An Energy-efficient Competitive Clustering Algorithm for Wireless Sensor Networks using Mobile Sink

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Abstract

Wireless sensor networks commonly consist of a large number of tiny sensor nodes that are deployed either inside the target area or very close to it to cooperatively monitor the target area. Energy efficiency and network lifetime are two challenges that most of researchers deal with. In this paper, to improve the performance of sensor networks, we propose an energy-efficient competitive clustering algorithm for wireless sensor networks using a controlled mobile sink. Clustering algorithm can effectively organize sensor nodes and the use of a controlled mobile sink node can mitigate hot spot problem or energy holes. The selection of optimal moving trajectory for sink nodes is an NP-hard problem. In our algorithm, we firstly study an competitive clustering algorithm in which cluster heads are rotated in each round and selected mainly based on their competition range and their residual energy. Besides, we use mobile sink node instead of fixed sink node. The mobile sink node moves at a certain speed along a predefined path and sojourn at some park position to collect data packets. Simulation results validate that competitive clustering algorithm outperforms LEACH and the use of mobile sink node significantly improve the performance of the sensor network.

Keywords: *wireless sensor network, clustering algorithm, mobile sink node*

1. Introduction

Wireless sensor networks are commonly composed of hundreds to thousands of spatially distributed autonomous sensor nodes to cooperatively monitor an area of interest. These sensor nodes can sense, process and transmit the monitored data certain remote sink node or base station in an an multi-hop manner. Today, wireless sensor networks have widely applied to military surveillance and tracking, environment monitoring and forecasting, wildlife animal protection, home automation and healthcare etc. [1, 2].

Wireless sensor networks are energy-limited and application-specific. Each battery-power sensor node is a constrained device with a relatively small memory resources, restricted computational power, and limited communication capability. Thus, to maximize the network lifetime, energy conservation is of paramount importance in the research of sensor networks.

There are many existing algorithms or protocols aiming at improving the performance of sensor networks, such as Low-Energy Adaptive Clustering Hierarchy (LEACH) [3], a Hybrid Energy-Efficient Distributed Clustering Approach (HEED) [4], and so on. All these methods improve the energy utilization in data transmission and prolong the network lifetime.

Compared with flat routing protocols, hierarchical routing protocols can effectively manage sensor nodes and provide an energy efficient way to find an available route and guarantee the good scalability of networks.

However most existing studies assume that the sink node is static, and the traffic follows a many-to one pattern. Sensor nodes nearer to the sink have to participate in forwarding data to the sink node for other sensor nodes. These sensor nodes carry heavier traffic loads and deplete their energy very faster, leading to the formation of energy holes. Thus data can not be forwarded to the sink node and a considerable amount of energy is wasted, resulting in the limitation of the network lifetime [5, 6, 8].

To avoid the formation of energy holes, using sink mobility to wireless sensor networks have attracted more attention recently. The advances in the field of robotics make the controlled mobile sink possible in wireless sensor networks. The mobile sink can improve the network lifetime to some extent by easing the overhead of sensor nodes nearer to the sink location [7, 9].

In this paper, we consider an controlled mobile sink node and aim to combine the clustering algorithm with sink mobility to improve the network performance. Thus we propose an energy-efficient competitive clustering algorithm for wireless sensor networks using a controlled mobile sink. We assume the sink node is static and located in the center of the sensing field. Based on the classical clustering algorithm, LEACH, we first study an competitive clustering (CC) algorithm that can make the cluster heads closer to the fixed sink node have smaller cluster sizes. Thus the cluster heads nearer to the fixed sink node consume lower energy during intra-cluster data gathering. Then in the same network environment, we consider a controlled mobile sink node effecting on the performance of entire sensor network. The mobile sink node traverses the sensor network and sojourn at some certain locations to collect data from the cluster heads in its communication range. The other cluster heads far away from the sink node transmit their collected data to the cluster node communicate with the sink node directly.

