A Reselection-based Energy Efficient Routing Algorithm for Wireless Sensor Networks

Jin Wang[1], Liwu Zuo[1], Zhongqi Zhang[1], Xiaoqin Yang[1] and Jeong-Uk Kim[2]

[1] *School of Computer & Software, Nanjing University of Information Science & Technology, Nanjing 210044, China*
[2] *Department of Energy Grid, Sangmyung University, Seoul 110-743, Korea*

Abstract

Clustering is an effective topology control approach, which can prolong the lifetime and increase scalability for wireless sensor networks (WSNs). The popular criteria for clustering technique are to select cluster heads with more residual energy and to rotate them periodically. However, hot spots will emerge in real network environment at locations where they have heavy traffic load to transfer. Sensors at such locations quickly deplete their energy resources and die much faster, lending to energy hole and network partition. In this paper, we proposed our Reselection-based Energy Efficient Routing Algorithm (REERA) for WSNs, which determines proper cluster size based on the distance to the base station. After all clusters are formed, cluster heads can be reselected according to the ratio of residual energy of each node to their distance from base station. Simulation results show that our proposed algorithm can be more efficient in saving energy consumption and prolonging lifetime of WSNs than traditional LEACH algorithm.

Keywords: *wireless sensor networks, clustering, energy consumption, network lifetime*

1. Introduction

Wireless sensor networks (WSNs) is a collection of large number of small, low-power and low-cost electronic devices called sensor nodes. Each node consists of four major blocks: sensing, processing, power and communication unit and it is capable of sensing, processing and wireless communications. These nodes collect the relevant data from the environment and then transfer the gathered data to base station (BS) or sink node in a multihop manner. Since WSNs has many advantages like self-organizing, infrastructure-less, fault-tolerance and locality, it has a wide variety of potential applications, such as military surveillance and tracking, environment monitoring and forecasting, wildlife animal protection, home automation and healthcare *etc*. [1, 2]. Considering that sensor nodes are usually deployed in difficult-to-access locations, it is impossible to recharge their batteries [3, 4]. Therefore, how to utilize the limited energy resource wisely to extend the lifetime of sensor networks is a very challenging research issue for WSNs.

Clustering is an effective topology control approach, which can prolong the lifetime and increase scalability for wireless sensor networks [5-7]. The popular criteria for clustering technique are to select cluster heads with more residual energy and to rotate them periodically. The basic idea of clustering algorithms is to use the data aggregation mechanism in cluster head to reduce the amount of data transmission. Thereby, to reduce the energy dissipation in communication and to achieve the purpose of saving energy of the sensor nodes is of utmost importance [8-9]. Low-Energy Adaptive Clustering Hierarchy (LEACH) [10] is the first implemented cluster-based routing protocol and is considered as a basic energy efficient hierarchical routing protocol for WSNs. LEACH can guarantee network scalability and prolong network lifetime up to 8-fold than other ordinary routing protocols. However, LEACH has some drawbacks [13]. One of the major issues is the hot spots problem [12]. When cluster heads cooperate with each other to transmit their data to BS, some of them (especially those cluster heads close to base station) are burdened with heavy relay traffic and tend to die much faster, lending to disruption in network services. Another issue is that LEACH does not consider the residual energy of each node. Thus, nodes with lower energy may be selected as cluster heads, which leads to the premature death of these nodes.

In order to address these two problems above, we proposed our Reselection-based Energy Efficient Routing Algorithm (REERA), which can be viewed as an improvement of LEACH. We use an unequal cluster head selection mechanism so that suitable cluster size can be determined according to the distance to the base station. Clusters closer to the base station are expected to have smaller size than those far away from the base station. It can also alleviate the hot spots problem. After the clusters are preliminary formed, we reselect the cluster heads of each cluster according to the ratio of residual of each node to their distance from BS. Those nodes with larger value of the ratio have greater probability to become cluster heads.

The rest of this paper is organized as follows. Section 2 presents some related work. Section 3 gives the system model. In Section 4, we describe our REERA in detail. Simulation results are provided in Section 5, and Section 6 concludes this paper.

2. Related Work

2.1. Overview of LEACH

LEACH is one of the most famous clustering mechanisms for WSNs and it is considered as a representative energy efficient hierarchical routing protocol. In this protocol, sensor nodes are combined together to form a local cluster. In each cluster, one sensor node is selected randomly to act as a cluster head (CH), which collects data from its member nodes, aggregates them and then sends to the base station. It separates the operation unit into many rounds and every round consists of two phases, namely the set-up phase and the steady phase.

