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Hybrid energy-efficient multi-path routing for wireless sensor networks☆

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ABSTRACT

The effectiveness of a wireless sensor network relies on the underlying routing protocol. In this paper, we propose a novel algorithm which leverages both flat and hierarchical routing schemes for maximizing energy efficiency. It designates some desired number of nodes as cluster heads leading to cluster formation in the network. Inside clusters, nodes adopt multi-hop routing scheme to communicate with cluster head, which on reception of data packets from all cluster members, transmits the aggregated data along the precomputed path to the sink. Intra-cluster communication can happen in two modes *viz., philanthropist*—maximal residual energy neighbor node is selected, and *selfish*—nearest node is selected as next hop. Our approach refrain nodes from transmitting along long links, thus minimizing the energy consumption of the network. We simulated our algorithm against established protocols, and results indicate that it outperforms other protocols for network characteristics like energy minimization and scalability.

1. Introduction

A wireless sensor network (WSN) consists of tiny, low-powered sensors communicating with each other possibly through multihop wireless links and collaborating to accomplish a common task [1]. As a bridge between physical and virtual information worlds, WSN collects data from it surrounding environment and communicate it to the digital world, such as computers. To accomplish their tasks, WSNs should address two needs: (i) sensing in the target area and (ii) communication between the sensor nodes. Since they operate on limited power supplies for pervasive computing it becomes essential to keep them functional as long as possible. It has been already established that a sensor node expends very less energy in sensing in comparison to communication [2]. In literature, many routing protocols have been proposed and specifically tailored to minimize the energy consumption of sensor nodes. They can be broadly classified into flat and hierarchical algorithms.

In flat routing like [3,4], a node generally transmits its packets to neighboring nodes within its communication range. Whereas in hierarchical routing like LEACH (low energy adaptive clustering hierarchy) [5] and HEED (a hybrid energy-efficient distributed clustering) [6], a node transmits its data to its nearest cluster head (CH) which in turn sends it to the sink. Both the approaches have their own merits and demerits. The foundational principle of flat routing is cooperative

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multi-hop forwarding, but in doing so, a large volume of traffic is generated (in simplistic case a packet from each node is generated and forwarded to the sink) and it results in energy depletion of many nodes. Whereas, in hierarchical routing scheme, there are some designated cluster head nodes which are responsible for data aggregation from their cluster members and finally sending the aggregated information to the sink themselves. This conserves the energy of cluster members but puts a heavy toll on *CHs* [7]. Also, since all the sensor nodes are bound to latch themselves to some *CH*, they may do so by communicating out of normal radio range. This further results in poor quality of service and degraded performance. Our proposed algorithm hybrid energy-efficient multi-path routing protocol (*HEEMP*), attempts to provide a solution to the aforementioned problems. It primarily aims at creating clusters in the network and within each cluster, nodes transmit their sensed data to CH in a multi-hop manner. Later, CH aggregates the received data and transmits it to the sink along the pre-computed path.

HEEMP is a hybrid approach as it incorporates both hierarchical and flat routing schemes. Initially, sink designate CHs based on *node degree* and *residual energy* of the sensor nodes. Once the CHs are elected, sink broadcast CH advertisement message, which leads to different cluster formation. But inside each cluster, cluster members refrain from transmitting their sensed data directly to CHs, rather adopt co-operative forwarding with fellow cluster members to communicate with CH.

In order to establish the efficacy of HEEMP, we compared it with four well-established routing algorithms *viz.,* LEACH [5], PEGASIS [8], GSTEB [9] and TBC [10] and observed that HEEMP outperformed all of them for various performance metrics like *network lifetime, scalability and residual energy etc.*

The major contributions of this research are:

- We propose a novel routing protocol HEEMP (hierarchical in design), which aims at *increasing the network lifetime* of the network.
- Important tasks like CH selection, route construction from sink to CH are carried out by sink itself; thereby reducing the load on the sensor nodes.
- Under its operation no node communicates more than d_0 distance (long link—discussed in Section 3.3) as it results in tremendous energy conservation.
- We also propose M-TBC (Modified tree based clustering) protocol, which is an improvement on existing TBC (Tree based clustering)[10] routing protocol.
- We compared HEEMP with other established routing protocols under various simulation settings (varying area, number of sensor nodes and sink locations) and found that it outperformed all. We observed 920% performance gain against LEACH[5], 290% against PEGASIS[8], 38% against GSTEB[9] and 761% against M-TBC.

The rest of the paper is organized as follows. In Section 2, we present our related research and in Section 3, we formulate our system model and the data aggregation schemes. The HEEMP protocol is described in detail in Section 4. Next, in Section 5, we address some shortcomings of TBC routing scheme and propose Modified-TBC (M-TBC) which is an improvement over TBC. In Section 6, we describe comparative analysis and simulation results of HEEMP protocol with other established protocols. Later, we describe how M-TBC is better protocol than TBC in Section 7 and in Section 8, we discuss our limitations and future work. Finally, in Section 9 we present our concluding remarks.

2. Related research

In WSN, the main task of each sensor is to transmit its sensed data periodically to the Base station (BS) or sink[1]). The simplistic approach to achieve this is Direct Transmission, which allows nodes to directly communicate with BS [5]. However, it leads to uneven energy depletion among the sensor nodes. Therefore, the nodes which are placed far from the BS, would drain out faster in comparison to the nodes which are placed closer to the BS. The high disparity in energy consumption of nodes, ultimately shortens the overall network lifetime, violating the basic criteria of WSN (*viz.*, energy conservation of sensor nodes). To overcome such issues, Low Energy Adaptive Clustering Hierarchy (LEACH) protocol [5] was proposed, where network is divided into various clusters, while network operation is divided into various rounds. Each round is further divided into two phases: the setup and the steady state phase. In the setup phase, each node computes a threshold value followed by a random number. If this random number has a lesser value than the threshold, it will elect itself as a cluster head. Each node latches itself to the nearest cluster head, leading to a cluster formation. During steady state phase, cluster head aggregates the data packets received from its cluster members and by adopting single hop communication it send data packets to BS. LEACH, improved the network lifetime, eight times more than the direct transmission.

In [11], Centralized Energy Efficient Distance (CEED) routing protocol was proposed (an enhancement of LEACH), which aimed at improving the cluster head selection and cluster formation. In CEED, CH selection is based on residual energy and distance of each node from the sink. In cluster formation also, each node chooses its CH on the basis of residual energy and distance parameter. It then constructs a chain between the cluster heads for transmitting data packets to the sink (in a multihop manner).

Later, authors in [12] propose a new CH selection scheme where each node competes to become a CH. The nodes having the high residual energy are given preference over low residual energy nodes. Once the CHs are elected and clusters are

[1] In this article, sink and BS are interchangeably used.