The rest of the paper is organized as follows. Section 2 is a literature survey about various sink node deployment strategies for wireless sensor networks. Section 3 gives the energy model we adopt. In Section 4, our algorithms are explained in details. Section 5 presents simulation results and Section 6 concludes this paper.

2. Related work

Hierarchical structure routing protocols are suitable for sensor networks since they can provide good scalability and effectively organize sensor nodes. Clustering provides an effective way to prolong lifetime of wireless sensor networks, such as the classical clustering algorithm LEACH [3] and HEED [4]. Current new studies on clustering algorithms mainly focus on selecting cluster heads with more residual energy and formatting clusters with unequal cluster sizes [5, 6].

Low-energy adaptive clustering hierarchy (LEACH) [3] is one of early famous clustering-based protocol which utilizes randomized rotation of local cluster heads to evenly distribute the energy load across the network. LEACH can guarantee network scalability and prolong network lifetime up to 8-fold than other ordinary routing protocols. However, the 5% of cluster heads are randomly selected and cluster heads communicate with the sink node directly. A hybrid, energy-efficient, distributed (HEED) [4] clustering protocol considered the residual energy of sensor nodes and the cost of communication within the cluster during cluster heads selection. It can not only minimize the control overhead, but also prolong network lifetime since cluster heads are well distributed. The authors in [5] proposed a multi-hop routing protocol with unequal clustering (MRPUC). MRPUC selects nodes with more residual energy as cluster heads, and clusters closer to the base station have smaller sizes to preserve some energy during intra-cluster communication for inter-cluster packets forwarding. When regular nodes join clusters, they consider not only the distance to cluster heads but also the residual energy of cluster heads. Cluster heads choose those nodes as relay nodes, which have minimum energy consumption for forwarding and maximum residual energy to avoid dying earlier. The authors in [6] proposed an unequal cluster-based routing (UCR) protocol which groups sensor nodes into clusters of unequal sizes. A greedy geographic and energy-aware routing protocol is designed for the inter-cluster communication, which considers the trade-off between the energy cost of relay paths and the residual energy of relay nodes.

However the cluster heads closer to sink nodes are burdened with heavier traffic load and deplete their energy very quickly, resulting partitioning of the network. That is hop spot or energy hole problem. To mitigate the hop spot problem, the mobility of a sink node has drawn more attention recently.

In [7], the authors summarized those existing data dissemination protocols supporting mobile sinks and analyzed the sink mobility, as well as its impact on energy consumption and the network lifetime. In [8], the authors proposed to change the location of mobile sinks when the energy of nearby sensors became low. Mobile sinks had to find new zones with richer sensor energy. The authors claimed that an improvement by 4.86 times in network lifetime was achieved compared with static sink case. In [9], the authors first explored and categorized the general problem of sink mobility in the context of trade-offs between data delivery delay and network lifetime. And then the authors studied a novel mobility control solution in which the network nodes cooperatively determine the sink trajectory, and navigate the mobile sinks for delay and energy optimized data collection. In [10], the authors studied the wireless sensor network with one mobile sink and one mobile relay individually and they claimed that the improvement in network lifetime over the all static network was upper bounded by a factor of four. In [11], the authors proposed a line-based data dissemination protocol. They defined a vertical line or strip that divides the sensor field into two equal parts. This line acts as a rendezvous area for data storage and look up. In [12], the authors proposed a distributed algorithm based on the sub-gradient method for computing the maximum lifetime of a noise-limited wireless sensor network and using the sink as leader. In [13], the authors formulated the distance constrained mobile sink problem as a mixed integer linear programming (MILP) and devised a novel heuristic. In [14], the authors addressed hot spot problem and purposed mobile sink based routing protocol (MSRP) for prolonging network lifetime in clustered wireless sensor network. In MSRP, mobile sink moves in the clustered sensor network to collect sensed data from the cluster heads within its vicinity. During data gathering mobile sink also maintains information about the residual energy of the cluster heads. Mobile sink based on the residual energy of cluster heads move to the cluster heads having higher energy. In [15], the authors proposed an intelligent agent-based routing (IAR) protocol to guarantee efficient data delivery to mobile sink and provided mathematical analysis and experimental results to validate the superiority of their proposed protocol in terms of delay, energy consumption and throughput.

