Network Formation using Ant Colony Optimization - A Comparative Analysis

Steven C. Oimoen, Gilbert L. Peterson, and Kenneth M. Hopkinson

Air Force Institute of Technology, Wright Patterson AFB, OH, USA
steven.oimoen@afit.edu

A significant area of research in the field of hybrid communications is the Network Design Problem (NDP) [1]. The NDP is an NP complete problem [1] that focuses on identifying the optimal network topology for transmitting commodities between nodes, under constraints such as bandwidth, limited compatible directed channels, and link and commodity costs. The NDP focuses on designing a flexible network while trying to achieve optimal flow or routing. If a link (or arc) is used, then an associated fixed cost of the edge is incurred. In addition, there is a cost for using the arc depending on the flow. The solution is a network topology connecting all of the nodes that minimizes the total system cost.

The specific topology control problem in this work is the Multi-Commodity Capacitated Network Design Problem (MCNDP) [1] [2]. The MCNDP adds capacity limits for each arc to the uncapacitated NDP. A formal description of the MCNDP can be found in [1] [2]. This paper presents a novel approach to solving this problem using the Ant Colony System (ACS) to construct the network topology and several heuristics for ACS to utilize to reduce computation time.

1 MCNDP Learning Using Ant Colony System (ACS)

Ant Colony Optimization (ACO) is a meta-heuristic technique that has been shown to be quite successful in solving many combinatorial optimization problems [3]. ACO mimics the foraging behavior of real ants, where ants deposit pheromone and over time identify the shortest paths from their nest to food.

The MCNDP solver uses ACS [4] to learn a graph similar to ACO learning of Bayesian Networks [5]. A network object contains lists of nodes and commodities. In addition, each node object contains a list of regular edges and potential edges. After all data is initialized, the list of edges used in the topology is empty. Each ant in building its solution uses the ACS selection strategy to select an edge from the list of all potential edges. The selected potential edges form the network topology. Ants iteratively select edges based on the pheromone on each edge, and the heuristic evaluation of the edge. Once all available potential edges have been explored, the ant stops searching.

The ACS algorithm was applied using two approaches, these are ACS Standard for the MCNDP (ACSS-MCNDP) and ACS Estimated for the MCNDP (ACSE-MCNDP). ACSS-MCNDP constructs a network topology and performs a full routing of commodities for each ant solution to evaluate the objective score of the proposed network. ACSS-MCNDP produces near optimal networks, at the cost of high run times due to performing routing. ACSE-MCNDP uses heuristics that replace the routing process in constructing the network. Routing only occurs at the end of the algorithm to evaluate the final network. Four heuristics were tested; a) fixed edge cost, b) sum of the fixed and variable edge costs, c) weighted sum of the fixed edge cost and capacity, and d) a weighted sum of the fixed edge cost and the edge value. The fixed edge cost is the cost associated with using a particular edge in the network (regardless of commodities using it). The variable edge cost is an average commodity cost associated with using an edge. The edge capacity is equivalent to its bandwidth and the edge value is the value of the commodity that would flow from that edge's source to its destination. Several combinations of the weighted cost heuristics were tested.

Both ACS algorithms found solutions with no dropped commodities for both 10-node and 15-node networks. For our ACSE approach we experienced mixed results. However, we did find that the 80 percent fixed cost and 20 percent edge capacity heuristic, although not consistent across all routing algorithms, closely approximated the ACSS solutions. Table 1 shows a comparative assessment of a Maximum Flow solution (1), our ACSS-MCNDP solution and our ACSE-MCNDP solution. The numbers in bold identify the best overall cost solutions.

Table 1. Algorithm Comparative Analysis Summary.

Number of Nodes	Max Flow	ACSS-MCNDP	ACSE-MCNDP
10	1083.39 (+/- 60.48)	**870.06** (+/- 8.11)	920.61 (+/-3.63)
15	5575.94 (+/- 6628.40)	**2066.75** (+/- 22.90)	2377.14 (+/- 16.38)

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