A Mobile Sink Based Uneven Clustering Algorithm for Wireless Sensor Networks

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Abstract

Improving energy efficiency and prolonging network lifetime is a challenging research issue for wireless sensor networks (WSNs). Nowadays, adding mobility technology into WSNs has drawn increasing attention. In this paper, we combine the uneven clustering algorithm with mobile sink strategy and propose our mobile sink based uneven clustering algorithm. First, we study the uneven clustering algorithm with a fixed sink node located at the center of a rectangle network. We analyze the performance of energy consumption and network lifetime, and compare our algorithm with LEACH. Then we use mobile sink node instead of fixed sink node to collect fused data under similar environment. Simulation results show that mobile sink node can efficiently mitigate hot spots near sink node as sink node moves either randomly or along a predetermined fixed path.

Keywords: Wireless sensor networks, Mobile sinks, Uneven clustering, Energy, Lifetime.

1 Introduction

Wireless sensor networks (WSNs) are usually composed of a large number of spatially distributed autonomous sensor nodes, which can sense, process and transmit data to certain remote sink node or base station in a direct or multi-hop transmission manner. Recent advances in wireless communication and micro-electronics technology have enabled the rapid development of sensor nodes, so that WSNs have more broad application such as military surveillance, environment monitoring and forecast, wildlife animal protection, structural monitoring and target tracking, home automation and healthcare [1-2].

Each sensor node is a constrained device. Their resources are limited, and the usage of resources is highly related to certain task which consumes a certain amount of energy, and bandwidth [1-2]. Autonomous sensors are usually powered with very limited energy supply. Moreover, they are usually deployed in harsh environment, where it is very difficult to recharge their battery. Thus, how to improve energy efficiency and prolong lifetime of sensor networks is a very challenging research issue.

Recently, introduction of mobility strategies into WSNs has attracted much attention to improve energy efficiency and lifetime. Moreover, advances in the field of robotics make the mobility possible for WSNs, and it is relative easy to deploy and manage sink nodes rather than normal sensors. In traditional sensor networks, the sink node is static, and the traffic pattern usually follows a many-to-one model. Thus sensors near sink node will bear more traffic load and deplete their energy much faster than those far away from sink node, causing hot spot problem, which has severely impact on network connectivity. Compared with traditional network scheme, sink mobility strategy can effectively alleviate the problem so that prolong network lifetime [5-9].

In this paper, we plan to use mobile sink node instead of static sink node, and try to combine uneven clustering algorithm with sink mobility strategies to improve performance. We propose our mobile sink based uneven clustering algorithm for WSNs. First, we assume the sink node is static and located at the center of a rectangular network area. Based on LEACH [3], uneven clustering algorithms [5-6] are studied where cluster heads (CHs) near the fixed sink node will have smaller cluster sizes. Thus CHs closer to the fixed sink will consume less energy during intra-cluster data gathering. Then we use a mobile sink node instead of fixed sink node to test network performance. Mobile sink node will either move randomly or move along a predetermined fixed path inside the network. It will sojourn at some locations to collect fused data from CHs in its communication range. Other CHs far away from the current location of the mobile sink node will transmit their collected data in a multi-hop manner to the sink node via intermediate CHs.

The rest of the paper is organized as follows. Section 2 presents a literature survey about related clustering protocols and sink movement strategies for WSNs. Section 3 gives the system model we adopt. In Section 4, our algorithm is explained in details. Section 5 provides simulation results and Section 6 concludes this paper.

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DOI: 10.6138/JIT.2013.14.6.04

2 Related Work

2.1 Clustering Protocols

Low-energy adaptive clustering hierarchy (LEACH) [3] is a classical hierarchical routing protocols which utilize randomized rotation of local CHs to evenly distribute energy load. It can guarantee network scalability and prolong network lifetime up to 8-fold than other ordinary protocols. However, 5% of CHs are randomly selected and CHs communicate with sink node directly, causing hot spot problem.