3. Energy Model

In this paper, we consider a wireless sensor network consisting of N sensor nodes uniformly dispersed over a rectangular sensor network to continuously monitor the environment. We make some assumptions about sensor nodes as follows:

- All sensor nodes are stationary after deployment;

- All sensor nodes are homeomerous. Each sensor node is assigned a unique identifier (ID) and a same initial energy.
- Sensor nodes are location-aware and can use regular their transmission power based on the distance to the destination node.
- Links are symmetric.

We use a simplified model shown in [3] for the communication energy dissipation. According to the distance between the source node and the destination node, we used the free space (d2 power loss) and the multi-path fading (d4 power loss) channel models. Thus, the energy spent for transmission of an l-bit packet over distanced d is:

$$E_{Tx}(l,d) = \begin{cases} lE_{elec} + l\varepsilon_{fs} d^2, d < d_o \\ lE_{elec} + l\varepsilon_{mp} d^4, d \geq d_o \end{cases} \quad (1)$$

$$d_0 = \sqrt{\varepsilon_{fs} / \varepsilon_{mp}} \quad (2)$$

To receive this message, the energy spent for the radio is:

$$E_{Rx}(l) = lE_{elec} \quad (3)$$

4. Our Proposed Algorithm

In this section, we consider an controlled mobile sink node and propose an energy-efficient competitive clustering algorithm for wireless sensor networks using controlled mobile sink.

4.1. Competitive Clustering (CC) Algorithm

Competitive clustering (CC) algorithm is a distributed clustering algorithm which is similar to LEACH operating in rounds. Cluster heads are rotated among sensor nodes in each round and the selection of final cluster heads is primarily according to the residual energy of candidate cluster heads. Details of the cluster formation and inter-cluster multi-hop routing setup are described in the following.

4.1.1. Cluster Formation: Each sensor node is assigned an equal initial energy and become candidate cluster head with the same probability T which is a predefined value. Thus several candidate cluster heads are randomly selected to participate in the final cluster heads competition. Those sensor nodes unchosen keep sleeping until the selection of cluster heads completing.

Each sensor node compute its approximate distance d to the location of the sink node and find the minimum distance d_{min} and the maximum distance d_{max}. On this basic, sensor node calculate its competition range R_i which is used to form clusters with unequal cluster sizes. The competition range R_i is predefined as follows:

$$R_i = \frac{d_{max} - d_{min}}{d_{max}} \times d_{(s_i, SN)} + d_{min} \quad (4)$$

In the formula 4, we can observe that the competition range R_i decreases as the distance to the sink node decreases. And then the candidate cluster heads compete to be the final cluster head based on their competition range R_i ,their residual energy and their ID. Each candidate cluster head have to broadcast a message including its competition range and its residual energy to its neighbor candidate cluster head. Here we define those candidate cluster heads within the limits of the competition range R_i are the neighbor candidate cluster heads of C_i. At the end of the competition, there will not be another candidate cluster head C_j existing in the competition range of candidate cluster head C_i that becomes a final cluster head. In Figure 1, we can see that candidate cluster heads c1 and c3 may become final cluster heads. The candidate cluster heads c1 and c2 can not become final cluster heads at the same time. We use the competition range to decide the neighbor candidate cluster heads of each candidate nodes. And if candidate cluster head C_i has the largest residual energy in its neighbors, it will win the competition and broadcast a message to its neighbors. If the residual energy is equal, the candidate cluster head with the smaller ID will be chosen. Thus the distribution of cluster heads can be controlled and clusters nearer to the sink node will have smaller cluster sizes. Compared with LEACH, after randomly selecting the candidate cluster heads, these candidate cluster heads still need to compete for becoming final cluster heads in each round. After all cluster heads selected, ordinary sensor nodes will join the anear cluster head.