During the set-up phase, clusters are formed and cluster heads are selected. Each sensor node generates a random number between 0 and 1. If the number is less than the threshold, then the node selects itself as a cluster head for the current round. The threshold $T(n)$ is given as follows [13]:

$$T(n) = \begin{cases} \frac{p}{1 - p*(r \bmod 1/p)} & if \;\; n \in G \\ 0 & otherwise \end{cases} \tag{1}$$

Where p is the desired percentage of cluster heads (usually p is set to 0.05), r is the current round, and G is the set of nodes which have not been selected as cluster head in the last $1/p$ rounds.

After selecting itself as a CH, the node broadcasts an advertisement message which contains its own ID. The non-cluster head nodes can decide which cluster to join according to the strength of the received advertisement signal. After the decision is made, each non-cluster head node must transmit a join- request message to the chosen cluster head to indicate that it will be a member of the cluster. The cluster head creates and broadcasts a time division multiple-access (TDMA) schedule to exchange data with non-cluster sensor nodes without collision after it receives all the join-request messages.

The steady phase begins after the clusters are created and the TDMA schedules are broadcasted. All of the sensor nodes send their data to the cluster head once per round during their allocated transmission slot according to the TDMA schedule and in other time, they turn off the radio in order to reduce energy consumption. However, the cluster heads must be awake all the time. Therefore, it can receive all the data from the nodes in their own cluster. Once receiving all the data form the cluster, the cluster head perform data aggregation and forward it to the base station directly. This is the whole process of steady phase. After a certain period of predefined duration, the network will step into the next round. The flowchart of LEACH is shown in Figure 1.

