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A novel differential evolution based clustering algorithm for wireless sensor networks

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ABSTRACT

Clustering is an efficient topology control method which balances the traffic load of the sensor nodes and improves the overall scalability and the life time of the wireless sensor networks (WSNs). However, in a cluster based WSN, the cluster heads (CHs) consume more energy due to extra work load of receiving the sensed data, data aggregation and transmission of aggregated data to the base station. Moreover, improper formation of clusters can make some CHs overloaded with high number of sensor nodes. This overload may lead to quick death of the CHs and thus partitions the network and thereby degrade the overall performance of the WSN. It is worthwhile to note that the computational complexity of finding optimum cluster for a large scale WSN is very high by a brute force approach. In this paper, we propose a novel differential evolution (DE) based clustering algorithm for WSNs to prolong lifetime of the network by preventing faster death of the highly loaded CHs. We incorporate a local improvement phase to the traditional DE for faster convergence and better performance of our proposed algorithm. We perform extensive simulation of the proposed algorithm. The experimental results demonstrate the efficiency of the proposed algorithm.

1. Introduction

The radical advances in micro-electro-mechanical-system (MEMS) and wireless communication technology enable the development of wireless sensor networks (WSNs). WSNs have attracted enormous attention for their potential applications in diverse areas such as disaster warning systems, environment monitoring, health care, safety, surveillance, intruder detection, etc. [1,2]. A WSN consists of a large number of tiny, low power and inexpensive sensor nodes, which are randomly or manually deployed over an unattended target area. The sensor nodes are equipped with sensing, processing and communication component along with a power unit. These sensor nodes periodically collect local information of the targets, process the data and finally send it to a remote base station (called sink). The sink is connected to the Internet for the public notice of the phenomena.

1.1. Motivation

The main constraint of a WSN is the limited and irreplaceable power source of the sensor nodes. Moreover, in many applications, it is almost impossible to replace the sensor nodes when their energy is completely depleted. Therefore, energy consumption for the sensor nodes is the most challenging issue for the long run operation of WSNs [3,4]. Various issues have been studied for this purpose that includes low-power radio communication hardware [5], energy-aware medium access control (MAC) layer protocols [6,7], etc. However, clustering is the most effective technique for energy saving of the sensor nodes.

In a cluster based architecture, the sensor nodes are divided into several groups called clusters. Each cluster has a leader known as cluster head (CH). All the sensor nodes sense local data and send them to their corresponding cluster head. The CHs then aggregate the local data and finally send it to the base station directly or via other CHs. The functionality of a cluster based WSN can be seen in Fig. 1. A cluster based WSN has the following advantages [8,9]:

(1) It enables data aggregation at cluster head to discard the redundant and uncorrelated data. It should be noted that the energy

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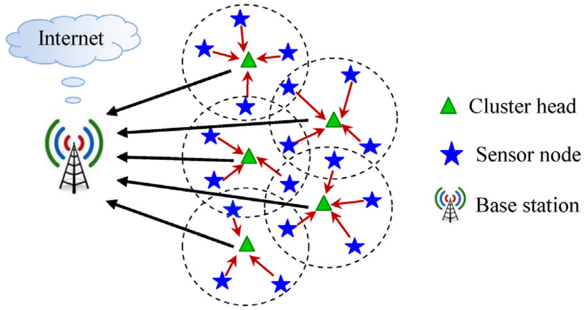

Fig. 1. A wireless sensor network model.

consumed to transfer one bit of data can be used in high volume of data aggregation. Thus it reduces energy consumption of the network by preventing to transmit high volume of redundant data rather than aggregated data.

(2) Routing can be more easily managed because only CHs need to maintain the local route set up of other CHs and thus require 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 exchange of redundant messages among themselves.