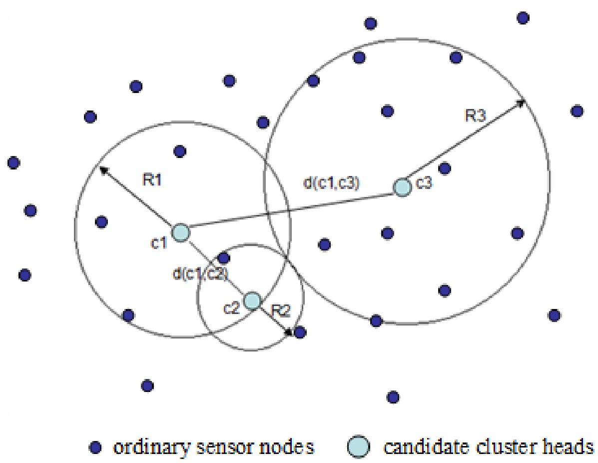


Figure 1. Competition for Cluster Heads

4.1.2. Inter-cluster Multi-hop Routing Setup: In the inter-cluster routing setup phase, we adopt a multi-hop communication protocol to save energy and set a threshold $d_{threshold}$. If the distance between the cluster head and the sink node is smaller than the threshold, the cluster head transmits the aggregated data to the sink node directly; otherwise, it will find an adjacent node as its relay node. We choose the relay cluster head node based on distance and residual energy. The cost of the relay node can be computed by the formula 5 shown as the follows [5].

After each cluster head has chosen the minimum cost node as its relay node, an inter-cluster route is constructed.

$$\cos t(j) = \omega * \frac{d(s_i, s_j)^2 + d(s_j, \mathrm{SN})^2}{\max(d(s_i, s_j)^2 + d(s_j, \mathrm{SN})^2)} + (1-\omega) * \frac{\max(E(j)) - E(j)}{\max(E(j))}, \omega \in [0,1] \tag{5}$$

4.2 Using An Controlled Mobile Sink

To mitigate the hop spot problem, we use an controlled mobile sink node to replace the fixed sink node in the same network environment. The network model we discussed is shown in Figure 2. he mobile sink node will move at a certain speed along the predefined path which is in the sensor network, and sojourn at some certain equidistant locations to collect data packets.