Many energy effective clustering algorithms have been further studied to save energy. Gong et al. [5] proposed a multi-hop routing protocol with unequal clustering (MRPUC). MRPUC selects nodes with more residual energy as CHs, and clusters closer to sink node have smaller size to preserve some energy during intra-cluster communication for inter-cluster packets forwarding. When regular nodes join clusters, they consider distance and residual energy. CHs elect those sensors with minimum energy consumption act as relay nodes. Chen et al. [6] proposed an unequal cluster-based routing (UCR) protocol which groups sensors 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 energy cost of relay paths and the residual energy of relay nodes.

2.2 Sink Movement Strategies

In the year 2003, Shah et al. [7] first proposed the basic idea of mobile sinks where the authors call them "data MULEs." The MULEs use random walk to pick up data in their close range and then drop off the data to some access points. The energy consumption for sensors can be largely reduced since the transmission range is short. However, a random moving sink is not aware of the residual energy of sensor nodes, and thus might threaten the energy balance among sensor nodes.

In the years 2005 and 2006, the idea of introducing mobility into WSNs was further studied, especially in [9-11]. Luo and Hubaux [8] considered a wireless sensor network with a mobile base station which repeatedly relocates to change the bottleneck nodes closer to the base station. Various predetermined trajectories were considered in the search for a combined optimum on the moving and routing strategies. Wang, Srinivasan and Chua [9] 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. Somasundara et al. [10] also considered a base station which moves along a predetermined path. Sensor nodes are organized in clusters, where CHs are the nodes closest to the mobile node trajectory. CHs are in charge of collecting data from their clusters and sending them to the mobile node when it passes by.

In the years 2008 and 2009, existing data gathering protocols supporting mobile sinks are summarized [11] and the optimal sink movement trajectory is further intensive studied in theories [12-14]. Hamida and Chelius [11] summarized the existing data dissemination protocols supporting mobile sinks and analyzed the sink mobility, as well as its impact on energy consumption and the network lifetime. Rao and Biswas [12] 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. Hamida and Chelius [13] proposed a line-based data dissemination protocol. They defined a vertical line that divides the sensor field into two equal parts. This line acts as a rendezvous area for data storage and look up. Shi and Hou [14] proposed theoretical results about the optimal movement of a mobile base station, which won the best paper prize. They showed that when base station location is un-constrained, the network lifetime can be at least $(1-\varepsilon)$ of the maximum network lifetime under their designed joint mobile base station and flow routing algorithm.

Recently, Nazir and Hasbullah [15] 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 CHs within its vicinity. During data gathering mobile sink also maintains information about the residual energy of the CHs. Mobile sink based on the residual energy of CHs move to the CHs having higher energy. Kim et al. [16] 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.

To jointly improve the amount of data and reduce energy consumption, Gao, Zhang and Das [17] proposed a novel data collection scheme, called the maximum amount shortest path (MASP) that increases network throughput as well as conserves energy by optimizing the assignment of sensors. MASP was formulated as an integer linear programming problem and solved with the help of a genetic algorithm. Safdar et al. [18] proposed a hybrid routing protocol for WSNs with mobile sinks. They proposed a combination of reactive and proactive approach to enhance routing protocols for low power networks for efficiently handling movement of multiple sinks.

Li et al. [19] proposed a novel localized integrated location service and routing (ILSR) scheme, based on the geographic routing protocol GFG, for data communications from sensors to a mobile sink in WSNs. In ILSR, sink updates location to neighboring sensors after or before a link breaks and whenever a link creation is observed. Considering both unpredictable and predictable sink mobility, the authors compared ILSR with an existing competing algorithm through simulation and validated that ILSR can generate routes close to shortest paths at dramatically lower message cost. Khan, Gansterer and Haring [20] provided a simulation-based analysis of the energy efficiency of WSNs with static and mobile sinks where the focus was on two important configuration parameters: mobility path of the sink and duty cycling value of the nodes. The authors quantitatively analyze the influence of duty cycling and the mobility radius of the sink as well as their interrelationship in terms of energy consumption for a well-defined model scenario. The analysis starts from general load considerations and is refined into a geometrical model. This model is validated by simulations which are more realistic in terms of duty cycling than previous work.