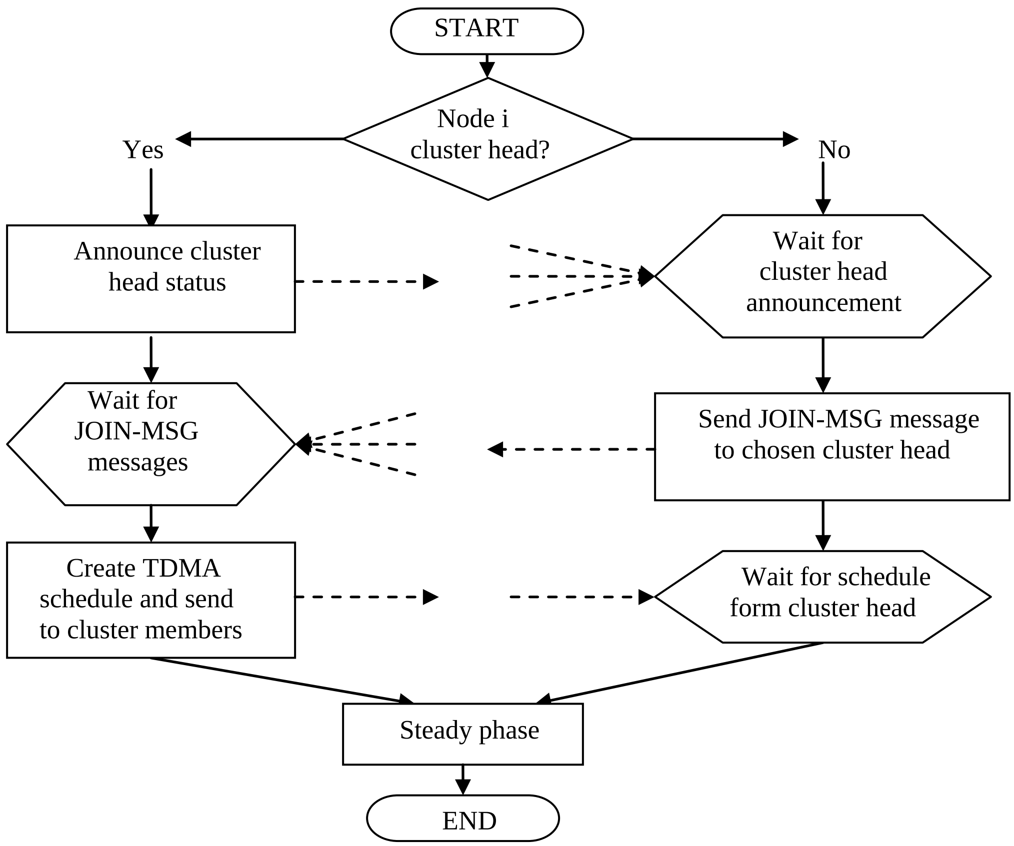

Figure 1. Flowchart of LEACH

2.2. Variations of LEACH

LEACH is the simplest hierarchical protocol which processes cluster approach and it can prolong the network lifetime when compared with multihop routing and static routing. However, there are still some drawbacks that we should pay attention to. LEACH does not take into consideration the residual energy to select cluster heads and construct clusters. As a result, nodes with lower energy may be selected as cluster heads and then die much earlier. Moreover, since a node selects itself as a cluster head only according to the value of probability, it is difficult to guarantee the number of cluster heads and their distribution. To overcome the shortcomings in LEACH, many researchers have done a lot of work and put forward various improved protocols, some of which are briefly described as follows:

Application specific protocol architecture for WSNs, which is known as LEACH-Centralized (LEACH-C) has been proposed in [8]. It is an enhancement over LEACH protocol. In LEACH-C, cluster formation is made by a centralized algorithm at the BS and the steady phase is the same as that in LEACH.

Hybrid Energy-Efficient Distributed clustering (HEED) has been proposed in [14]. An initial set of cluster heads are selected in HEED according to the residual energy of each node, which is the primary parameter. After that, these temporary cluster heads compete to be the final cluster heads based on the secondary parameter. The secondary parameter here means the intra-cluster communication cost. HEED terminates in a constant number of iterations, independent of the size of the network. In the meantime, the distribution of the cluster head is fairly uniform.

In [15], the authors have suggested building a two-level hierarchy to realize a protocol that can save more energy. Here, sensor nodes can be classified into three types: a top cluster-head called primary cluster head, a second level represented by secondary cluster head, and finally simple node, indicated as SN. Secondary cluster heads collect data from their respective clusters and do the fusion. Primary cluster heads collect data from their respective secondary cluster heads, also do the fusion and at last transmit to the base station. The number of nodes that need to transmit to the base station is reduced by this way and then more energy is saved.

In [16], An Energy Efficient Clustering Scheme in Wireless Sensor (EECS) has been proposed to reduce the energy consumption and prolong the lifetime of WSNs. In cluster head election phase, every node selected itself as a candidate node with a probability T and then broadcast its residual energy to its neighbors. If a candidate node does not find any node having more energy than its own, it becomes a final cluster head. In cluster formation phase, cluster's distance from the base station is taken into consideration. According to a weighted function, the farther the clusters away from the base station, the smaller size they have. Therefore, more energy can be saved during intra-cluster communication and then be used for forwarding data to the base station.

In [17], an unequal cluster-based routing (UCR) protocol has been proposed, which groups sensor nodes into clusters of unequal sizes. Cluster heads closer to the base station have smaller cluster size, thus they can preserve some energy for the purpose of inter-cluster data forwarding. The authors also proposed a greedy geographic and energy-aware routing protocol for the inter-cluster communication, which considers the trade-off between the energy cost of relay paths and the residual energy of relay nodes.

3. System Model

3.1. Network Model

We assume that a set of sensors are randomly dispersed within a rectangular field and continuously monitor the surrounding environment. Figure 2 demonstrates the network model. The static sink node, which plays the role of base station, is located far away from the sensing field.

The whole network is divided into several clusters with different size. In each cluster, there is a cluster head, which can perform data fusion after collecting all the raw data from its ordinary members.

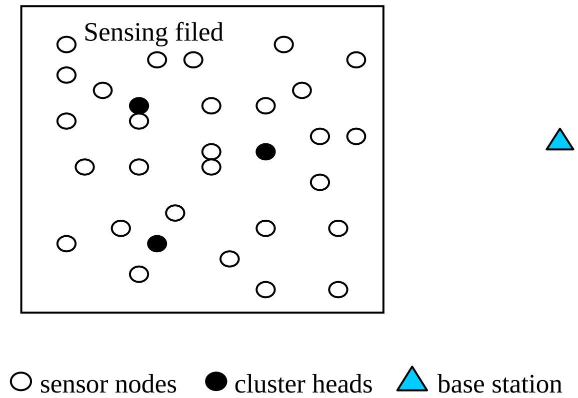

Figure 2. Network Model

3.2. Energy Model

We use the famous first order radio as the energy model [2]. If the distance between the transmitter and the receiver is larger than a threshold d_0, the multi-path (d^4 power loss) model is used; otherwise, the free space (d^2 power loss) is used. Therefore, the energy spent to transmit an l-bit packet over distance d can be calculated as follows:

$$E_{Tx}(l,d) = \begin{cases} lE_{elec} + l\varepsilon_{fs}d^2 & d < d_0 \\ lE_{elec} + l\varepsilon_{mp}d^4 & d \geq d_0 \end{cases} \tag{2}$$

where E_{elec} denotes the electronics energy, which depends on factors such as the digital coding, modulation and so on; ε_{fs} and ε_{mp} denotes the amplifier energy to maintain an acceptable signal-to-noise ratio; $d_0 = \sqrt{\varepsilon_{fs} / \varepsilon_{mp}}$ is a constant.