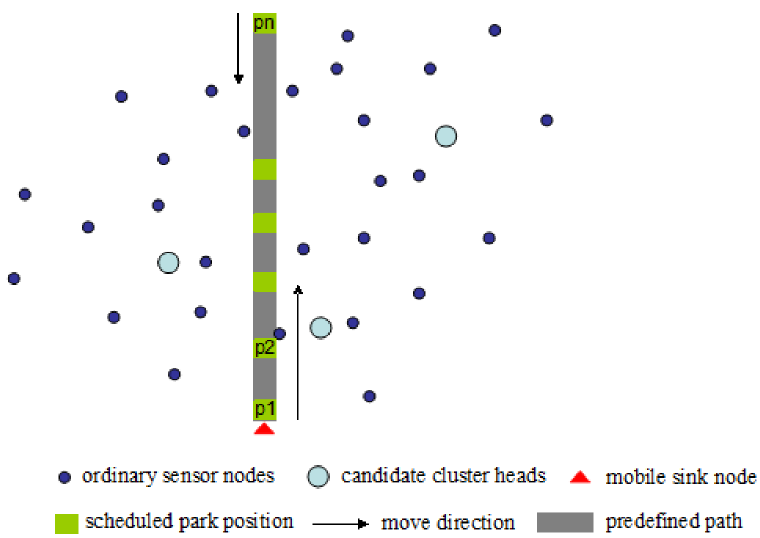


Figure 2. Network Model

In each round, each sensor node generates an l-bits data packet that need to be forwarded to the sink node. In order to reduce the loss of data during the data transmission, we use competitive clustering algorithm to select cluster head which can aggregate data packets from its member nodes and forward the fused data packet to the sink node. Each cluster head can autonomic find the optimal park position of the sink node to forward data packets and then send a message including its ID, residual energy and the position to the sink node. If cluster head C_i choose the park position P_i as its destination node, we can regard the cluster head C_i as the neighbor od the park position P_i. The mobile sink node arriving the scheduled park location broadcasts a arrival information to its neighbors. As neighbor cluster heads will forward their fused data packets to the sink node in the sojourn time. The mobile sink node will move along the path back and forth to collect data packets.

5. Performance Evaluation

5.1 Simulation Environment

We use MATLAB simulator to evaluate the performance of our algorithm. As shown in Table 1, there are 100 sensor nodes dispersedly deployed in a 100*100 m^2 rendezvous sensor network. Simulation parameters are listed in Table 1.

Table 1. Simulation Parameters

Parameter	Definition	Unit
E_{elec}	Energy dissipation to run the radio device	50 nJ/bit
ε_{fs}	Free space model of transmitter amplifier	10 pJ/bit/m^2
ε_{mp}	Multi-path model of transmitter amplifier	0.0013 pJ/bit/m^4
l	Packet length	2000 bits
d_0	Distance threshold	$\sqrt{\varepsilon_{fs}/\varepsilon_{mp}}$ m

5.2 Performance Analysis

In this paper, we proposed an energy-efficient competitive clustering algorithm for wireless sensor networks using a controlled mobile sink. We consider combining the clustering algorithm and the mobile sink aiming to improve the network performance, such as reducing energy consumption and prolonging network lifetime to some extent. In the competitive clustering algorithm, every sensor node participate in competing for cluster heads and cluster heads are rotated in each round. During the selection of candidate cluster heads, we set a parameter T to randomly select candidate cluster heads among all sensor nodes. Thus in Figure 3, we analyze the residual energy of entire network with different T in 30 to 50 round. Here, the initial energy of sensor node is 2 Joule.

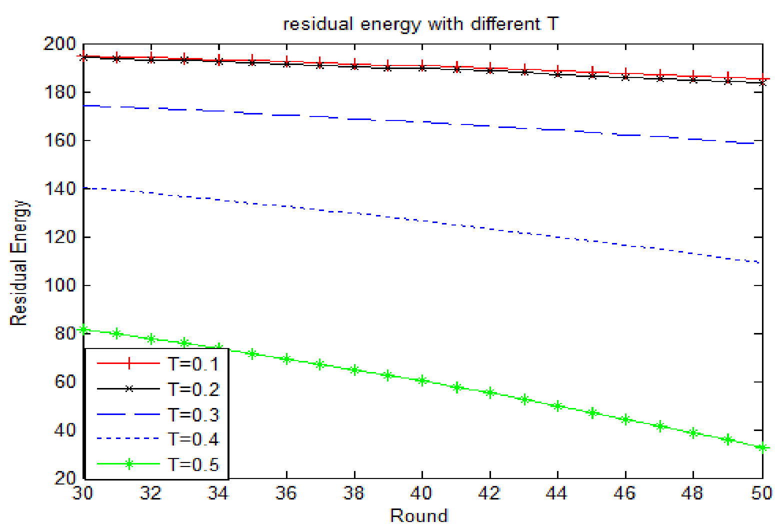
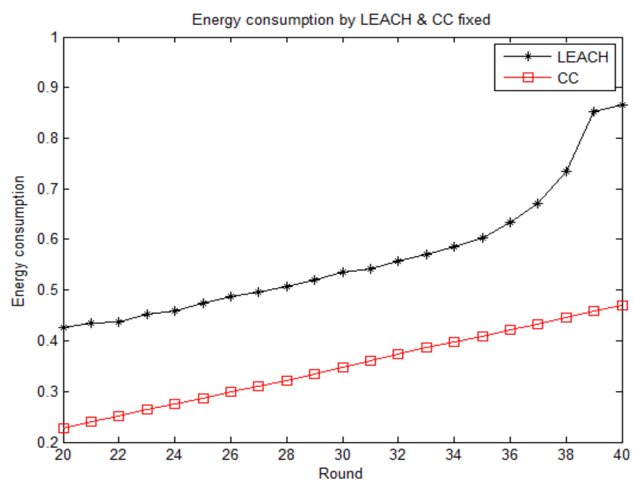