3 System Model

3.1 Basic Assumptions

Each sensor node has a unique identifier (ID) to differ from others. We make several basic assumptions as follows:

- All sensors are stationary after been deployed.
- Wireless links are symmetric.
- Sensor nodes are location-aware.
- Each sensor node can adjust their transmission power based on relative distance.
- Moving sink node is energy unconstraint.

3.2 Network Model

In this paper, we consider a sensor network consisting of N sensors randomly dispersed over a rectangular network. Sensor network can be modeled as a graph $G = <V, E>$ where V is the set of all sensor nodes and E is the set of all links (i, j). Here, i and j are neighboring nodes. Node i can communicate directly with its neighbor node j if their Euclidean distance is smaller than its transmission radius.

In the network model under uneven clustering algorithm, sensor nodes are randomly deployed and the static sink node is located at the center of the sensing field. All sensors need to compete for being CHs candidate, and CHs are chosen mainly based on competition range and residual energy from CHs candidate. To achieve better network performance, mobile sink node replaces the static sink node, and mobile sink node will moves along the predetermined path back and forth to gather data packets from CHs.

3.3 Energy Model

We use the first order radio model [4] as energy model. Based on the distance between source node and destination node, a free space (d^2 power loss) and multi-path (d^4 power loss) fading channel will be used. Energy spent for an l-bit packet communication over distanced d is calculated in Equations (1) and (2), where the threshold d_0 can be defined as $d_0 = \sqrt{\varepsilon_{fs} / \varepsilon_{mp}}$ when $\varepsilon_{fs} d^2 = \varepsilon_{mp} d^4$. If the distance is less than d_0, the free space model is used; otherwise, the multipath model is used.

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

$$E_{Rx}(l) = lE_{elec} \tag{2}$$

3.4 Traffic Model

Traffic pattern, including time-based, event-based, query-based and hybrid traffic pattern, has very important influence on network performance such as energy consumption and latency. Time-based traffic pattern is used when each sensor take turns to send data in a time series manner. Event-based traffic pattern is applied to target tracking or intrusion detection. Query-based pattern means remote commanders can send query information to obtain observations in certain area. Hybrid traffic pattern is a combination of the above three traffic models, which is more frequently used in practice. For example, during the time-based traffic monitoring period, remote sink node may send a query to demand for certain information simultaneously.

In this paper, the sink node moves along a predetermined fixed path inside the network. Data communication process is described as follows. First, CHs collect data from its members. Then CHs wait for an arrival message from the mobile sink node. Once the mobile sink node arrives at the sojourn position, it will broadcast a message to its neighbor CHs to inform them to send data packets. After completing the data forwarding, mobile sink node will move to the next sojourn position and next data collection will begin.

4 Our Proposed Algorithm

In this section, we plan to add a mobile sink node into WSNs and combining it with the uneven clustering algorithm aiming at improving network performance.

Uneven clustering algorithm is a distributed clustering algorithm similar to LEACH. CHs are rotated among sensor nodes in each round. Different from ordinary clustering algorithms, the selection of CHs is mainly based on the competitive range and the residual energy.

4.1 Cluster Heads Selection

During the period of cluster formation, each sensor node will participate in competing for being CHs candidate with the same probability T. Thus several CHs candidate are randomly selected. Those sensor nodes which fail to become CHs will keep sleeping until the end of CHs completion.

