Duty – Cycle Aware Minimum Energy Multicasting with Mobile Sinks in Sensor Networks

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Abstract— In duty-cycled wireless sensor networks, the nodes switch between active and dormant states, and each node may determine its active/dormant schedule independently. This complicates the Minimum-Energy Multicasting (MEM) problem, which was primarily studied in always-active wireless ad hoc networks. In this paper we study the minimum energy multicasting for the case of one-to-many multicasting with support of mobile sinks to aid the multicasting process.

INTRODUCTION

WIRELESS sensor networks (WSNs) are decentralized systems without any preexisting infrastructures, and the sensor nodes are usually powered by batteries. As the limited battery lifetime imposes a severe constraint on the network performance, it is imperative to develop energy conservation mechanisms for WSNs. One common approach for energy conservation in WSNs is duty-cycling, in which each node switches between active and dormant states, and the active/dormant schedule can vary from node to node [1]–[5]. Duty-cycling is easily implementable and is proven to be an effective way for energy conservation [1]. As a result, duty-cycled wireless sensor networks (DC-WSNs) have been adopted by various applications [6]–[8].

As a crucial component of wireless networking, multicasting has been applied to WSNs in supporting data dissemination for distributed data management (e.g., [9]). Therefore, designing an energy-efficient multicast protocol is of great importance. In an always-active wireless ad hoc network (AA-WANET), the network topology is static, and each forwarding node can cover all its neighboring nodes by only one transmission. Therefore, the main task of the Minimum-Energy Multicasting (MEM) problem in AA-WANETs is to select appropriate forwarding nodes such that a multicast tree with minimum energy cost can be constructed. This problem was proved to be NP-hard, and some approximation algorithms have been proposed [10]–[13].

In DC-WSNs, however, new challenges to the MEM problem arise. More specifically, the network topology is now only intermittently connected, and a forwarding node may need to transmit the same data packet many times to reach its neighboring nodes. Therefore, designing energy-efficient multicasting algorithms in DC-WSNs requires not only that the forwarding nodes should be selected appropriately to construct a multicast tree, but also that the transmissions of each forwarding node need to be scheduled intelligently to cover the receiving nodes with a minimum number of transmissions. More importantly, these two aspects must be handled jointly so that the total energy cost can be reduced to the largest extent.

In paper “Duty-Cycle-Aware Minimum-Energy Multicasting in Wireless Sensor Networks” authors Kai Han, Yang Liu proposed a solution to select the best forwarding nodes for multicast. But the solution can be applied for bigger networks. In this paper we extend their solution for bigger networks with the assistance of mobile sink. We implement the proposed solution and measure the energy consumption and multicast construction overhead between the proposed solution and solution proposed by Kai Han. We found that our solution performs better.

Related Work

The MEM problem in AA-WANETs has been studied in [10]–[13].

Wan et al. [13] studied the minimum-power multicast routing problem in a scenario where each node can adjust its transmission power continuously, and the communication links can be symmetric or asymmetric. They proposed several
centralized approximation algorithms with constant approximation ratios.

Liang [11] considered a scenario in which each wireless node can adjust its transmission power in a discrete fashion and the communication links are symmetric. He proposed a centralized approximate algorithm with performance ratio for $4*\ln|M|$ for building a minimum-energy multicasting tree, where $M$ is the set of terminal nodes in a multicast request.

Li et al. [10] considered a case in which all nodes have fixed transmission power and the communication links are asymmetric. They converted the minimum-energy multicasting problem to an instance of the Directed Steiner Tree (DST) problem [14] and presented several heuristics.

Liang et al. [12] further considered a scenario where the transmission power is either fixed or adjustable. They studied the minimum-energy all-to-all multicasting problem in such a network and tried to build a shared multicast tree such that the total energy consumption of realizing an all-to-all multicast session by the tree is minimized. They proved that finding such a multicast tree is an NP-complete problem and proposed several approximation algorithms for it. All the aforementioned algorithms assume that the network nodes are always-active; they cannot directly apply to DC-WSNs.

Su et al. [15] studied the minimum-latency unicast routing problem in DC-WSNs and provided some optimal algorithms.

Guo et al. [4] considered the effect of unreliable links on broadcasting and proposed an opportunistic forwarding scheme (a heuristic) to reduce the broadcast delay and total broadcast transmissions in DC-WSNs.

