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Chapter VIII

Ant Colony Algorithms for Steiner Trees: An Application to Routing in Sensor Networks

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ABSTRACT

This chapter introduces ant colony optimization as a method for computing minimum Steiner trees in graphs. Tree computation is achieved when multiple ants, starting out from different nodes in the graph, move towards one another and ultimately merge into a single entity. A distributed version of the proposed algorithm is also described, which is applied to the specific problem of data-centric routing in wireless sensor networks. This research illustrates how tree based graph theoretic computations can be accomplished by means of purely local ant interaction. The authors hope that this work will demonstrate how innovative ways to carry out ant interactions can be used to design effective ant colony algorithms for complex optimization problems.

INTRODUCTION

Ants live in colonies and have evolved to exhibit very complex patterns of social interaction. Such interactions are clearly seen in the foraging strategy of ants. Despite the extremely simplistic behavior of individual ants, they can communicate with one another through secretions called pheromones, and this cooperative activity of the ants in a nest gives rise to an emergent phenomenon known as *swarm intelligence* (Bonabeau et al., 1999). **A**nt **C**olony **O**ptimization (ACO) algorithms are a class of algorithms that mimic the cooperative behavior of real ant behavior to achieve complex computations.

Ant colony optimization was originally introduced as a meta-heuristic for the well-known traveling salesman problem (TSP), which is a path based optimization problem. This problem is proven to be NP-complete, which is a subset of a class of difficult optimization problems that are not solvable in polynomial time (unless P=NP). Since an exponential time algorithm is infeasible for larger scale problems in class NP, much research has focused on applying stochastic optimization algorithms such as genetic algorithms and simulated annealing to obtain good (but not necessarily globally optimal) solutions. The ant colony approach was subsequently shown to be a very effective technique for approaching a variety of other combinatorial optimization problems in class NP.

An intrinsic advantage of ACO is the relative ease of implementation in a decentralized environment. These algorithms have therefore been applied to distributed network based problems that involve optimal path computations, such as routing, load balancing, and multicasting in computer networks (Bonabeau et al., 1998; Das et al., 2002; Navarro-Varela & Sinclair, 1999; Schoonderwoerd, 1997). In the rest of this chapter, we will use the terms *distributed algorithm*, *online algorithm* and *decentralized algorithm* interchangeably to imply algorithms that do not require any form of global computation. Algorithms that do require it will be referred to as *centralized*, or *offline algorithms*.

This chapter explores the application of ant colony algorithms to the data-centric routing in sensor networks. This problem involves establishing paths from multiple sources in a sensor network to one or more destinations, where data are aggregated at intermediate stages in the paths for optimal dissemination. When only a single destination is involved, the optimal path amounts to a minimum Steiner tree in the sensor network. The minimum Steiner tree problem is a classic NP-complete problem that has numerous applications. It is a problem of extracting a sub-tree from a given graph with certain properties. A formal description of the problem is postponed until later.

The second section introduces the ant colony optimization approach. The Steiner tree problem is introduced here and its applicability to sensor networks taken up in detail. The third section provides the details of the algorithm. It first describes an offline algorithm that can be used to compute Steiner trees of any graph. A preliminary set of simulations carried out to demonstrate the algorithm's effectiveness is included. This is followed in the fourth section by a detailed description of the online algorithm to establish optimal paths for data-centric routing. Simulation results for three separate randomly generated networks are analyzed. In the fifth section, further extensions and applications of the present algorithm are suggested. Conclusions are provided in the last section.

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