First, each sensor node needs to compute its approximate distance d to current location of sink node and find the minimum distance $d_{\min}$ and the maximum distance $d_{\max}$. On this basis, sensor node can calculate its competition range R_i which is used to form clusters with different cluster sizes. To ensure that clusters close to sink node has smaller cluster sizes, the competition range R_i of sensor node close to sink node is smaller than those far away from sink node. Namely the competition range R_i decreases as the distance to sink node decreases. Based on [5-6], the competition rang R_i of each sensor node is computed according to Equation (3).

$$R_i = \frac{d_{\max} - d_{\min}}{d_{\max}} \times d_{(s_i, SN)} + d_{\min} \tag{3}$$

Final CHs will be selected from CHs candidates based on their residual energy and ID. Each cluster head candidate will broadcast a message including its competition range, residual energy and ID to its neighbor CHs candidates. Cluster head candidates will keep a table to save the messages from its neighborhood. Here we define those CHs candidates within the limits of the competition range R_i as the neighbor CHs candidate of C_i. At the end of the competition, there will not be another candidate C_j existing in competition range of C_i that becomes a final cluster head. We use competition range to decide the neighbor CHs candidate of each candidate nodes. If cluster head candidate 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 cluster head candidate with the smaller ID will be chosen.

4.2 Intra-Cluster and Inter-Cluster Phases

Through the above selection of CHs, the distribution of CHs can be effectively controlled and clusters close to the sink node will have smaller cluster sizes. CHs will broadcast a cluster head message to other ordinary sensor nodes. Ordinary sensor nodes will join the cluster head according to the signal strength. Member sensor nodes transmit data packets to the cluster head directly.

In order to improve the efficiency of remote transmission, we adopt a multi-hop communication protocol and set a threshold $d_{threshold}$. If the distance between the cluster head and the sink node is smaller than the threshold $d_{threshold}$, the cluster head will transmit aggregated data packets to the sink node directly; otherwise, it will find an adjacent cluster head node as its relay node. We choose the relay cluster head node based on their distance and residual energy. The cost of the relay cluster head node can be computed by Equation (4). Those CHs with the minimum cost will be chosen as the relay node. After all CHs have selected their next hops, the inter-cluster route is constructed.

$$\begin{aligned} \cos t(j) = \omega * \frac{d(s_i, s_j)^2 + d(s_j, \mathrm{SN})^2}{\max(d(s_i, s_j)^2 + d(s_j, \mathrm{SN})^2)} + \\ (1-\omega) * \frac{\max(E(j)) - E(j)}{\max(E(j))}, \omega \in [0,1] \end{aligned} \tag{4}$$

4.3 Data Transmission

The entire network is composed of one mobile sink node and a large number of sensor nodes. Sensor nodes are fixed once they are deployed in the network. In our paper, the mobile sink node will move at a certain speed along a predefined movement path across the network, and sojourn at some certain equidistant locations to collect data from other CHs.

Each sensor will generate an l-bits data packet which needs to be forwarded to the mobile sink node. To effectively collect data, CHs will be elected from all sensors based on the uneven clustering algorithm. In other words, all sensors will participate in the competition of CHs. CHs will aggregate data from their members and forward fused data to the mobile sink node. Thus, each CHs need to know the current position of the mobile sink node. Several sink movement locations will be set in advance. CHs can autonomic find the optimal sojourn position of the mobile sink node to transmit fused data packets and then send a message including its ID, residual energy and the position to the mobile sink node. If cluster head C_i choose the sojourn position P_i as its destination node, we can regard the cluster head C_i as the neighbor of the position P_i. Once the mobile sink node reaches the scheduled sojourn location, it will broadcast an arrival message to its neighbors. Then neighbor CHs will forward their fused data packets to the mobile sink node within sojourn time. The mobile sink node will move along the predetermined path back and forth to collect data.

5 Performance Evaluation

5.1 Simulation Environment

We use MATLAB simulator to evaluate the performance of our algorithm. In a 100 × 100 m^2 rectangle sensor network, there are 100 sensor nodes randomly distributed, and some relevant simulation parameters are listed in Table 1.

