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Discrete Optimization

MEALS: A multiobjective evolutionary algorithm with local search for solving the bi-objective ring star problem☆

Herminia I. Calvete[a,*], Carmen Galé[b], José A. Iranzo[a]

[a] Departamento de Métodos Estadísticos, IUMA, Universidad de Zaragoza, Pedro Cerbuna 12, Zaragoza 50009, Spain
[b] Departamento de Métodos Estadísticos, IUMA, Universidad de Zaragoza, María de Luna 3, Zaragoza 50018, Spain

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ABSTRACT

In this paper we develop a hybrid metaheuristic for approaching the Pareto front of the bi-objective ring star problem. This problem consists of finding a simple cycle (ring) through a subset of nodes of a network. The aim is to minimize both the cost of connecting the nodes in the ring and the cost of allocating the nodes not in the ring to nodes in the ring. The algorithm preserves the general characteristics of a multiobjective evolutionary algorithm and embeds a local search procedure which deals with multiple objectives. The encoding scheme utilized leads to solving a Traveling Salesman Problem in order to compute the ring associated with the chromosome. This allows the algorithm to implicitly discard feasible solutions which are not efficient. The algorithm also includes an ad-hoc initial population construction which contributes to diversification. Extensive computational experiments using benchmark problems show the performance of the algorithm and reveal the noteworthy contribution of the local search procedure.

1. Introduction

The ring star problem consists of locating a simple cycle, the ring structure, through a subset of nodes of a network, while the nodes not in the ring are directly connected to nodes in the ring. This is the star structure (see Fig. 1). There are two different costs involved, the ring cost given by the sum of the costs of its edges, and the allocation cost given by the sum of the costs of the links connecting the nodes not in the ring to nodes in the ring. This problem has been dealt with in different ways depending on the manner in which the ring cost and the allocation cost are handled.

The single objective ring star problem (RSP), also known as the first version of the Median Cycle Problem, minimizes an objective function obtained by adding the ring cost and the allocation cost. It arises in telecommunications network design problems where concentrators are installed in the nodes of the ring whereas the remaining nodes are connected to their closest concentrator. It also models logistic problems where the retailers in the ring are served in a single-vehicle route and are used as small depots from which the remaining retailers are supplied. The RSP has received the most attention in the literature. Pérez, Moreno-Vega, and Martín (2003) use the model to test a heuristic that combines variable neighborhood search and tabu search. Labbé, Laporte, Martín, and González (2004) formulate the problem as a mixed integer linear program. They present a polyhedral analysis of the problem and propose a branch-and-cut algorithm. Renaud, Boctor, and Laporte (2004) develop a multistart greedy add heuristic and a random keys evolutionary algorithm. Dias, de Sousa Filho, Macambira, Cabral, and Fampa (2006) propose a heuristic that combines variable neighborhood search and a greedy randomized adaptive search procedure. Branch-and-cut algorithms have also been introduced by Kedad-Sidhoum and Nguyen (2010), who propose a new formulation of the RSP based on chains, and by Simonetti, Frota, and de Souza (2011), who reformulate the problem as a minimum Steiner arborescence problem. Calvete, Galé, and Iranzo (2013) propose an evolutionary algorithm based on a formulation of the RSP as a bilevel programming problem with one leader and two independent followers. This approach leads to a new form of chromosome encoding which provides very accurate solutions to the set of benchmark problems within short computing times.

The bi-objective ring star problem (B-RSP) has been proposed in a series of papers by Liefooghe, Jourdan, Basseur, Talbi, and Burke (2008a), Liefooghe, Jourdan, Jozefowiez, and Talbi (2008b), Liefooghe, Jourdan, and Talbi (2010). They recognized the importance of handling the ring star problem as a bi-objective problem aiming to minimize both the ring cost and the allocation cost. Liefooghe and

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* Corresponding author. Tel.: +34 976 762210.
E-mail addresses: herminia@unizar.es (H.I. Calvete), cgale@unizar.es (C. Galé), joseani@unizar.es (J.A. Iranzo).

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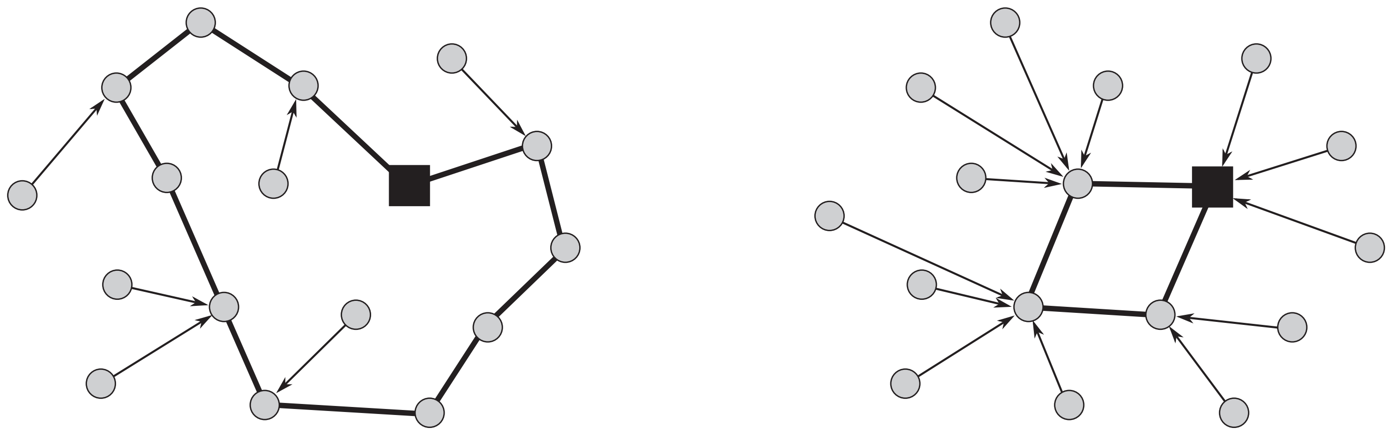

