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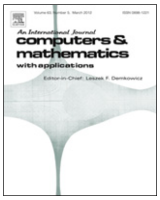

Distributed ant colony optimization for minimum energy broadcasting in sensor networks with realistic antennas[☆]

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ABSTRACT

One of the important tasks in wireless sensor networks is broadcasting, which arises when a sender node has to communicate information to all the other nodes of the network. In order to save energy, which is often a limited resource, broadcasting has to be done efficiently from an energy perspective. Energy efficiency can hereby be achieved by adjusting the transmission power levels of the sensor nodes' antennas. This classical problem is known as the minimum energy broadcast (MEB) problem. In this work we deal with a generalization of this problem which is known as the minimum energy broadcast problem in sensor networks with realistic antennas (MEBRA). The difference to the classical MEB problem is to be found in a more realistic antenna model. In this work we propose a distributed ant colony optimization algorithm for solving the MEBRA problem. The experimental evaluation of the proposed algorithm shows that it generally improves over the centralized version of a classical heuristic. Moreover, depending on the exact antenna model used, the results of the distributed ant colony optimization algorithm are very close to the results of the centralized algorithm version.

1. Introduction

In the 1980s a computer easily filled a whole room and communication between computers was possible by wired links. In the last 20 years many technological advances have pushed the development of new methodologies for networking. Nowadays, not only computers are able to communicate, but also small devices such as mobile phones may be linked by wireless communication networks. The introduction of wireless technology has caused wireless networks to be created on the fly (wireless ad hoc networks). As a result, networks form spontaneously as soon as devices are within the communication range of each other.

The above mentioned technological advances have also resulted in the development of a new type of wireless networks, called sensor networks [1]. Sensor nodes are rather small devices whose size ranges from approximately one to seven inches including the wireless radio. Sensor nodes owe their name due to the fact that they are equipped with various sensors which allow them to monitorize physical data such as humidity, light or acceleration. During recent years quite a few applications for sensor networks have been proposed. Examples include environmental monitoring, patient monitoring in health care, etc. Researchers are specially attracted by the ease of use and the numerous features of these networks, which come at a relatively low cost. From an algorithmic perspective, sensor networks are also a useful testbed for distributed algorithms.

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Their working is based on the exchange of local information between nodes in order to achieve a global goal. Cooperation between the sensor nodes is an important feature for the compensation of their shortcomings when solving complex tasks.

Ad hoc and sensor networks are sometimes implemented in regions without a reliable power supply. Therefore, nodes are usually equipped with batteries. In this scenario, energy becomes a scarce resource which must be carefully controlled. Energy-aware algorithms and protocols aim at extending network lifetime and performance by minimizing the energy consumption of all regular operations. In this paper we deal with one of these regular operations, namely *broadcasting*, which is the action of one sender node transmitting information (possibly in a multi-hop fashion) to all other nodes of the network. In this paper we deal with the *minimum energy broadcast problem* in sensor networks *with realistic antennas* (MEBRAs) which was introduced in [2]. This problem is a generalization of the classical minimum energy broadcast (MEB) problem from the literature [3]. In contrast to the assumption made in the MEB, real antennas are not able to transmit at any given transmission power, that is, any real value between 0 and the maximum one allowed by the hardware. Instead, real antennas usually have a set of fixed transmission power levels. For example, sensor node manufacturers such as Coalesenses GmbH (iSense) or Sun Microsystems (SunSPOTs) use antennas with six, respectively 200, transmission power levels (in addition to the state of turning the antennas off).

1.1. Related work

The classical MEB problem, especially in the case of considering omni-directional antennas, has been intensively tackled in the literature. A comprehensive survey can be found in [3]. The current state of the art among centralized approaches is the *ant colony optimization* (ACO) algorithm from [4,5]. This algorithm, which makes intensive use of the r-shrink local search procedure proposed in [6], compares very favorably in comparison to other approaches both in computation time consumption and in solution quality. In addition to the case of considering omni-directional antennas, the above-mentioned ACO algorithm was successfully applied to three other versions of the MEB problem: (1) the MEB problem considering directional antennas, enabling nodes to adjust the beam direction and the beam width of the transmission for saving energy and avoiding collisions; (2) the minimum energy multicast (MEM) problem, which considers the case of transmitting information only to a subset of the nodes in the network; and (3) the MEM problem with directional antennas, which considers both multicasting and directional antennas simultaneously. Other solution approaches based on local search include [7,8] and power-based methods such as [6]. Even more sophisticated metaheuristic approaches have been developed in [9–12].

Among the centralized deterministic heuristics for the MEB problem with omni-directional antennas, the *broadcast incremental power* (BIP) algorithm [13,14] is regarded as a classical benchmark algorithm. Other competitive heuristics include *multipoint relaying* (MPR) [15] and *dominant pruning* (DP) [16]. Concerning BIP, it is worth mentioning that the algorithm has also been adapted to work for multicasting [14] and for the MEB problem considering directional antennas [17]. The basic working of the BIP algorithm can be described as follows. It creates a broadcast in a step-by-step manner, starting with a partial solution which only includes the original sender node. At each step, the algorithm identifies the node that can be included into the current partial solution with the lowest increase in total transmission power required by the solution. Note, that including a node in a solution means that its position must be covered by the transmission area of another node which is already in the solution.

In contrast to centralized approaches, work concerning distributed approaches for tackling the MEB problem is quite rare. The best ones among these approaches are a distributed version of the BIP algorithm (known as DBIP) which was introduced by Wieselthier et al. in [18], and *fractional transmission scheme* (FTS) proposed by Vellambi et al. in [19]. Another work is the one by Chen et al. [20], which also considers broadcasting. However, the authors focus on a slightly different problem concerning the reduction of the broadcast time. Although the authors of [20] also give importance to the efficient use of power resources, they show that their algorithm consumes much more energy than DBIP.

1.2. Our contribution

In this paper we introduce a distributed ant colony optimization algorithm for solving the MEBRA problem. The working of this algorithm is based on the classical BIP heuristic. However, in order to be able to use the mechanism of BIP, we introduce a new localized criterion for extending partial solutions during solution construction. The obtained results show that the distributed ant colony optimization algorithm even outperforms the classical (centralized) BIP heuristic. This is in contrast to the distributed version of BIP (labeled DBIP), which performs significantly worse than BIP.

1.3. Organization of the paper

The rest of this paper is organized as follows. In Section 2 we formally describe the minimum energy broadcast problem in sensor networks with realistic antennas. In Section 3 we introduce the BIP algorithm as well as the new localized way of extending partial solutions. Furthermore, in Section 4 we introduce the new distributed ant colony optimization algorithm for the MEBRA problem, which is the main contribution of this research. Finally, in Section 5 we show the results obtained by our algorithm on different sets of benchmark instances, and in Section 6 we provide conclusions and deal with future work.