Table 1 Simulation Parameters

Parameter	Definition	Unit
E_0	Initial energy of sensor nodes	2 J
E_{elce}	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	2,000 bits

5.2 Performance Analysis

Every sensor node needs to participate in the competition for CHs and CHs will be rotated in each round. We set a threshold T and analyze the residual energy of entire network with different T in 30 to 50 rounds, as is shown in Figure 1. In Figure 1, the residual energy can be the largest when T is equal to 0.1. Thus candidate cluster head can be selected among all sensors. And final CHs are chosen mainly based on competition range and residual energy.

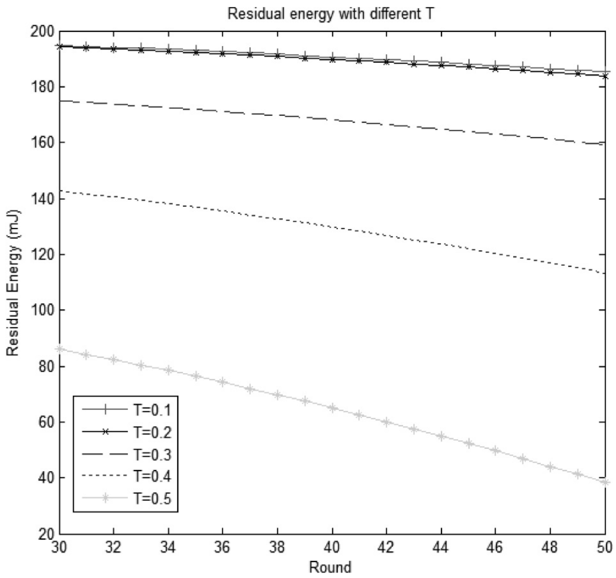

Figure 1 Residual Energy with Different T

We compare the uneven clustering protocol with LEACH to analyze the different energy consumption. Figure 2 shows the residual energy comparison between the two protocols. Compared with LEACH, the distribution of CHs is more evenly and multi-hop routing algorithm reduces the energy consumption to some extent during the remote data transmission. Therefore, residual energy distribution of entire network nodes using uneven clustering protocol s much higher than that used LEACH.

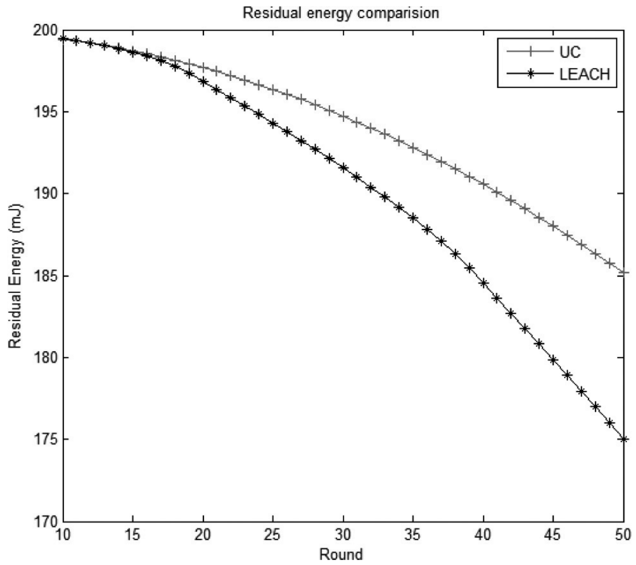

Figure 2 Residual Energy Comparison

In previous experiments, sink node is fixed at the center. Sensors near the sink node will carry heavier traffic loads and deplete their energy rapidly, leading to the problem of hot spots. To alleviate the hot spot problem, we combine the uneven clustering protocol with the mobile sink node.

First, we assume the sink node moves at a certain step length and a random angle randomly in the network. Here we assume the step length is 15. Sink node will randomly move to a new location in each round. Figure 3 shows the random movement trajectory of the sink node in 10 rounds, which is noted with number [1-10]. Second, we assume the mobile sink node moves at a certain speed along a predetermined path in the network and sojourn at some scheduled positions to collect data packets. This predetermined path is also shown in Figure 3, where the gray thick line is the moving path and the small black square on the moving path is the sojourn positions. The mobile sink node will move along the path back and forth.