Fig. 1. Two feasible solutions of the RSP.

colleagues argue that both objectives are comparable only if they are proportional one to another, which is rarely the case in practice. Moreover, the RSP and the variant in which the allocation cost is treated as a constraint (Pérez et al., 2003) can be considered as two formulations which transform the bi-objective problem into a single objective problem by using scalar approaches (Ehrgott, 2005). In their papers, Liefooghe and colleagues propose different approaches to identify a good approximation of the set of Pareto optimal solutions or the Pareto front. In Liefooghe et al. (2008a), the authors use state-of-the-art instances involving up to 299 nodes to compare three metaheuristics: IBMOLS, which is a population-based local search method, and two evolutionary algorithms based on IBEA and NSGA-II, which are well-known multiobjective methods. The Nondominated Sorting Genetic Algorithm II, NSGA-II, was proposed by Deb, Agrawal, Pratap, and Meyarivan (2002). The best individuals are selected in accordance with the nondomination rank and, in the case of a tie, the crowding distance is applied. This distance gives an estimate of the density of solutions surrounding a particular solution in the population. The Indicator-Based Evolutionary Algorithm, IBEA, was introduced by Zitzler and Kunzli (2004) and is based on a pairwise comparison of solutions by using the binary additive ϵ-indicator. In Liefooghe et al. (2008b), they propose a hybrid method which incorporates a specialized Traveling Salesman Problem (TSP) heuristic into an elitist multiobjective evolutionary algorithm. The TSP heuristic is used both to construct the initial population and to improve the ring cost of each population member at every generation of the evolutionary algorithm. They analyze the hybrid algorithm in benchmark instances up to 264 nodes obtaining that the method outperforms previously proposed algorithms. Finally, in Liefooghe et al. (2010) they extend the comparisons in Liefooghe et al. (2008a) by including what they call a Simple Elitist Evolutionary Algorithm (SEEA) and two variants of a cooperative approach which combines SEEA and IBMOLS. The SEEA method handles an archive of potentially efficient solutions which is updated at each generation with solutions obtained by applying variation operators to randomly chosen archive members. The authors conclude that the cooperative approaches improve the results in a large number of benchmark instances, particularly in large-size ones (up to 1002 nodes).

In this paper we address the B-RSP and present a hybrid metaheuristic to approach the Pareto front based on evolutionary algorithms. The key points of the proposed algorithm are the encoding scheme, the embedded local search procedure and the initial population construction. In the evolutionary algorithms proposed in the literature for solving the B-RSP, the encoding provides a feasible solution of the B-RSP directly, i.e. the genes identify which nodes are in the ring and the order in which they are visited. Then, the nodes not in the ring are allocated to the closest node in the ring. Note that two chromosomes with the same nodes in the ring have the same allocation cost, but can have very different ring costs, depending on how the ring nodes are visited. Based on this fact, in the algorithm proposed the chromosome does not provide us with the ring, but the nodes in the ring. This fact gives us the opportunity of implicitly discarding feasible solutions which for sure are not efficient. This is done when associating a feasible solution of the B-RSP with the chromosome in order to evaluate its quality. For this purpose, optimization techniques as well as local search procedures are embedded in the evolutionary algorithm. The optimization techniques are applied when solving the TSP. The local search procedures concern the implementation of operators which allow us to asses the advisability of changing the role of nodes in the feasible solution associated with the chromosome. Several variants of the method are proposed based on NSGA-II, IBEA and SEEA and their performance compared in benchmark instances. The paper is organized as follows. Section 2 formulates the B-RSP. Section 3 describes the characteristics of the hybrid metaheuristic developed to solve the problem. Section 4 presents a computational study to analyze the performance of variants of the algorithm on benchmark instances dealt with in the literature. Besides, the results provided by the algorithm are compared with the current best Pareto front approximation found in the literature. Finally, Section 5 concludes the paper with some final remarks and main lines for future work.

2. Formulation of the bi-objective ring star problem

Let $G = (V, E \cup A)$ be a mixed graph, where $V = \{0, 1, \ldots, n\}$ is the set of nodes, $E = \{[i, j] : i, j \in V\}$ is the set of edges and $A = \{(i, j) : i, j \in V\}$ is the set of arcs. Node 0 represents the depot. Edges in E refer to undirected links which are used in the ring structure. We assume that there is a nonnegative ring cost c_{ij} associated with each edge $[i, j]$. Arcs in A refer to directed links used in the star structure. We assume that there is a nonnegative allocation cost d_{ij} associated with each arc (i, j), referring to the cost of node i being allocated (connected) to node j.

A ring R is a simple cycle visiting a subset of nodes $V_R \subseteq V$ including the depot. The nodes in the ring will be called ring nodes. The remaining nodes are the non-ring nodes. For each $i \notin V_R$, let j denote the index of the ring node to which node i is allocated. A feasible solution of the B-RSP consists of a ring R and a set of index pairs $A_R = \{(i, j) : i \notin V_R, j \in V_R\}$. Let $\mathcal{X}$ be the set of feasible solutions in the decision space.

The ring cost of the solution $X = (R, A_R) \in \mathcal{X}$ is defined as:

$$Z_1(X) = \sum_{[i,j] \in R} c_{ij} \quad (1)$$