

Efficient Routing for Energy Harvesting in Wireless Sensing Networks

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Abstract—A wireless sensor network (WSN) is consisting of a set of sensor nodes with a limited energy stored in their batteries. Generally, replacing or charging the battery is hard and inefficient. Further, the main critical aspect of applications based on wireless sensor networks is their lifetime. Therefore, judicious power management with optimized routing protocols can effectively optimize the energy consumption of sensor nodes and thus extend the network lifetime. In this paper, an optimized routing protocol for wireless sensor nodes is proposed. We are interested in constructing an efficient routing spanning tree that minimizes the energy consumption among all nodes in the network and fit for WSN with reduced energy for achieving a longer lifetime. The main idea of this algorithm comes from the Minimum Spanning Tree (MST) graph theory. This approach focuses on the minimal hop count of each node to reach the destination (sink node) within an optimal path.

Index Terms— Wireless Sensor Networks, Network Lifetime, Energy Consumption, Routing protocols, Minimum Spanning Tree.

I. INTRODUCTION

Wireless Sensor Networks (WSNs) have been widely used in numerous real-life applications, such as health care, pollution monitoring, target tracking, fault detection, or environmental measuring (temperature, humidity, pressure, position, vibration, sound, etc). Every single node mainly includes various components such as a radio transceiver with an antenna, a microcontroller and an energy source typically a small battery difficult to recharge or replace due to the unattended and harsh environment, which makes it constrained in energy for long-term deployment. Routing in WSN is a very important task that determines how the routes are discovered and how to efficiently deliver data from source to destination even if the routes in between are broken, so as to establish a communication. So, many routing protocols have been proposed by researchers or industries in order to optimize the energy consumption and to maximize the network lifetime. Energy consumption, node deployment, scalability, connectivity, coverage and security are the main challenges of routing protocols for WSNs [1].

In this paper, an improved routing algorithm is proposed. It can effectively improve the network lifetime and ensure a minimal power consumption. The proposed protocol utilizes a “minimum hop distance to reach the destination” as path selection criteria in every node belonging to a minimum spanning tree (MST) network. As in [2], the path selection criteria is a measure used by a routing protocol for selecting the best path among all the possible paths between a pair of nodes (source and destination). The path selection criteria are usually based on weights, which can be either the sum of distances cost along the communication path, or the number of hops to reach the destination node. In this paper, we want to demonstrate the performance of our proposed routing

protocol by comparing two different path selection criterias in term of energy efficiency: distance-based and minimum hop count-based routing criterias.

The rest of this paper is organized as follows: Section II proposes a global presentation of the multi-hop communication for WSNs, as well as the MST graph theory that our work is based on, and some related works. The proposed approach is presented in section III and the simulation results of the routing algorithm are provided. Finally, a conclusion and a discussion are presented in Section IV.

II. BACKGROUND

A. Multi-hop communication

Wireless sensor nodes can communicate in two ways: single-hop or multi-hop communication, as seen in Fig. 1. In multi-hop communication, a packet has to go through different nodes in order to reach its final destination address. In a Single-hop communication, all the sensors (blue circles in Fig. 1) can send the collected information, directly to the sink node (red circle in Fig. 1). In the case of a multi-hop communication, the sensors send their data to one of their neighbor node, to reach the base station.

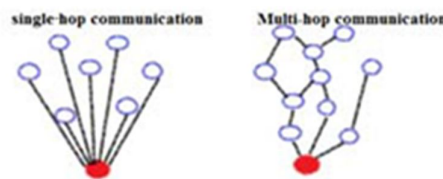


Figure. 1: Single-hop and Multi-hop communications in WSN

The design of each type of communication is based on energy conservation of the sensor node. In this paper, a multi-hop network topology has been adopted. Our purpose is to optimize the energy consumption of each sensor. To do so, we propose to find the shortest path of transmission that costs the minimal number of hops to deliver the packets between the source and its destination.

As a result, aggregated data is efficiently transmitted along the shortest path through multiple hops from nodes towards the sink, helping to reduce the number of individual transmissions.

B. Minimum Spanning Tree

The proposed WSN can be modelled as a connected graph $G = (VG, E)$, where VG is the set of N fixed sensors, and E is the set of wireless links. This work is based on the minimum spanning tree (MST) concept of graph theory, for finding the shortest path to connect all the nodes in the network. By constructing the MST with a given set of nodes, we can route in an efficient manner the data from all sensor nodes to the sink with a minimum number of hops in a short time.

A MST of an undirected and connected graph is a sub graph that connects all the vertices of that tree with a minimal overall edge weight. A single graph can have many spanning trees. The overall weight of a tree is the sum of weights of its edges. Obviously, different spanning trees will have different weights or lengths [3].

The MST is constructed using either the Kruskal's algorithm [4] or the Prim's algorithm [5]. The location of the root node is not taken into consideration in these algorithms. In our work, the MST is constructed using the Prim's algorithm.

