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Energy-aware routing algorithm for wireless sensor networks ☆

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ABSTRACT

The main constraint of wireless sensor networks (WSNs) is the limited and generally irreplaceable power source of the sensor nodes. Therefore, designing energy saving routing algorithm is one of the most focused research issues. In this paper, we propose an energy aware routing algorithm for cluster based WSNs. The algorithm is based on a clever strategy of cluster head (CH) selection, residual energy of the CHs and the intra-cluster distance for cluster formation. To facilitate data routing, a directed virtual backbone of CHs is constructed which is rooted at the sink. The proposed algorithm is also shown to balance energy consumption of the CHs during data routing process. We prove that the algorithm achieves constant message and linear time complexity. We test the proposed algorithm extensively. The experimental results show that the algorithm outperforms other existing algorithms in terms of network lifetime, energy consumption and other parameters.

1. Introduction

Wireless sensor networks (WSNs) have gained enormous attention for their usage in monitoring environment, security surveillance, heath and underground mines [1]. However, the main limitation of WSNs is that the sensor nodes are operated on limited power sources. Moreover, in several applications such as in battlefields, dense forest etc. sensor nodes are not easily accessible due to hostile nature of such environment and therefore they cannot be recharged. Thus energy conservation of the sensor nodes to maximize the network lifetime is one of the most challenging issues in WSNs. Therefore, a lot of research has been carried out for energy saving of the sensor nodes for the long run operation of the WSNs.

One of the techniques to save the energy consumption is clustering sensor nodes [2–14]. In clustering process, sensors nodes are organized into distinct groups, called clusters and each cluster has a coordinator referred as cluster head (CH) and remaining nodes within a cluster act as cluster members (CMs). Each sensor node must belong to one and only one cluster. Sensor nodes send their sensed data to their corresponding CHs. CHs then aggregate them and send it to a remote base station called sink using single hop or multi-hop communication. Many cluster-based multi-hop routing algorithms have been developed in the literature which can be found in [15–22]. In most of these techniques, periodic re-clustering is performed to balance the energy consumption of the CHs. However, in such routing techniques, all neighbor CHs may route their data packets to a single CH which may deplete its energy quickly. As a result, the whole network may get partitioned in the very early stage. In addition to this, clustering algorithm also influences the performance of the routing algorithm owing to inefficient CH selection, uneven CH distribution and ineffective cluster formation. A sensor node cannot sustain as a CH if its residual energy is very low since the CHs are burdened with extra work as compared to their member sensor

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nodes. If the selected CHs are not well distributed in the network, then the distance between the CHs and their member sensor nodes is not minimal. This consumes more energy for intra-cluster communication. Furthermore, inappropriate selection by a sensor node to join a CH also leads to improper energy utilization.

In this paper, we propose a new energy-aware routing algorithm, called ERA for a cluster based wireless sensor network that addresses the above mentioned issues. In our approach, all the sensor nodes are organized into distinct clusters. To select CHs, each node starts the campaign to become a CH by initiating a time delay which depends on its residual energy. To form clusters, nodes join CHs by considering their residual energy and distance. Then, a directed virtual backbone (DVB) of CHs rooted at the sink is constructed using all the CHs to facilitate the routing of the data. In data routing, each CH forwards the data packets to next hop CHs in such way that their energy consumption can be balanced. Experiments are performed on the proposed algorithm, ERA. The results are compared with existing routing algorithms such as EEPA (energy-efficient and power-aware) [18] and EADC (energy-aware distributed clustering) [23] and also with our previous works such as BDCP (backoff-based distributed clustering protocol) [14] and EMRA (energy-aware multi-level routing algorithm) [25]. The results demonstrate the effectiveness of the proposed algorithm in terms of network life time, energy consumption, power imbalance factor, and data aggregation.

The remainder of the paper is organized as follows. We review some related works in Section 2.The system models for the proposed algorithm are presented in Section 3. The proposed algorithm is described in Section 4. We present experimental results and their comparison with other existing algorithms in Section 5 followed by the conclusion in Section 6.

2. Related works

Many clustering algorithms have been developed for WSNs. LEACH (low energy adaptive clustering hierarchary) [3] is a well known distributed clustering algorithm in which CHs are selected with some probability and remaining nodes join the nearest CH without considering its residual energy. Although the role of CH is rotated among the nodes, the overall energy consumption of nodes is neither balanced nor minimized. Moreover, this approach does not ensure even distribution of the CHs across the whole network. HEED (a hybrid energy-efficient distributed clustering) [4] is another popular distributed clustering algorithm that selects CHs by considering residual energy of the sensor nodes and intra-cluster distance as the primary and secondary criteria respectively. It achieves well distribution of CHs and minimizes intra-cluster communication cost. However, HEED introduces extra communication overhead to compute the communication cost with its neighbors by exchanging large number of messages. Many other clustering algorithms have been proposed in the literature [5–14]. All these algorithms introduce high message complexity in selecting CHs and forming the clusters, almost similar to HEED.

Multi-hop based data transmission has been considered as an efficient technique to conserve the energy of the sensor nodes. Some of the proposed techniques can be found in [15–22]. In CPEQ (cluster-based, periodic, event driven, and query processing) [15], a CH sends its data to the sink via minimum number of intermediate sensor nodes. To find the minimum hops, the sink starts the restricted flooding mechanism to configure all the nodes into number of hops away from the sink. Then a CH forwards the data to the next hop CH which is closest to the sink. In EEPA [18], a CH floods the route request packet to the sink. Upon receiving multiple copies of the packet via different paths, the sink computes the total cost of the each path, a cost is embeds by each node along the path. The cost depends on the residual energy of the CHs along the routing path and communication energy consumed by these nodes. Then, the sink sends back the route reply message in the same reverse paths. The message contains the total cost of the path. Upon receiving the multiple copies of the route reply message, the CH chooses one of the paths with minimum cost and confirms the route. However, this technique constructs efficient route at the cost of huge control messages and multiple paths are constructed without use of most of them. Other approaches as reported in [19–22] try to build routing tree for data transmission and switch to different tree structures to alleviate the imbalance energy consumption of the sensor nodes along the routing path. Recently, an energy-aware routing algorithm called EADC has been proposed in [23]. In this algorithm, a CH is selected on the basis of the ratio between its residual energy to the average residual energy of its neighbors. To form clusters, each node chooses the nearest CH without considering its residual energy. To route the data to the sink, a CH chooses the next hop CH by considering its residual energy and load i.e., number of CMs. However, one common problem in all these techniques is that they do not assure that the relaying load of the CHs is balanced with respect to their residual energy. In other words, all the CHs are not participating in relaying the data of other CHs resulting imbalance of energy consumption of the CHs. Hence, it limits the network lifetime. The authors of this paper proposed an energy aware multilevel routing algorithm for cluster based WSNs, called EMRA [25]. However, the algorithm suffers from high message complexity. We also presented a clustering algorithm called BDCP [14]; but this was without any routing algorithm. However, the algorithm was experimented by assuming single hop communication between the CHs and the sink similar to LEACH [3]. In the present version, we extend the work of BDCP by developing a new multi-hop routing algorithm. We also incorporate a cluster formation technique which is different and more efficient than the BDCP. The advantages of the proposed algorithm are summarized as follows:

(1) Each sensor node independently decides its candidature for CH selection. Therefore, this technique does not require exchange of any control messages.
(2) For efficient formation of clusters, each node decides itself to join a CH by considering both the residual energy of the CHs and the distance. This results in energy saving of the WSNs.