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Energy–efficient grid–based routing algorithm using intelligent fuzzy rules for wireless sensor networks☆

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ABSTRACT

In Wireless Sensor Networks, the sensor nodes are energy constrained and hence the design of energy- efficient routing protocol is an important challenge to be addressed. Among the different clustering procedures used for energy-efficient routing, grid-based clustering method is more efficient in energy optimization. Therefore, we propose an Energy-Efficient Grid-based Routing algorithm for sensor network in this work for preserving the energy in sensor nodes and to enhance the network lifetime. Moreover, routing is performed through a Grid Coordinator that applies fuzzy rules to find the optimal route in order to reduce the number of hops in the routing process. From the simulations carried out in this work, it is observed that the proposed routing algorithm provides better performance in terms of residual energy and network lifetime when it is compared with other existing grid and cluster based routing protocols.

1. Introduction

Wireless Sensor Networks (WSNs) comprise of sensor nodes that are communicating with one another through wireless links for effective data collection and routing. In such networks, each of the sensor nodes are autonomous devices equipped with capabilities for detecting, preparing and communicating with other nodes. One of the major issues in WSN is the optimization of energy available in the sensor nodes in order to boost the network lifetime which can be achieved by developing an energy-efficient routing algorithm. In a WSN, the sensor nodes are densely organized in a geographical region and the nodes are used to sense the environment and to perform the task of data collection. Moreover, the data collected by the sensor nodes are routed through intermediate nodes in order to send them to the base station called sink node where it is collected and stored for further analysis. In such a scenario, the sensor nodes expend more energy in the transmission of data from the sensor nodes to the sink node and hence the energy consumption for transmission becomes more than the energy required for processing the data at the base station.

In cluster based routing, nodes are grouped into small groups called clusters which help to reduce the energy by sending the data through the cluster heads. In this scenario, the coordinators or cluster heads can send the data directly to the sink node if they are present near to the sink node. On the other hand, the coordinators have to send the data to the sink node through multi-hop communication with other coordinators if the coordinators are not present near to the sink node. If the same node remains as the coordinator for a longer time, then its energy is drained fast and hence it will lead to reduction in network lifetime. This issue is addressed earlier in Low Energy Adaptive Clustering Hierarchy (LEACH) [1] and the Hybrid Energy-Efficient Distributed (HEED) clustering approach [2], where the rotation of coordinator nodes was proposed for achieving uniform energy depletion and load

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balancing. Among the different clustering techniques available in the literature to perform cluster based routing, grid-based clustering is more proficient due to its straight forward, feasible and uniform structure handling method leading to reduction in routing overhead.

In grid-based clustering, a sensing and data collection field is partitioned into smaller grids of certain length. From each grid, one sensor node is chosen as the Grid Coordinator (GC) which aggregates the data collected from other sensor nodes which are present in the same grid and routes the aggregated data to the base station. The nodes of the grid closer to the sink node are over-burdened by subsequent data arrival from the other participating nodes. Therefore, the energy of those nodes is exhausted rapidly. This makes the networking system to be disconnected from such nodes and this phenomenon is termed as hot spot problem. To address this issue, many variations of the basic grid-based routing scheme have been proposed in the past by various researchers.

In order to address the energy consumption issue effectively, we propose a new Energy-Efficient Grid-based Routing (EEGBR) algorithm in this paper which overcomes the hotspot problem and utilizes the energy of nodes more efficiently. This algorithm consists of three different phases namely Grid formation, Grid Coordinator election and Grid-based routing phases. The GC for each grid is elected by applying fuzzy logic where the fuzzy variables are used for GC selection based on the residual energy of the nodes, their mobility pattern and the distance of the nodes from the sink node. As the transmission consumes energy based on the distance, the distance to the sink is considered as an important parameter in this work to select the GC so that the energy utilization is monitored perfectly. Moreover, the GC of neighbouring grid is also considered for making routing decisions. The major advantages of the proposed algorithm are preservation of energy, reduction in transmission delay and an augmentation of the network lifetime. The major contributions of this work are as follows:

- Proposed a new Energy-Efficient Grid-based Routing (EEGBR) algorithm to overcome the hot spot problem.
- Developed a fuzzy inference system for Grid Coordinator selection with two membership functions and fuzzy rules.
- Proposed a grid-based routing algorithm to enhance the network performance.
- Mobility of nodes is considered in the proposed Grid-based Routing algorithm and delay is reduced.

The remainder of this paper is composed as follows: In Section 2, the literature survey carried out in the areas related to the proposed methodology is briefly explained. In Section 3, the proposed energy-efficient grid-based routing algorithm has been explained. In Section 4, assessment of this proposed work is carried out by providing the results and discussions. At last, this paper is concluded in Section 5 by highlighting the salient features of this work and suggesting some future work.

2. Related works

In the past, numerous works have been carried out by many researchers in the areas of routing and grid-based routing in WSN for effective communication [3,4]. While outlining the WSN, since energy assumes an imperative part in the system lifetime, more concentration is to be given on energy utilization of the sensor nodes. In WSN, cluster based approach saves the energy of the sensor nodes. In all the clustering algorithms, the cluster head election is imperative for the preservation of energy. Moreover in different works on grid and cluster based routing, decision on next hop is made based on the leftover energy of the individual nodes in a cluster [5]. In the past, fuzzy logic was used to make decisions on the formation of clusters [6,7]. In [7], a Fuzzy logic Based Unequal Clustering (FBUC) approach has been utilized for making decisions in the selection of cluster heads in which the member nodes are provided with a provision to join the cluster by communicating with the cluster head.

In [8], an energy-efficient Multi-Mode Cluster Maintenance (M^2CM) algorithm was presented for clusters maintenance to improve energy utilization rate and also to improve the network lifetime. This M^2CM maintains the damaged cluster according to its change in time and space field, node's remaining energy under threshold, load imbalance of the cluster head, joining in or moving out from existing cluster. In [9], an energy-aware clustering protocol called Prolong Stable Election Protocol (P-SEP) was presented to maximize the network lifetime. In their work, the CH was selected randomly at each round to achieve load balance, energy consumption and to extend lifetime of the network. In [10], the authors proposed a new routing algorithm in which fuzzy logic was used to perform decision making based on different parameters namely the residual energy, the energy consumption by the nodes, number of neighbour nodes, the average distance between the neighbouring nodes and the distance from the sink node. In their model, the authors used a threshold on energy level for each of the routing technique namely intra-cluster and inter-cluster routings through multi-hop communication mechanism in order to reduce the energy consumption.

In [11], the authors developed a new energy-efficient cluster-based routing protocol which forms balanced clusters and prolongs the network lifetime through routing using cluster heads in WSNs. They used fuzzy c-means algorithm for cluster formation and Sugeno fuzzy system to select the proper cluster head. The authors in [12] presented a multi-clustering algorithm where the sensor nodes are clustered using different clustering algorithms. Moreover in their work, the cluster heads are not selected for each round in order to reduce the number of transmission messages. In [13], the authors presented a novel fuzzy clustering scheme to find an optimal clustering structure of three dimensional WSN in terms of network lifetime and energy consumption. However, the number of non-CHs connected to CHs and the number of re-clustering rounds of their work are not providing energy efficiency when it is compared with other related algorithms.

In the past, many grid-based routing protocols were proposed to provide effective routing facility in WSNs [14]. In [15], a grid-based joint routing protocol was proposed for wireless rechargeable sensor networks. The important features of their algorithm include the introduction of a technique for charging the local energy balance and the assignment of distinctive charging time at various charging points. Preetha and Kevin [16] developed an energy-efficient zone clustering algorithm to increase the network