The energy spent to receive this message can be calculated as follows:

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

4. Our Proposed REERA Algorithm

Considering the defects of LEACH, we propose our Reselection-based Energy Efficient Routing Algorithm (REERA) which is an improved version of LEACH. We consider the residual energy and distance between each node and the base station as two critical parameters when selecting cluster heads and constructing clusters. Our proposed algorithm consists of three fundamental phases as follows: candidate cluster heads selection phase, cluster formation and final cluster heads selection phase and the data transmission phase.

4.1. Candidate Cluster Heads Selection Phase

After the network deployment, the base station broadcasts a BS_ADV message to all the nodes at a certain power level so that each node can compute its approximate distance d to the base station according to the received signal strength. Then each node also computes a parameter K^i which is set as following:

$$K^i = E_{residual} \big/ d(i, BS) \tag{4}$$

where $E_{residual}$ represents the residual energy of node i and $d(i, BS)$ is the distance between node i and the base station.

Here, $d_{\max}$ and $d_{\min}$ represent the maximum distance and the minimum distance between sensor nodes and the base station. Then, we define the competition radius R^i of the node i as following:

$$R^i = \frac{(d_{\max} - d_{\min}) * d(i, BS)}{d_{\max}} + d_{\min} \tag{5}$$

Each node decides whether it is able to compete to be a candidate cluster head based on a probability $T(n)$, which is the same in LEACH. If the number of a node, which is created randomly, is lager then the threshold, the node becomes a member node. Otherwise, it checks whether it is within the cluster radius of other candidate cluster heads. If yes, the node gives up the competition and becomes a member node and on the contrary, it selects itself to be a candidate cluster head and broadcasts a message to inform his neighbor nodes. By this way, the cluster heads will be distributed more densely in the region closer to the base station and thus, hot spots problem can be alleviated.

4.2. Cluster Formation and Final Cluster heads Selection Phase

In this phase each member node determines to which cluster it belongs according to the received signal strength. After the decision is made, it informs the candidate cluster head that it will be a member of this cluster by sending a JOIN_MSG (ID, K_i). The candidate cluster head receives all the JOIN_MSG from its own cluster and then it can discover which member node has the biggest value of K. As is known, energy consumption is proportionate to transmission distance and the cluster head are burdened with heavy relay traffic and tend to die early. Therefore, in order to balance the energy consumption of the whole network, those nodes which are closer to the base station and have more residual should be selected as cluster heads. In view of a tradeoff between these two parameters, we select the final cluster heads according to the value of K, which has been calculated in Section 3.1. In each cluster, the candidate cluster head becomes a member node and send a message, which contains the ID of all the member nodes besides its own ID, to the node which has the biggest value of K. The node which receives this message becomes a final cluster head and creates a TDMA schedule, telling its member nodes when they can forward the sensed data. This is the whole process of this phase.

4.3. Data Transmission Phase

The data transmission phase begins after the final cluster heads are selected and the TDMA schedules are fixed. All the member nodes will send their sensed data to their cluster head during their allocated slot according to the TDMA schedule. The radio of each node is turned off until the node’s allocated slot becomes in order to decrease energy consumption. After receiving all the data from their member nodes, the cluster heads do data fusion and transmit to the base station using multihop transmission. This is the operation of data transmission phase and after a period of time, which is predefined, the next round begins. The flowchart of our proposed algorithm is shown in Figure 3.

