignment of terminals to concentrators, the cost or objective function depends on the entire solution provided to the communication network, and thus the cost of a single assignment cannot be calculated in advance (Salcedo-Sanz & Yao, 2004). In these situations, some of the previous algorithms, such as the greedy algorithm in (Abuali et al.,

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doi:10.1016/j.cie.2010.12.014

1994), are no longer applicable to the TEAP (Salcedo-Sanz & Yao, 2004). To solve the problem which the cost function depends on the entire solution, Salcedo-Sanz and Yao (2004) proposed a Hopfield neural network (HNN) GA (HNN-GA). Their simulation results on a set of TEAP instances of different difficulties show that the HNN-GA outperforms previous approaches to the problem. They also applied the HNN-GA to solve other COPs in different fields, such as task assignment problem (TAAP) (Salcedo-Sanz, Xu, & Yao, 2005a), switches assignment problem (CTAP) (Salcedo-Sanz & Yao, 2008), frequency assignment problem (FAP) (Salcedo-Sanz & Bousoño-Calzón, 2005a), broadcast scheduling problem (BSP) (Salcedo-Sanz, Bousoño-Calzón, & Figueiras-Vidal, 2003), FPGA segmented channel routing problems (Salcedo-Sanz, Xu, & Yao, 2005b), and others (Salcedo-Sanz & Bousoño-Calzón, 2005b; Salcedo-Sanz, Portilla-Figueras, García-Vázquez, & Jiménez-Fernández, 2006).

Some new metaheuristics have been developed during the last decade. This suggests the exploration of the potentials for the TEAP using the new metaheuristics. This paper first introduces a novel discrete particle swarm optimization algorithm (PSO) based on estimation of distribution (EDA), named DPSO-EDA. EDAs sample new solutions from a probability model which characterizes the distribution of promising solutions in the search space at each generation. The DPSO-EDA incorporates the global statistical information collected from personal best solutions of all particles into the PSO and therefore each particle has comprehensive learning and search ability. Then the DPSO-EDA is applied to the TEAP. In the DPSO-EDA for the TEAP, a modified constraint handling method based on HNN is also introduced to fit nicely into the framework of the PSO and thus utilize the merit of the PSO. The DPSO-EDA adopts the asynchronous updating scheme. Further, the DPSO-EDA is applied to a problem directly related to the TEAP, the task assignment problem (TAAP), in order to show that the DPSO-EDA can be generalized to other related COPs. Simulated results show that the DPSO-EDA outperforms the existing algorithms for the TEAP and TAAP.

The organization of this paper is as follows. Section 2 presents a formulation of the TEAP. In Section 3, the DPSO-EDA is introduced. In Section 4, the DPSO-EDA is applied to the TEAP, and the comparison of simulation results with the existing algorithms is given in Section 5. In Section 6, the DPSO-EDA is applied to the TAAP. In Section 7, the computational cost of the DPSO-EDA is discussed, and some insights for the problems studied are given. Finally, Section 8 concludes the paper.

2. Problem formulation

Given a set of terminals $T = \{T_1, \ldots, T_N\}$ with weights $W = \{w_1, \ldots, w_N\}$, and concentrators $C = \{C_1, \ldots, C_M\}$ with capacities $P = \{p_1, \ldots, p_M\}$, where w_i is the weight, or capacity requirement of terminal T_i. The weights and capacities are positive integers and $w_i < \min\{p_1, \ldots, p_M\}$ for $i = 1, \ldots, N$. The N terminals and M concentrators are placed on the Euclidean grid, i.e., T_i has coordinates (T_{i1}, T_{i2}) and C_j is located at (C_{j1}, C_{j2}). Let X be a binary matrix such that, for every element on it, $x_{ij} = 1$ if terminal i has been assigned to concentrator j, and $x_{ij} = 0$ otherwise. The objective of the TEAP is to find X which minimizes (Abuali et al., 1994; Brudaru, 2003; Khuri & Chiu, 1997; Salcedo-Sanz & Yao, 2004) the following objective function:

$$f(X) = \sum_{j=1}^{M} \sum_{i=1}^{N} cost_{ij} x_{ij}, \tag{1}$$

subject to

$$\sum_{j=1}^{M} x_{ij} = 1, \tag{2}$$

and

$$\sum_{i=1}^{N} w_i x_{ij} \leqslant p_j, \tag{3}$$

where $f(X)$ is the cost of all of the links in the network, and $cost_{ij}$ is the cost of assigning terminal i to concentrator j. Note that the first constraint, from (2), ensures that each terminal must be associated with one and only one concentrator, and the second constraint, from (3), implies that the capacity constraint on each concentrator cannot be violated.

The cost function $cost_{ij}$ is defined as (Salcedo-Sanz & Yao, 2004):

$$cost_{ij} = A \cdot bal_{ij} + B \cdot dist_{ij} x_{ij}, \tag{4}$$

where distance term $dist_{ij}$ is the matrix of the Euclidean distances between a terminal i and a concentrator j, and balance term bal_{ij} is defined as follows:

$$bal_{ij} = \begin{cases} 10 & \text{if } \sum_{i=1}^{N} x_{ij} = round\left(\frac{N}{M}\right) + 1 \\ 20 \cdot \left| \sum_{i=1}^{N} x_{ij} - \left(round\left(\frac{N}{M}\right) + 1\right) \right| & \text{otherwise.} \end{cases} \tag{5}$$

In the cost function Eq. (4), the balance term (5) encourages solutions with a balanced assignment of terminals into concentrators, and the distance term encourages Euclidean distances between terminals and concentrators must be as small as possible. Parameters A and B ($A + B = 1$) are used to control the importance of each term in the cost function. The cost function Eq. (4) includes some global information about assignment of terminals described by the balance term Eq. (5), and therefore cannot be known before a feasible solution is provided to the communication network. In this situation, the greedy algorithm is no longer a valid option, since it needs the cost function values in advance in order to generate a feasible solution for the TEAP. In this paper, parameters A and B in the cost function Eq. (4) are set to 0.9 and 0.1, respectively, which is the same as in Salcedo-Sanz and Yao (2004).

Tables 1 and 2 indicate an example of the TEAP with $N = 10$ terminal sites and $M = 3$ concentrator sites (Khuri & Chiu, 1997; Salcedo-Sanz & Yao, 2004). The weight requirements and the coordinates based on a 100×100 Euclidean grid for each terminal site are specified in Table 1. The coordinates for the concentrator sites and their capacities are listed in Table 2. The optimal assignments of the problem described by Tables 1 and 2 are shown in Fig. 1, where squares denote the concentrators and circles denote the terminals. Note that Fig. 1a is the solution without considering the balance term; Fig. 1b is the solution with considering both the balance and distant terms.

The TEAP is very similar to some COPs, for example, bin packing problem (BPP), switches assignment problem (CTAP), the task assignment problem (TAAP). Bins in the BPP can be seen

Table 1
Terminal capacity requirements (weights) and terminal coordinates for the example problem.

Terminal #	Weight	Coordinates
1	5	(54, 28)
2	4	(28, 75)
3	4	(84, 44)
4	2	(67, 17)
5	3	(90, 41)
6	1	(68, 67)
7	3	(24, 79)
8	4	(38, 59)
9	5	(27, 86)
10	4	(07, 76)