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Memetic algorithm for minimum energy broadcast problem in wireless ad hoc networks

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ABSTRACT

The problem of finding a broadcast tree with minimum power consumption has received much attention due to two reasons. They are (a) the limited bandwidth of wireless networks and (b) the nodes are battery operated. This work proposes heuristic memetic algorithm to find minimum energy broadcast tree in wireless ad hoc networks. The simulation results on numerous problem instances confirm that the proposed algorithm significantly outperforms several heuristic algorithms in terms of solution quality. The experimental evaluation of the memetic algorithm shows that it generally improves over other recently proposed algorithms. By solving well-known benchmark problem instances with 20 and 50 nodes, it also demonstrates the effectiveness of memetic algorithm in terms of computation time.

1. Introduction

Ad hoc network is a self-organizing multi-hop wireless network, which relies neither on fixed infrastructure nor on predetermined connectivity. Wireless ad hoc networks are used commonly in the military and emergency situations because of their quick, easy setup and robust properties.

In a wireless ad hoc network, each wireless node has an omnidirectional antenna and other nodes within the transmission range of the node will receive the message. A wireless node can receive the signal from another node if it is within the transmission range of the sender else communication is through multi-hop wireless links by using intermediate nodes to relay the message. If transmission range of a wireless node is high, then it can communicate directly with more neighbors, but it takes more energy for power consumption. The total transmission power can be reduced by using intermediate nodes. One major constraint of ad hoc networks is the limited energy, since the nodes are battery operated. Frequent recharging or replacement of batteries is not possible in such networks. This makes energy efficiency an important metric in ad hoc networks.

In this paper, we present heuristic memetic algorithm for the minimum energy broadcasting (MEB) problem in wireless ad hoc networks. Broadcasting in wireless networks is different from broadcasting in wired networks because every node in wireless networks is equipped with omnidirectional antennas and several nodes are covered in a single transmission. Each node within the transmission range of the sender in wireless network can receive the broadcast without any additional cost to the sender. This feature is known as wireless multicast advantage (WMA). One way of broadcasting in wireless networks is by adjusting the transmission power of the source node such that its transmission can reach the farthest node from it, which will cover all other remaining nodes because of the WMA. A broadcast scheme is energy efficient, so the main objective is to construct a minimum-energy broadcast tree rooted at the source node with minimum energy consumption.

Wieselthier et al. [6,7] proposed algorithms to find energy efficient broadcast and multicast trees in wireless networks. They proposed broadcast incremental power (BIP) algorithm and adapted it for multicast operation by introducing the multicast incremental power algorithm, for some of the fundamental issues associated with energy efficient broadcasting and multicasting in wireless networks. The problem they addressed involves the designation of which nodes are to transmit and at what power levels. These algorithms exploit the broadcast nature of the wireless communication environment and address the need for energy efficient operation.

Das et al. [2] have proposed the r-shrink procedure, which is a simple local search heuristic to improve the broadcast trees in wireless networks. After generating initial broadcast trees, r-shrink procedure is carried out to minimize the power consumption. Given an initial broadcast tree, the transmission radii of each transmitting non-leaf node in the tree is shrunk sequentially and the algorithm finds a better position to accommodate the nodes, which have been disconnected from the tree as a result of the shrinkage operation. This process is repeated until no further improvement is possible. If the value of r is 1, then only one node is removed. Similarly if r is 2, then two nodes are removed.

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A hybrid approach combining genetic algorithm operations cycle crossover and swap mutation, with local search heuristic for this problem is proposed by Singh and Bhukya [1]. In the local search operation they have implemented two variations of r-shrink procedure. The genetic algorithm with 1-shrink procedure is given as GA-1. The combination of genetic algorithm with 1-shrink and 2-shrink procedure is given as GA-2. Compared to GA-1, GA-2 identifies the solution the maximum number of times out of 30 runs.

An integer programming model and heuristic algorithm was proposed by Yuan et al. [4]. This heuristic algorithm does not perform exhaustive search, they rather execute a predefined number of search moves by simply adopting a maximum time limit.

Wu et al. [14] proposed permutation encoded genetic algorithm to find a minimum energy broadcast tree. They formulated the problem mathematically to a constrained optimization problem using graph representation and then genetic algorithm based approach is developed to obtain the broadcast tree.

Kang and Poovendran [5] proposed an iterated local optimization (ILO) technique at the cost of additional computational complexity to solve the minimum energy broadcast problem over wireless ad hoc networks. Montemanni et al. [10] have presented a new heuristic algorithm based on the simulated annealing paradigm for solving the minimum power broadcast problem in wireless networks.