Figure 3. Residual Energy with Different T

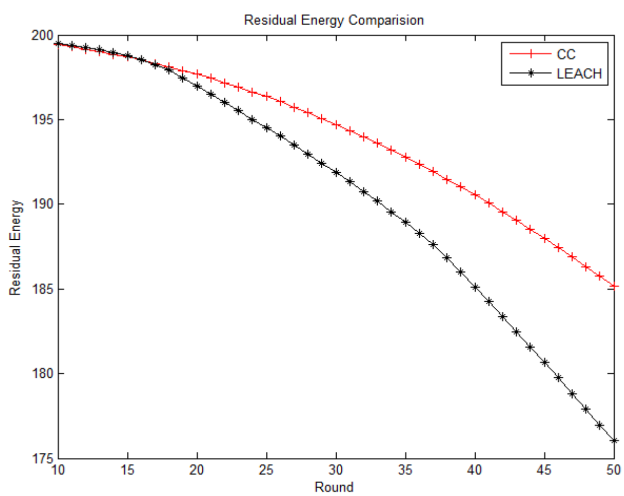
Candidate cluster heads are selected according to the value of T. In Figure 3, the residual energy can be the largest when T is equal to 0.1. Thus candidate cluster head can be selected among all sensor nodes. And final cluster heads are chosen mainly based on the competition range and the residual energy. To analyze the energy consumption of the competitive clustering algorithm, we simulate it and compare it with the classical clustering algorithm, LEACH.

In Figure 4, we compare the competitive clustering algorithm (CC) with LEACH in the energy consumption. In Figure 4 a, CC consumes less energy than LEACH in 20 to 40 round. And in Figure 4 b, the residual energy of entire network in CC is much higher than LEACH. This mainly because of the more evenly distribution of cluster head in CC and the multi-hop routing can reduce the energy consumption during the remote data transmission.

To mitigate the hop spot problem and prolong network lifetime, we use a controlled mobile sink moving at a certain speed along a predefined path to collect data packets. The network model is shown in Figure 5.



a.) Energy consumption in 20 to 40 round



b.) Residual energy in 10 to 50 round.

Figure 4. Energy Comparison between CC and LEACH

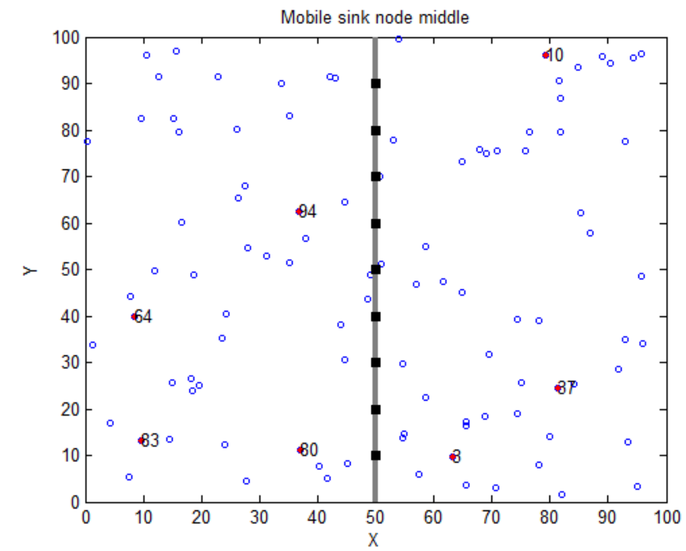


Figure 5. Network Model using a Mobile Sink Node

The mobile sink node moves along the predefined path and sojourn at some scheduled positions. The cluster heads selected by CC will automatically find the optimal sojourn position of the mobile sink and forward data packets when the sink node arriving the sojourn position. Thus we analyze the energy consumption with different distance between sojourn positions, as is shown in Figure 6.

