Heuristic Methods for Solving Euclidean Non-uniform Steiner Tree Problems

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Abstract. In this paper, we consider a variation of the Euclidean Steiner Tree Problem in which the space underlying the set of nodes has a specified non-uniform cost structure. This problem is significant in many practical situations, such as laying cable networks, where the cost for laying a cable can be highly dependent on the location and the nature of the area through which it is to be laid. We empirically test the performance of a genetic-algorithm-based procedure on a variety of test cases of this problem. We also consider the impact on solutions of charging an additional fee per Steiner node. This can be important when Steiner nodes represent junctions that require the installation of additional hardware. In addition, we present novel ways of visualizing the performance and robustness of the genetic algorithm.

The minimal spanning tree (MST) problem deals with connecting a given set of nodes in a graph in a minimal cost way. In a Steiner tree, we are allowed to use additional nodes if doing so reduces the total cost. Steiner tree problems find applications in various areas such as the design of communication networks, printed circuits, and the routing of transmission lines. There are many versions of the Steiner tree problem. The most common is the Euclidean Steiner tree problem, in which a given set of nodes is connected in Euclidean space. Another version involves rectilinear configurations, in which the arcs have to be either North-South or East-West. Modified versions of this include the hexagonal and octagonal grids [1,2].

We consider the problem of finding near-optimal, non-directed Steiner trees on a non-uniform grid. Each location in the grid has an associated cost and a given set of nodes has to be connected in the form of a spanning tree. This kind of problem is of relevance to many practical situations, such as laying cable networks. There may be regions where laying cable is prohibitively expensive, such as a prime location in a metropolitan area, or other regions where it is cheaper. So the objective is to find a set of additional nodes in the grid that can be used to connect all the given nodes at a minimum cost. The performance of our genetic algorithm (GA) is illustrated in Fig. 1

Our GA uses a fairly simple encoding (lists of Steiner node coordinates) and simple operators: spatial crossover, queen bee selection, and random mutation. It

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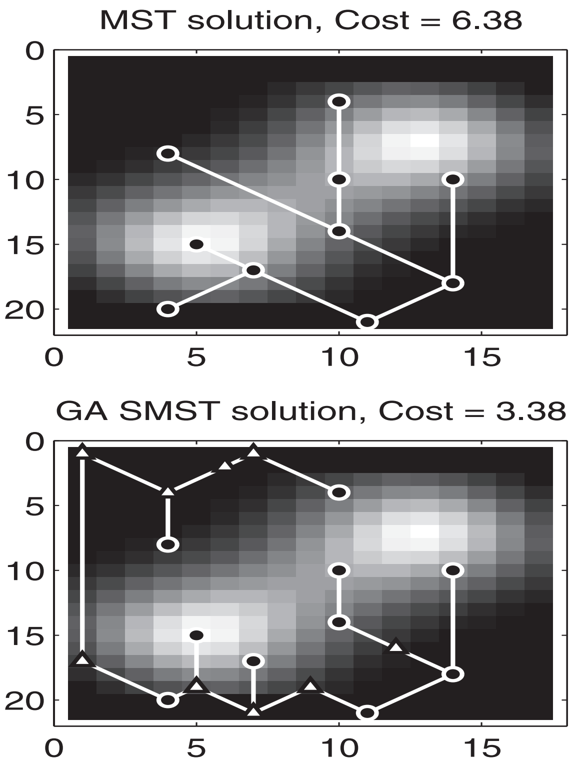

Fig. 1. MST (top) and Steiner MST (SMST) (bottom) for a sample problem. Black circles indicate terminal nodes. White triangles indicate Steiner nodes. The lighter the shading, the more costly the cell.

finds solutions significantly better than those of the minimal spanning tree and comparable to those of an enumerative algorithm we designed called progressive addition (PA). We point out, however, that the GA scales better with increasing problem size than the PA. The solution trees are able to correctly avoid high cost areas while finding low cost regions.

References

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