However, in a cluster based approach, CHs bear some extra work load owing to receiving the sensed data, data aggregation and communication with the BS. Moreover, in many WSNs, the CHs are usually selected amongst the normal sensor nodes which can die quickly for this extra work load. In this context, many researchers [9–14] have proposed the use of some special nodes called gateways or relay nodes, which are provisioned with extra energy. These gateways are treated as the cluster heads which are responsible for the same functionality of the CHs and therefore they can be used interchangeably for the rest of the paper. Unfortunately, the gateways are also battery operated and hence power constrained. Life time of the gateways is very crucial for the long run operation of the network. Moreover, if the sensor nodes are not properly assigned to the gateways for cluster formation, then some gateways may be overloaded with high number of sensor nodes. Such overload may lead initial death of these gateways and also increase latency in communication and degrade the overall performance of the WSN. Particularly, this is a pressing issue when the sensor nodes are not distributed uniformly. Therefore, proper assignment of the sensor nodes to the gateways is very crucial for balancing the energy consumption of the gateways. This is also worth noting that in order to balance the energy consumption of the gateways, some sensor nodes are assigned to a gateway which may be farther from it. As a result, their energy may be drained out due to long haul transmission and may die quickly. Therefore, while designing clustering algorithm, one should take care not only the energy consumption of the CHs but also energy consumption of the sensor nodes to increase the network life time. It is noteworthy that for a WSN, with n sensor nodes and m gateways, the number of possible clusters is m^n. This implies that the computational complexity to find out optimal cluster for a large WSN seems to be very high by a brute force approach.

In this paper, we address the following problem: given a WSN with n sensor nodes and m gateways find the optimal clusters of the sensor nodes surrounding the gateways so that the network lifetime is maximized. Differential evolution (DE) [15,16] is one of the most suitable heuristics that can be applied to solve this problem when the solution space is very large.

1.2. Our contribution

In this paper, we propose a novel differential evolution (DE) based clustering algorithm for WSNs called DECA. The main objective of the DECA is to prolong the network life time of the WSN by taking care of the energy consumption of the common sensor nodes and the gateways (i.e., CHs). By the network life time, we mean the time from the deployment of the WSN till the death of the first CH. The death of the first CH is delayed through balancing the energy consumption of the CHs which is implemented by the rate of energy consumption and residual energy. In order to find out fast and efficient solution, we introduce a local improvement phase in the traditional DE. This local improvement phase helps our DE based approach to converge faster than the traditional DE and the genetic algorithms (GAs) [9]. We perform extensive simulation of the proposed algorithm. The experimental results demonstrate the efficiency of the proposed algorithm in terms of network life, energy consumption and convergence rate. Our main contributions in this paper can be summarized as follows:

- A DE based clustering algorithm for WSNs to prolong network lifetime.
- An efficient vector encoding scheme for complete clustering solution.
- Mathematical derivation of the fitness function for DE based solution.
- Incorporation of a local improvement phase into the traditional DE for faster convergence and better performance of the algorithm.
- Simulation to demonstrate that the proposed algorithm is superior to existing protocols in terms of network life, number of dead sensor nodes, energy consumption of the network and convergence rate of the algorithm.

The rest of the paper is organized as follows. The related work is presented in Section 2. An overview of the differential evolution is given in Section 3. The system model is discussed in Section 4 which includes energy model, network model and used terminologies. The proposed algorithm and the experimental results are presented in Sections 5 and 6 respectively and we conclude our paper in Section 7.

2. Related works

A number of clustering algorithms [8,17,18] have been developed for WSNs. We present the review of such works based on heuristic and meta-heuristic approaches.

2.1. Heuristic approaches

LEACH [19] is a popular technique that forms clusters by using a distributed algorithm. It dynamically rotates the work load of the CH amongst the sensor nodes which is useful for load balancing. However, the main disadvantage of this approach is that a node with low energy may be selected as a CH which may die quickly. Moreover, the CHs send directly the packet to BS via single-hop communication which is impractical for WSNs with large coverage area. Therefore, a number of improved algorithms have been developed over LEACH such as PEGASIS [20], HEED [21], etc.

Compared to LEACH, PEGASIS promotes network lifetime. Rather than forming multiple clusters, PEGASIS forms chains of sensor nodes so that each sensor transmits and receives from a neighbor and only one node is selected from that chain as group head to convey data to the BS. However, it requires dynamic topology adjustment and the data delay is significantly high which