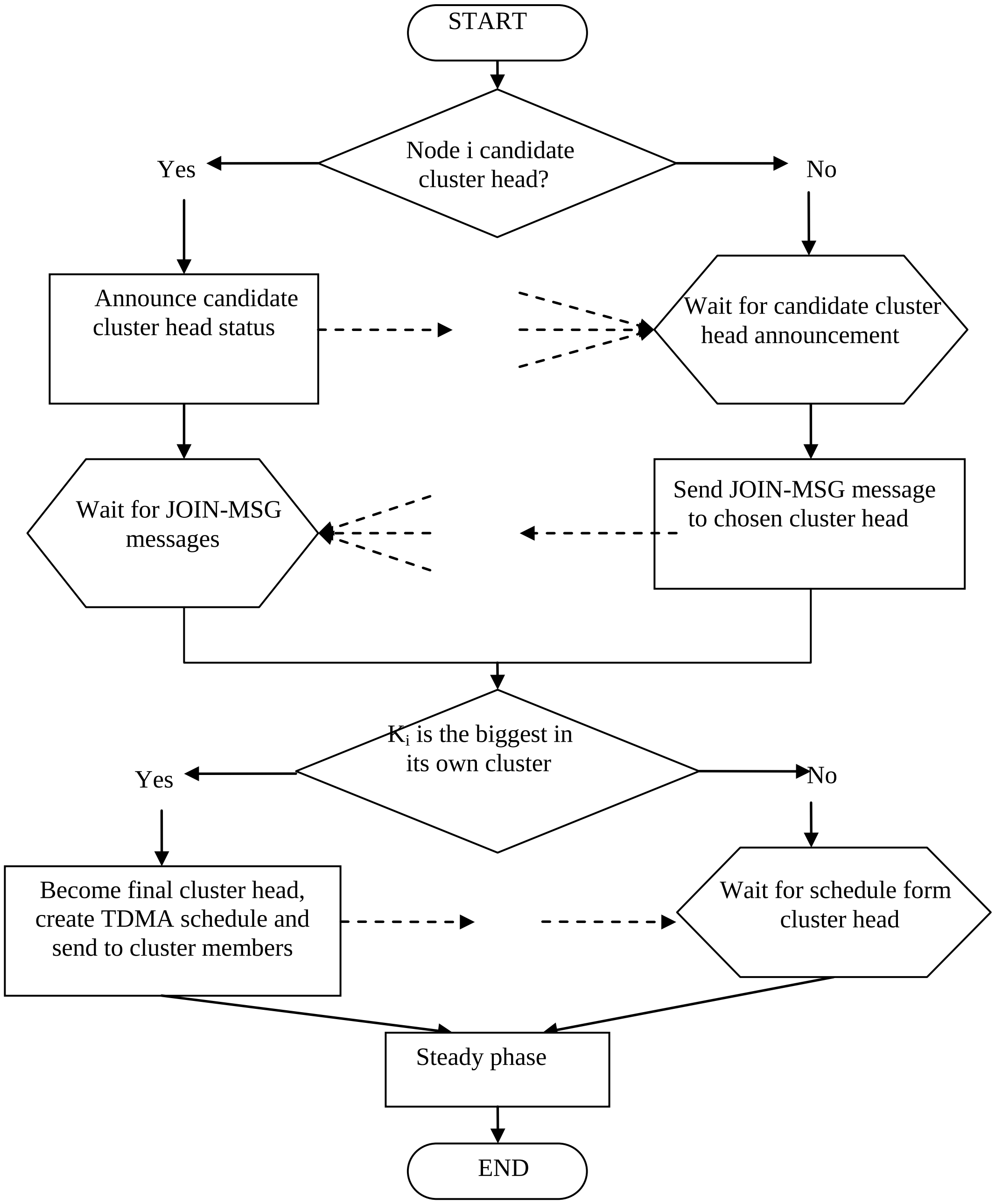

Figure 3. Flowchart of REERA

5. Performance Evaluation

We use MATLAB to evaluate the performance of our proposed algorithm. Assuming that 100 sensor nodes with the same initial energy are distributed randomly in a square region of $100 \times 100 m^2$ and relevant simulation parameters are listed in Table 1.

Table 1. Simulation Parameters

Parameter	Definition	Unit
N	Number of sensor nodes	100
E_0	Initial energy of sensor nodes	2J
R	Transmission radius	50m
E_{elec}	Energy dissipation to run the radio device	50 nJ/bit
ε_{fs}	Free space model of transmitter amplifier	10 pJ/bit/m2
ε_{mp}	Multi-path model of transmitter amplifier	0.0013 pj/bit/m4
l	Packet length	2000 bits
d_0	Distance threshold	$\sqrt{\varepsilon_{fs}/\varepsilon_{mp}}$ m
BS_Location	Base station position	(200,50)

In order to analyze the network performance, we compare our proposed algorithm with conventional LEACH protocol. Figure 4 illustrates the comparison of them in terms of residual energy. Our proposed algorithm differs from LEACH in that the distribution of cluster heads is more suitable and multihop communication is adopted. Therefore, in a given period of time, our proposed algorithm can save more energy, *i.e.*, its residual energy is higher than that of LEACH.