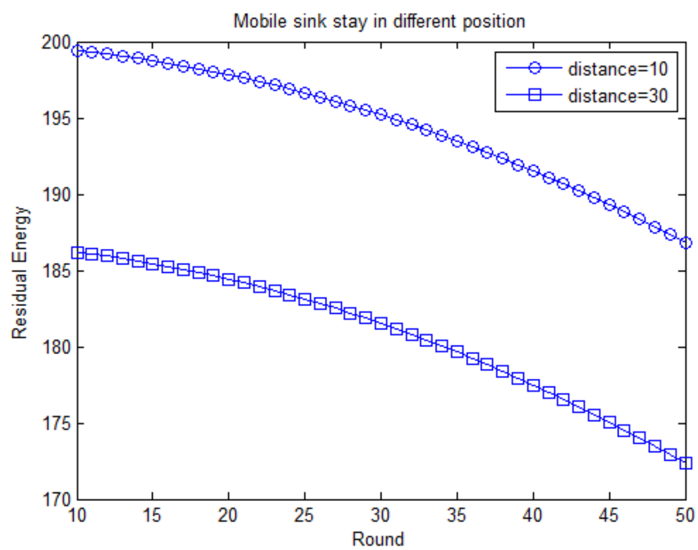
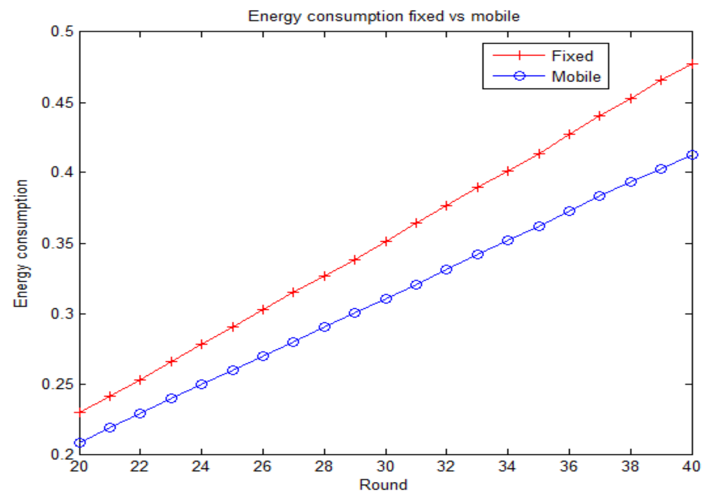
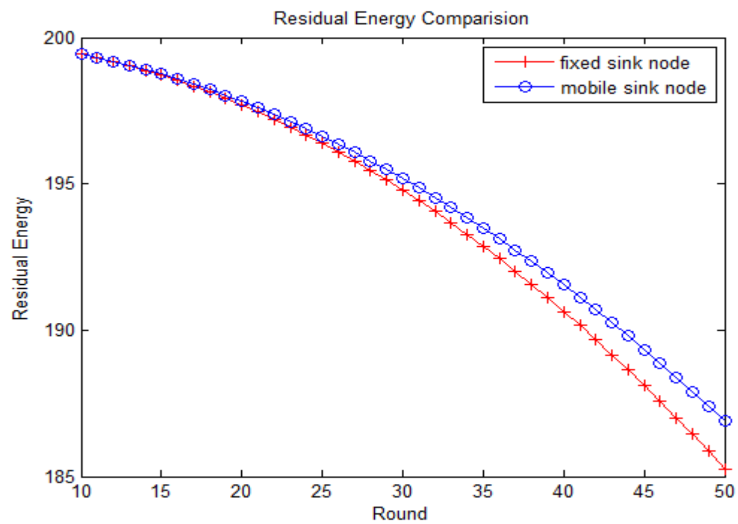