We analyze the impact of the different distance between sojourn positions on residual energy, as is shown in Figure 4. Here, the distance between sojourn positions is equal. We can observe that the shorter the distance is (with the more sojourn positions), the less energy will be consumed.

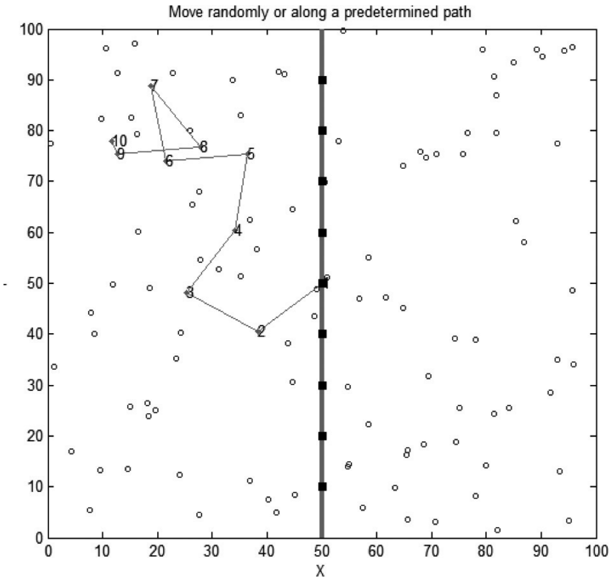

Figure 3 Random and Predetermined Movement Strategies

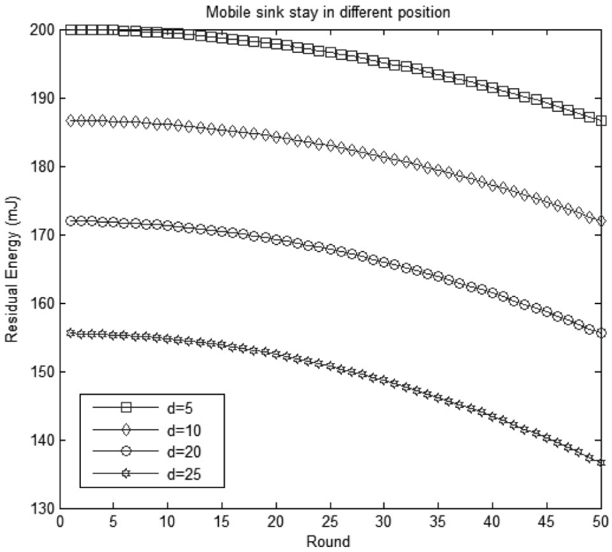

Figure 4 Energy Consumption with Different Distance

However, we also observe that more delay will occur which is not desirable. In this paper, we choose 10 as sojourn distance to make a trade-off between delay and residual energy.

Figure 5 shows the residual energy of the three sink movement strategies from 120 to 150 rounds. We can observe that mobile sink node can save much energy than fixed sink node. Mobile sink node moving along a predetermined path can conserve more energy than when it moves randomly.

Through the above simulation experiments, we can conclude that mobile sink node instead of fixed sink node with uneven clustering algorithm can largely reduce the energy consumption during data transmission. Figure 6 shows the network lifetime of the four strategies with

