Sequential and parallel ACO methods for solving the Generalized Steiner Problem

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The Generalized Steiner Problem (GSP) is an extension of the Steiner Tree problem in graphs, which is very useful to model the design of communication networks that are resilient to component failures. A GSP instance consists in a set of nodes, a set of feasible links (with their corresponding nodes), a set of distinguished nodes (called terminals) and connectivity requirements between pairs of terminals. The objective is to find a subset of links of minimum cost, so that between every pair of terminals there are a number of link-disjoint paths greater or equal to the connectivity requirement for this pair. This generalizes the Steiner Tree Problem (STP), where the connectivity requirement is one for each pair of terminals. The GSP incorporates additional connectivity requirements that real-life situations demand, leading to topologies with path redundancy which ensures tolerance to component failures. As STP is a NP-complete problem, GSP belongs to the NP-hard class, and there are no known efficient algorithms for solving it exactly.

Ant Colony Optimization (ACO) [Dor08] is the name of a family of metaheuristics methods, which have been used to approximately solve many difficult combinatorial optimization problems, and in particular many problems that can be modelled in terms of graphs (like the Travelling Salesman Problem). The methods in the ACO family share the following characteristics: the search is conducted by a number of “ants” (or agents), each building a solution by adding components, chosen probabilistically on the basis of heuristic information about the solution being constructed, and of shared information about the solutions built by preceding ants. The shared information is called “pheromone” by analogy with the substance used by real ants to mark the paths they follow when exploring for food or going back to the nest. These pheromone trails are continuously updated by deposition (to reinforce components of the best solutions found) and evaporation (to avoid convergence to locally optimal solutions), following mechanisms which vary with the different flavors of the method.

In this work, we present the details of both sequential and parallel ACO methods for solving the GSP, and we compare the results with the ones obtained by other heuristic methods in the literature. For the sequential ACO we explore different alternatives to solve the problems posed by the special characteristics of the GSP problem. In particular, a main difficulty is that a natural way to build a solution is to iteratively satisfy the connection requirements for each pair of terminals, but that in doing so it is important to take into account the information about the links already added in the partial solution being constructed. This can be done, either by adding one edge at a time or a whole path to the partial solution; these possibilities are explored, and their respective performances compared over a set of test problems. We also discuss how to parallelize an ACO method for solving the GSP; in particular, while in the literature ACO models based on multiple colonies (distributed model), and based on master-slave paradigms, have been explored for solving many different problems, there are no examples of cellular parallelism being used [DS04,JMM05]. We develop a cellular ACO algorithm, and we study its performance on the set of test problems mentioned, comparing its performance versus the sequential version as well as other parallel methods used in the literature [Nes05,NCA07] for solving the GSP.

References

[Dor08] M. Dorigo: *The Ant Colony Optimization Home Page*. http://iridia.ulb.ac.be/~mdorigo/ACO/ACO.html (last access November 2008).

[DS04] M. Dorigo and T. Stützle: *Ant Colony Optimization*. MIT Press, Cambridge, MA, USA, 2004.

[Nes05] S. Nesmachnow: *Evaluating simple metaheuristics for the Generalized Steiner Problem*. Journal of Computer Science & Technology, 5(4), 2005.

[NCA07] S. Nesmachnow, H. Cancela and E. Alba: *Evolutionary algorithms applied to reliable communication network design*. Engineering Optimization, 39:831–855(25), 2007.

[JMM05] S. Janson, D. Merkle and M. Middendorf: *Parallel Ant Colony Algorithms*. In E. Alba (editor): *Parallel Metaheuristics*, 171-201. Wiley, 2005.