Figure 6. Energy Consumption with Different Distance

Besides, we analyze energy consumed by the fixed sink node and the mobile sink node in Figure 7. Energy consumption and residual energy of entire network of fixed sink node and mobile sink node is shown respectively in Figure 7 a and b. We can observe that using mobile sink node can save much energy than using the fixed sink node. The saving energy contributes to the network lifetime.



a.) Energy consumed by fixed sink node and mobile sink node in 20 to 40 round



b.) Residual energy after 50 rounds

Figure 7. Energy Consumption of Fixed Sink Node and Mobile Sink Node

Through the simulation experiment on the energy consumption, we can conclude that mobile sink node instead of fixed sink node in the competitive clustering algorithm can largely reduce the energy consumption during the data transmission. Then we analyze the network lifetime adopted competitive clustering based on fixed sink node and mobile sink node respectively, and compare with LEACH. The number of alive node in sensor network over simulation time is illustrated in Figure 8. Here, we define the network lifetime as the period of time until the first node depletes its energy and the initial energy of sensor node is 0.5Joule. The round of first death node appears in sensor network is listed in table 2. Figure 8 shows that our algorithm is more dominant at network lifetime extending.

Table 2. The Round of First Death Node Appears

Algorithms	Rounds
LEACH	42
Competitive clustering using fixed sink node	93
Competitive clustering using mobile sink node	97

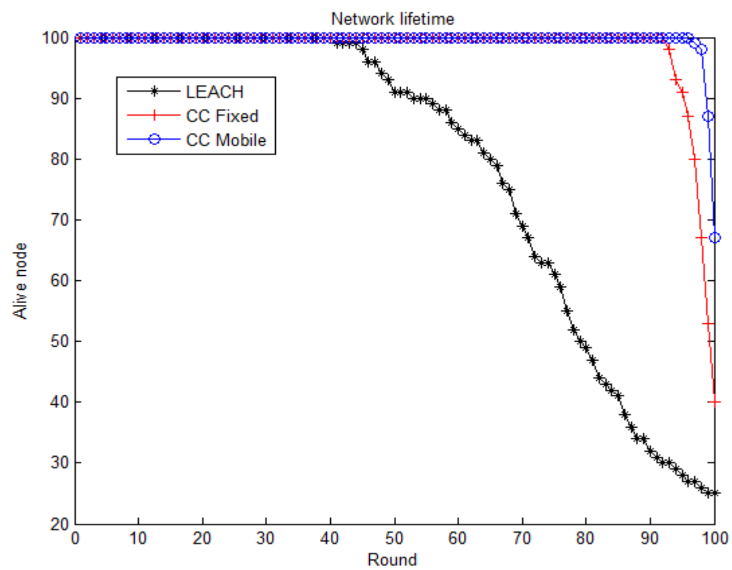


Figure 8. Network Lifetime

6. Conclusions

In this paper, we propose an energy-efficient competitive clustering algorithm for wireless sensor network using a controlled mobile sink. In competitive clustering (CC) algorithm, each sensor node needs to participate in competing for cluster heads. Cluster heads will be selected based on the competition range and the residual energy. On the basic, we use a controlled mobile sink to instead of the fixed sink node to mitigate the hop spot problems. The mobile sink node moves at a certain speed along a predefined path and sojourn at several park positions to collect data packets from cluster heads selected according the competitive clustering algorithm. Simulation results validate that competitive clustering algorithm outperforms LEACH, and the use of mobile sink node can significantly improve the performance of sensor networks, such as improving energy utilization and prolonging network lifetime. In our work, the mobile sink node moves at a certain speed along a predefined path and we ignore the movement speed of the sink node and the data transmission delay among sensor nodes. We will then study the data transmission delay and the movement speed of the sink node to optimize our algorithm.

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