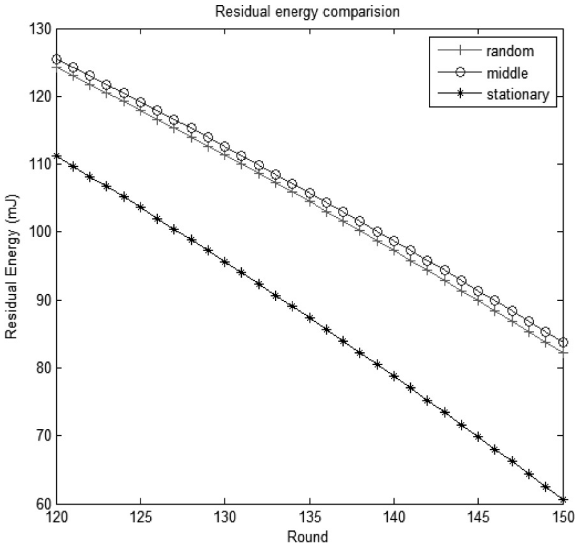

Figure 5 Energy Consumption under 3 Strategies

Table 2 The Round when First Node Dies

Algorithms	Rounds
LEACH	42
Stationary	91
Random move	94
Controlled move (middle)	98

Controlled move (middle) | 98

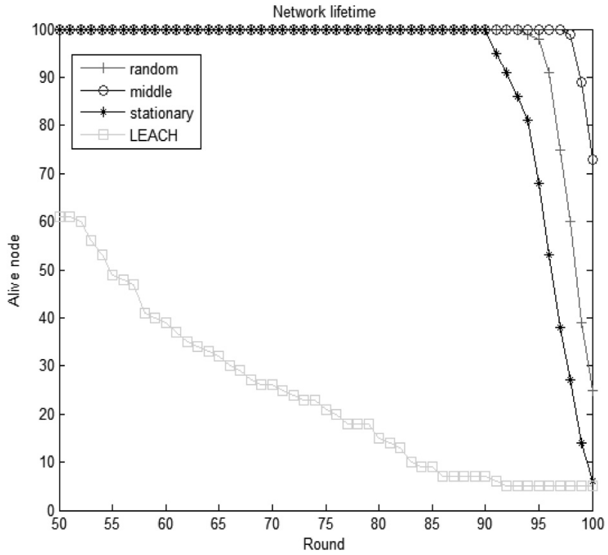

Figure 6 Network Lifetime Comparison

different rounds. Here, we define the network lifetime as the time when the first node depletes its energy and the initial energy sensor node is 0.5 Joule to reduce simulation time. The round when first node dies is listed in Table 2.

6 Conclusion and Future Work

In this paper, we propose mobile sink based uneven clustering algorithm to improve network performance for WSNs. We study the uneven clustering algorithm with a fixed sink node and a mobile sink node respectively. In uneven clustering algorithm, CHs will be selected mainly based on their competition range and their residual energy to guarantee data collection and transmission. The mobile sink node will move at a certain speed along a predetermined path back and forth and sojourn at some special locations to communicate with sensors. Here, the movement path is located in the middle of the rectangular network. Simulation results show that our proposed algorithm can largely improve energy efficiency and extend network lifetime compared with LEACH. Besides, uneven clustering algorithm with a sink node moving along predetermined path outperforms the one with fixed sink node.

We observe that all the above experiments are conducted in an ideal environment. For example, we assume that there are no big obstacles existing in the sensor network to ensure the communication quality between nodes. However, this is obviously impractical. Compare with randomly deployment, effective nodes deployment strategy is needed to be further studied to achieve high quality coverage, such as the obstacle-resistant full-coverage deployment algorithm which considers the boundaries and rectangular obstacles [21]. We will try to introduce the effective deployment strategy into our routing algorithm, and consider the movement trajectory of sink node and data delay among sensors for next stage.

Acknowledgements

This work was supported by the National Research Foundation of Korea (NRF) grant funded by the Korea government (MEST) (2011-0030823), National Natural Science Foundation of China (61173072, 61271240, 61070133, 61311140264) and Natural Science Foundation of Jiangsu Province (BK2012461). It was also supported by the Industrial Strategic Technology Development Program (10041740) from MOTIE Korea, a project funded by Nanjing University of Information Science and Technology (S8110246001), and PAPD of Jiangsu Higher Education Institutions.

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Biographies

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