Al-Shihabi et al. [11] studied a new hybrid heuristic algorithm to solve MEB problem by combining nested partitioning with local search and linear programming. The major part of this work is the nested partitioning, where a generic partitioning scheme was implemented.

A new evolutionary local search for the minimum energy broadcast problem by Wolf et al. [13] used a modified r-shrink procedure as local search and random increase in transmission power of some nodes as mutation operator. The algorithm has shown to find optimal or near-optimal solutions in reduced computation time for the considered test instances. A detailed survey on the MEB problem for wireless ad hoc networks with omni-directional and directional antennas can be found in [12].

MEB problem for an antenna model that is realistic for sensor networks is proposed in [16]. The classical MEB problem is formulated for antennas where the transmission power can be adjusted to any desired real value between 0 and the maximum transmission power. In this paper, an antenna model with transmission power chosen from a finite set of discrete values is taken for consideration.

A distributed ant colony optimization algorithm for solving the MEB problem in sensor networks with realistic antennas is proposed in [17] based on the classical BIP heuristic. A new localized criterion for extending partial solutions during solution construction is introduced in order to make use of the mechanism of BIP.

Enan et al. [18] proposed an evolutionary based clustering protocol for the routing problem in wireless sensor networks, where all the transmissions are based on single-hop communication. They formulated a new objective function that can have a significant impact on the overall performance of the wireless sensor networks. It is modified to meet the contradictory goals, maximal stability period until first node dies, maximal network longevity until last node dies, at the same time minimizing energy consumption throughout the network lifetime.

Sengupta et al. in [19] proposed an energy efficient sensor manager for tracking of dynamic objects through differentiated coverage. They developed a technique for tracking of moving objects in an area that changes their position with time through differentiated coverage. The sensor management process consists of tracking and energy efficient optimization. They mainly perform the operation of sensor manager through optimization by evolutionary algorithm. The process is to obtain an energy efficient tracking of the moving group so as to extend the net lifetime of the sensor network.

In [20] they have considered the deployment of sensor nodes in a given area with the following objectives, (i) minimizing the number of sensor nodes to reduce cost of deployment, (ii) minimizing the net energy consumed by all the nodes, (iii) maximizing the area covered by the nodes, (iv) maximizing the lifetime of the network. They formulated the sensor node deployment task as a constrained multi-objective optimization problem. They developed multi-objective evolutionary algorithm that uses a new fuzzy dominance based decomposition approach.

For the minimum energy broadcast problem, the approaches analyzed above suffered from the trade-off between solution quality and running time. Computation time is an important factor to validate an algorithm. Therefore, an algorithm is still needed for broadcast scheduling problem that improves the solution quality in reduced computation time even for a large network. The objective of this work is to find optimal or near optimal broadcast tree in an acceptable execution time.

Genetic algorithms (GAs) work successfully to solve many search and optimization problems. However, they may drop into local optimal solutions or they may find the optimal solution by low convergence speed and GA blindly wanders over the search space. To overcome these problems, we used Memetic algorithm (MA) to enhance the GA. MA proposed in this study reduces the processing time nearly 50% when compared very recent algorithm in [1]. A series of simulations is conducted to evaluate the performance of the proposed MA in terms of solution quality and running time, and to verify its superiority over other recent heuristic algorithms.

MA establishes local search techniques at specific parts of the GA optimization process, with an aim to increase its performance. It is a blooming dialect, mainly due to their success in solving many hard optimization problems. A particular feature of MA is greatly responsible for this unlike traditional evolutionary computation (EC) methods. MA is intrinsically concerned with exploiting all available knowledge about the problem under study this is something neglected in evolutionary algorithms (EA) for a long time.

In addition to Darwinism, MA adopts the Lamarckian theory that offspring can inherit the knowledge or characteristics that their parents acquire during their lifetime. The MA implements this idea by integrating a local enhancement, such as local search and repair operator, into the canonical EA, and making the enhancement inheritable, this integration significantly improves the exploitation ability of EA. In genetic algorithm, the mutation creates new genes for the population and the crossover operator orients seeking the best solution from the genes in the population. In MA, this orientation is achieved by local search. Local search reduces the search space and reaches to the high quality solution faster. MA actively aims on improving solution and explicitly concerned with exploiting all available knowledge about the problem.

The rest of this paper is organized as follows: Section 2 gives a formal definition of the problem, along with the constraints. In Section 3, we describe the algorithm and its operators. The details of simulation results, computation time by MA with other competitive algorithms are discussed in Section 4. Finally, conclusions are drawn in Section 5.

2. Minimum energy broadcast problem

Broadcasting is a method to allow all nodes to share the data efficiently with all the other nodes in the wireless networks.