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Energy efficient fault tolerant clustering and routing algorithms for wireless sensor networks ☆

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ABSTRACT

Conservation of energy and fault tolerance are two major issues in the deployment of a wireless sensor network (WSN). Design of clustering and routing algorithms for a large scale WSN should incorporate both these issues for the long run operation of the network. In this paper, we propose distributed clustering and routing algorithms jointly referred as DFCR. The algorithm is shown to be energy efficient and fault tolerant. The DFCR uses a distributed run time recovery of the sensor nodes due to sudden failure of the cluster heads (CHs). It takes care of the sensor nodes which have no CH within their communication range. We perform extensive experiments on the proposed algorithm using various network scenarios. The experimental results are compared with the existing algorithms to demonstrate the strength of the algorithm in terms of various performance metrics.

1. Introduction

Wireless sensor networks (WSNs) have gained enormous attention for their wide range of applications such as environmental monitoring, military surveillance, health care, and disaster management [1]. One of the major constraints of WSNs is the limited and generally irreplaceable power sources of the sensor nodes. Even, in many applications, it is impractical to replace the sensor nodes as they work under harsh environment. Therefore, reducing energy consumption of the sensor nodes is considered as the most critical challenge for long run operation of WSNs. Extensive researches have been carried out in designing energy saving protocols which include low-power radio communication hardware, energy-aware MAC protocols, etc. However, energy efficient clustering and routing algorithms [2,3] are the most two promising areas that have been studied extensively for WSNs.

In a cluster based WSN (refer Fig. 1), the sensor nodes are organized into distinct groups, called clusters. Each group has a leader, called cluster head (CH) and each sensor node belongs to one and only one cluster. Clustering WSN has following advantages. (1) It enables data aggregation at cluster head to discard the redundant and uncorrelated data, thereby reducing energy consumption of the sensor nodes. (2) Routing can be more easily managed because only CHs need to maintain the local route setup of other CHs and thus requiring small routing information. This in turn improves the scalability of the network significantly. (3) It also conserves communication bandwidth as the sensor nodes communicate with their CHs only and thus avoid the exchange of redundant messages among themselves. However, in clustering approach, a CH bears some extra work load, i.e., receiving sensed data sent by member sensor nodes, data aggregation and data dissemination to the BS.

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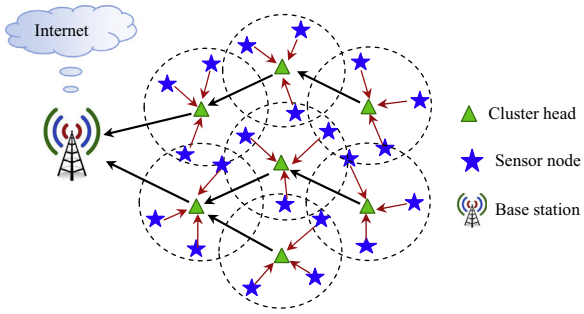

Fig. 1. A model of wireless sensor network.

Moreover, in many WSNs, the CHs are usually selected amongst the normal sensor nodes, which can die quickly as they consume more energy due to such extra work load. In this context, many researchers [4–10] have proposed the use of some special node called gateways or relay nodes that are provisioned with extra energy. These gateways are treated as the cluster heads (CHs) which are responsible for the same functionality of the CHs. Unfortunately the gateways are also battery operated and hence power constrained. Therefore, it is extremely important to properly utilize their energy in the process of both clustering and routing.

Furthermore, sensor nodes are very prone to failure due to several factors such as environmental hazards, energy depletion and device failure. The failure can affect the overall network life time and degrades the overall performance of the network. However, failure of the CHs is catastrophic as it can limit the accessibility of the sensor nodes under their supervision and prevents data aggregation and data dissemination. Therefore, in order to keep WSN operational, the clustering and routing algorithms should cope with the fault tolerant aspects, especially the failure of the CHs.

In this paper, we address the problem of designing energy efficient clustering and routing algorithms for WSNs which are fault tolerant. We present two distributed fault tolerant algorithms, one for clustering and the other for routing in WSNs. The algorithms give emphasis on the failure of the CHs. We name these algorithms as DFCR (Distributed Fault-tolerant Clustering and Routing) in together. The DFCR addresses the issues of energy efficiency. In the clustering phase, sensor nodes select its CH based on a cost function that consists of residual energy of the CH. This is also based on the distance between sensor node to the CH and the distance from the CH to the base station. The algorithm takes care of the sensor nodes which have no CH within their communication range. The DFCR presents a distributed run time recovery of the faulty cluster members due to sudden failure of the CH. To achieve fault tolerance, our method adopts neither redundant deployment of the CHs nor re-clustering approach. In data routing phase, the CHs select their next hop neighbor CH in such a way that their energy consumption will be balanced and minimized. The algorithm can tolerate the sudden failure of CHs in routing path.

We perform extensive experiments on the proposed algorithm through simulation run and compare their results with the fault tolerant clustering algorithm proposed by Gupta and Younis [9], MHRM (Minimum Hop Routing Model) [11] and a distributed routing algorithm DEBR (Distributed Energy Balanced Routing) [12]. Results show that our proposed method performs better than these algorithms with respect to the number of live sensor nodes, number of live gateways, the number of inactive sensor nodes and the energy consumption. Our main contributions are summarized as follows.

- A distributed algorithm for energy efficient fault tolerant clustering for two tire wireless sensor networks.
- A distributed run time recovery of the faulty cluster members due to sudden failure of cluster heads.
- A distributed algorithm for energy efficient fault tolerant routing.
- Experiments of the proposed algorithms through simulation run on different network scenarios.
- Comparison of experimental results to demonstrate superiority of the proposed algorithm over the existing algorithms.

The rest of the paper is organized as follows. The related work is presented in Section 2. The system model is discussed in Section 3 which includes network model, energy model and fault model. The proposed algorithms and the experimental results are presented in Sections 4 and 5 respectively, and Section 6 concludes the paper.

2. Related works

Clustering and routing algorithms have been studied extensively for WSNs. Some of them are centralized approach and the others are distributed. Centralized algorithms are executed by the base station and the clustering or routing information is sent to the gateways (i.e., CHs). However, to execute the algorithm, the base station needs the global information of the network, in contrast to distributed approach which takes decisions based on the local information. Here, we present a review of a few popular centralized and distributed algorithms as follows.

Low et al. [6] have proposed an algorithm which uses a bipartite graph of the sensor nodes and the gateways for finding a maximum matching of assigning a sensor node to a CH. The algorithm has the time complexity of $O(mn^2)$ for n sensor nodes and m CHs. This is very high for a large scale WSN. It also requires building a BFS tree for an individual sensor node which takes a substantial amount of memory space. In [8], we have proposed an algorithm with $O(n \log n)$ time, which is an improvement