Hong et al. [3] adopted a restricted duty-cycling model where only one active time-slot exists in the working period of any node, and they proposed several approximation algorithms for the Minimum-Transmission Broadcasting problem in DC-WSNs. However, extending [3] to the multicasting problem in DC-WSNs can be highly nontrivial.

In [5], the authors adopted a duty-cycling model in which the active time-slots of any node must be consecutive in a round and proposed two optimal algorithms (“oCast” and “DB-oCast”) for the minimum-energy one-to-many multicasting problem in DC-WSNs. Although oCast and DB-oCast were both claimed to be optimal in [5], their time complexity grows exponentially with respect to the number of terminal nodes. Consequently, they both require the number of terminal nodes in a multicast session to be very small, which may not hold in many applications.

In [39] authors presented approximation algorithms with guaranteed approximation ratios for the MEMTCS problem and the MEMBCS problem and proposed a distributed implementation of their algorithms, as well as a simple but efficient collision-free scheduling scheme to avoid packet loss.

**Problem Statement**

The solution provided in [39] is so far the best solution for MEMTCS problem, but the problem in the solution is that it takes lot of overhead when applied to larger networks. The solution suffers from scalability problem for larger networks. In this paper we propose a mobile sink based extension to the solution in [39] to solve the scalability problem. The mobile sink travels in a particular pattern and becomes carrier for multicast packets in our solution.

**Proposed Solution**

Our solution is based on usage of mobile sink as the carrier.

The solution consist of 3 stages

1. Clustering of network
2. MEMTCS multicast tree in each cluster
3. Mobile sink based relay

**Clustering of Network**

We initially partition the network into multiple zones to form clusters. The clusters are formed using the Leech clustering algorithm. The cluster head node selected in leech clustering should have shorter or no duty cycle. All other nodes will attach to the cluster whose cluster head is nearby to the node. The cluster head node must also know the multicast groups and information of nodes in the multicast groups.

**MEMTCS multicast tree in each cluster**

In each cluster, taking the nodes as vertex and links between the nodes as edges, a graph is constructed. The weight of the edges is the LCM (Least Common Multiple) of the duty cycle duration of nodes. With this graph, a minimum cost Steiner tree is constructed with cluster head in the Steiner tree.

**Mobile Sink Based Relay**

Mobile sinks visits all the cluster heads in the network. To do this taking cluster head position in the graph as vertex points, travelling salesman problem algorithm is applied to find the shortest time in which all vertex can be visited and returned back. The mobile sink will move in this path.
Every time mobile sink moves near a cluster head, it will exchange the multicast packets in its buffer which are for delivery and collects multicast packet from the cluster head which need to be relayed. The Mobile sink maintains a buffer to queue the multicast packets. It also maintains a hop count for each multicast packet in its buffer. When the multicast packet is propagated to all the cluster heads, the packet is removed from the buffer.

When any node in the multicast group wants to multicast packets, it will forward along the steiner tree within its cluster, so that multicast group nodes within that cluster will receive the packets. The cluster head node buffers the multicast packet and waits for the sink node to arrive. If the sink node arrives within a configured interval, it will send the multicast packet to sink for relaying & remove the packet from its buffer. If the sink does not arrive in the preconfigured interval, it will broadcast to its neighboring cluster head nodes and remove the packet from its buffer.

**Performance Analysis**

We have implemented the proposed algorithm for energy efficient multicasting in Jprowler simulator.

We measured the multicast overhead, delay, packet delivery ratio in our proposed solution and compared with the MEMTCS algorithm proposed in [39].

We did this experiment for different networks of size 1000*1000,2000*2000,3000*3000,4000*4000 with number of nodes with node density of 80% uniform over the network.

The results are as follows.

The communication overhead is reduced because of mobile sink relay and thereby the number of packets that needs to be communicated in the network for multicast tree construction & packet forwarding is reduced.

The delay is slightly higher in our scheme because of the movement speed of the sink (relay delay).

The packet delivery ratio is higher in our approach because sink is very reliable in holding the packets and no loss occurs during transition.

**CONCLUSION**

We have detailed our proposed solution for energy efficient multicasting in duty cycled sensor networks. Through simulation we have proved our mechanism is able to keep the overhead low even for large sized networks. The delay in our
REFERENCES