C. State of art

With the purpose of optimizing energy consumption during communication, the metric of optimal hop number or corresponding individual distance is preserved as the main issue. Indeed, it influenced on many network metrics like energy consumption, latency, routing overhead, etc. [6].

In [7], the authors studied different energy models

under general wireless network environment. The authors in [8] presented the selection of transmission manner from probability point of view. They presented a probability of P_i to transmit data through multi-hop manner and a probability $(1-P_i)$ to transmit through single hop manner to sink node. Also, the energy consumption by using single-hop or multi-hop transmission is studied by authors in [9]. They confirmed that choosing multi-hop or single hop routing protocols is subject to the reception cost and the distance between source and sink. In [10], the author suggested a Multi-hop/Direct communication scheme to divide data traffic into two branches. He used in his work multi-hop transmission to optimize energy consumption and enhance the performance of the network

lifetime. In [11], the authors proposed a Hop-based Energy Aware Routing (HEAR) algorithm in order to reduce energy consumption and prolonging network lifetime.

Routing based on the Minimum Spanning Tree (MST) graph theory is frequently used by researchers for networks energy efficiency issues, but it doesn't takes into account both the minimum cost of edges and the average of the residual energy of nodes during the construction of the spanning tree.

In this work, we proposed a novel approach for constructing an energy efficient spanning tree based on the minimum hop-count to route the data from sensor nodes toward the sink node and the maximal residual energy of each node.

III. PROPOSED ENERGY-EFFICIENT ROUTING PROTOCOL

A. Network Model

Let a node $s \in VG$ a sink node $sk \in VG$. Let Path $(s1, sk)$ be the sequence: $s1, s2...sk$. We define Hopcount $(s1, sk)$

as the number of hops along the Path $(s1,sk)$. We recall that Hopcount $(sk)=0$.

In this work, the energy model of the sensor network has been designed with only the communication energy.

First order radio model is used for the calculation of energy consumption. In this simple radio model, it is assumed that the energy dissipated to run the transmitter circuitry E_{elec} is the same as the receiver circuitry.

An illustration of the first order radio model is shown

in Fig. 2. Let E_{Tx} and E_{Rx} the energy consumed during the transmission and the reception respectively. In our work, we assume that all transmissions over the network have data packets of the same size.

As proposed in [3], and under our assumption, the energy consumption of transmitting an m -bit data packet at a

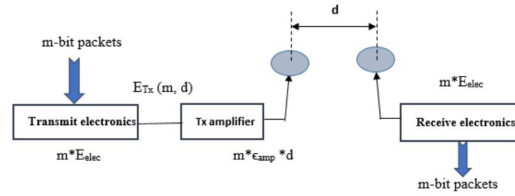


Figure. 2: The first order radio energy dissipation model

B. Proposed Protocol description

Problem Statement: A network is composed of N static nodes randomly deployed in an uncertain area, each node having a communication range of radius R . The N static nodes communicate data to a single sink node which has fixed coordinates in advance and presents the final recipient of all the sensed data. The aim is to transfer the data between nodes and the sink node, by calculating the shortest path using the minimum number of hops between the intermediate nodes and the sink node.

Assumptions: Sensors are assumed to be homogeneous (same computing capability, memory...) and know its fixed geographic location in advance. We also assume that location of the sink is fixed and known to all the nodes in the network.

Motivation: A set of 30 nodes, then 100 nodes randomly deployed over an area of 100×100 meters communicating with each others within a communication range of radius $R=20$ meters, as shown in Fig. 3 and Fig. 4 respectively.

The sink node is located at $(0,0)$. We provide an energy consumption and a Hopcount parameters as the modification to the above classical Prim's algorithm to form a minimum spanning tree (MST) as an energy efficient tree. Our algorithm generates a MST which is constructed from the sink taking as inputs, for the same topology, the residual energy of each node and either the minimal distance between nodes involved in the communication of data (distance-based routing as shown in Fig. 6 and Fig. 8) or the minimum number of hops within each path to route the data (hop-based routing as shown in Fig. 5 and Fig. 7), with respect to minimize the energy consumption per node as much as possible.

Each iteration considers the lowest cost edge (minimum number of hops or minimal distance in addition to the minimal energy consumption for the transmission) within its communication range R to extend the tree with one more node. Based on the adjacent matrix that shows the number of hops of each node to reach the sink and on values of energy consumption per node, the algorithm calculates a cost for every edge connected to the sub tree, chooses the lowest cost edge and adds the node in the tree. Then, it determines all optimal routes between nodes

and the sink within the tree. In order to ensure the establishment of an optimal path that minimizes energy consumption during data transmission, we aim to minimize the count of nodes involved in the N transmission (i.e. number of hops).

The sink maintains a route table containing all the shortest routes, i.e. those with a minimum Hop count and maximal residual energy $RES(s, r)$ per node, to all nodes in the network.

In table I, the Example of *RoutesSinktable* illustrates an example of routes between the sink (assuming that the ID of the sink is 1) and some network nodes by the hop-based routing and by the distance-based routing. After retrieving incoming messages from the sink, each sensor maintains a route table containing the optimal route to transmit data collected to the sink.

We can conclude from the table I that the *RoutesSink* resulted from the hop-based routing is more simplified (i.e. minimal number of intermediate nodes in the path) comparing to that resulted from the distance-based routing. In this way, the number of hops and messages transmitted will be reduced which minimized energy consumption of nodes.

IV. RESULT ANALYSIS

MATLAB platform has been used to evaluate the results. Some assumptions are made to simulate the results as discussed:

- Starting energy of each nodes is equal
- Nodes are fixed
- Distribution of nodes is homogeneous in nature
- For energy dissipation, limited transmission range is used.
- Data is transmitting through nodes only.

The different parameters used in proposed work are given in table 1. The performance parameters are analyzed using MATLAB 2016a.

TABLE I: SIMULATION PARAMETERS FOR PRESENT WORK

Parameters	Values
No. of sensor nodes	100
Starting node energy	0.1 J
Percentage of CH selection	0.05
Transmitter/Receiver electronics E_{elec}	50 nJ/bit
The energy for aggregation E_{DA}	5 nJ/bit/signal

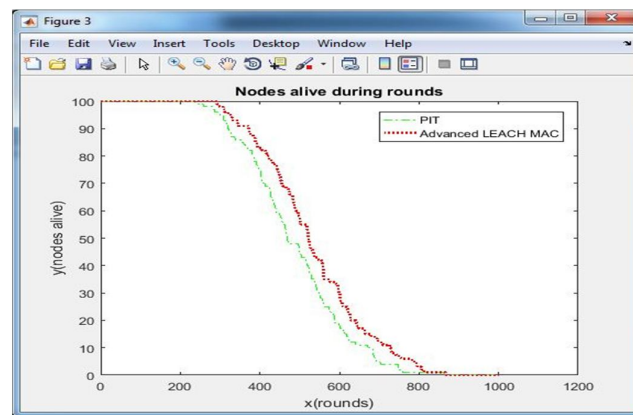


Figure. 3 Nodes alive during round

Figure 3 represents alive nodes during each round. Advanced LEACH MAC protocol for heterogeneous network having more no. of alive nodes as compared to traditional PIT protocols. Numbers of alive nodes are maximum from 100 to 400 rounds as shown in Figure. After this level alive nodes are decreases because of the enhancement in number of rounds. It has been observed from the results that the energy and the lifetime of proposed advanced LEACH MAC protocol are enhanced by the 40% in comparison to the traditional PIT.

Figure 4 represent packet sent to base station. There are two methodology used to achieve the packets transfer. The packet transfer is more in proposed methodology as compared to traditional PIT.

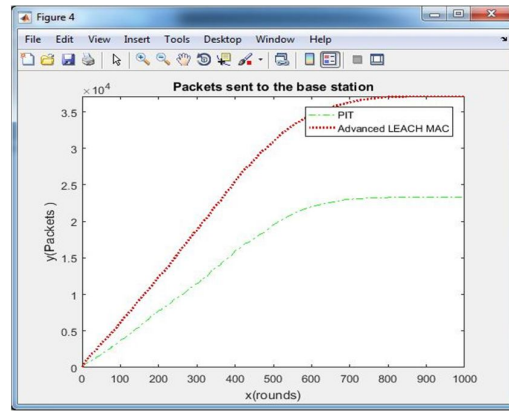


Figure. 4 Packet Sent to base Station

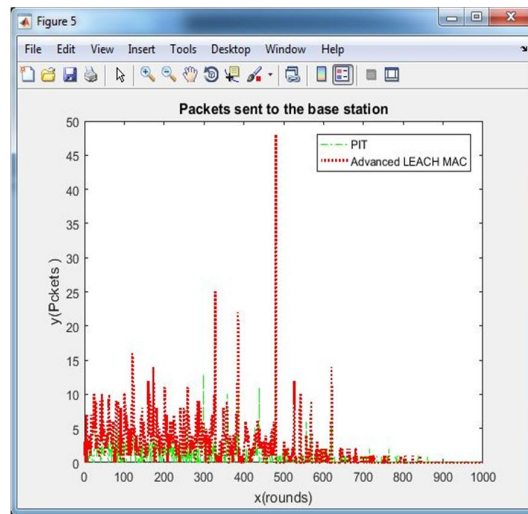


Figure. 5 Packet Sent to base Station

Figure 5 represent packet sent to base station. There are two methodology used to achieve the packets transfer. The packet transfer is more in proposed methodology as compared to traditional PIT.

V. CONCLUSION

The proposed work offers priority to the higher energy node for the selection of cluster head. Simulation results show that LEACH-MAC improves the overall lifetime of the network. This approach has brought down the cluster head variations in the optimal range. Energy efficient algorithm has been proposed for enhancing the energy and lifetime of the network. Results of the energy efficient algorithm have been presented through the simulation using MATLAB platform. The results show that the energy and the lifetime of devised model have been enhanced by the 40% in comparison to the traditional LEACH protocol. In future, advanced LEACH can be applied to the real time environment.

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