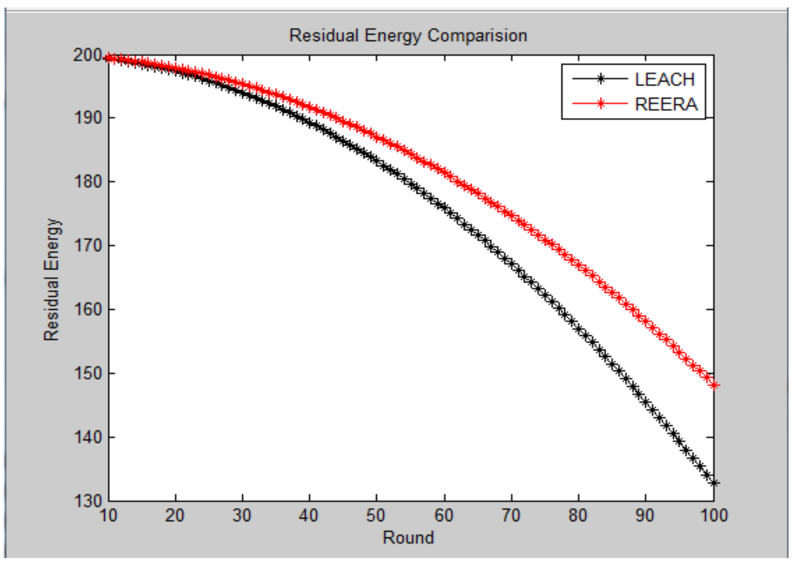

Figure 4. Residual Energy Comparison

Figure 5 shows the network lifetime of our proposed algorithm and LEACH with different rounds. It is clear that our proposed algorithm prolongs the network lifetime (both the time first node dies and the last node dies). The reason is that in LEACH, those nodes with low residual energy may also be selected as cluster heads and then die too early. However, in our proposed algorithm, cluster heads are selected according to the ratio of residual of each node to their distance from BS and multihop communication is adopted, so the network lifetime can be prolonged. The round when first node and last node dies is listed in Table 2.

Table 2. The Round when First Node and Last Node Dies

Algorithms	Rounds	
	First node dies	Last node dies
LEACH	159	185
REERA	192	202

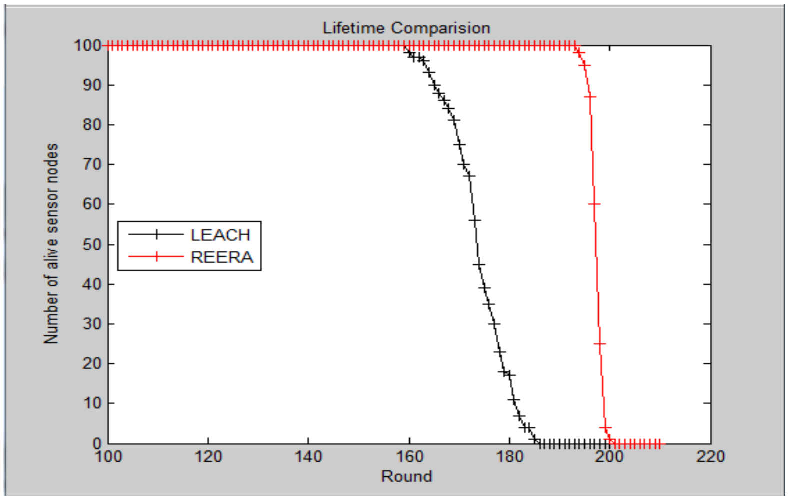

Figure 5. Lifetime Comparison

6. Conclusions and Future Work

When designing the routing protocol for wireless sensor networks (WSNs), lifetime is one of the most critical topics for research. LEACH, which is one of the most famous clustering mechanisms, can prolong the network lifetime. However, LEACH has some drawbacks which may influence its performance. In this paper, we improve LEACH by using an unequal cluster head selection mechanism and taking into consideration the residual energy and the distance between each node and the base station. Performance evaluation in Section 4 shows that our proposed algorithm enhances the functioning of LEACH protocol by increasing the network lifetime.

In this paper, nodes compute the approximate distance from each other according to the received beacon signal strength to, assuming that the transmitting power is known. However, there is a premise that we do not take the noise into consideration. Therefore, errors will arise when our proposed protocol is put into use in real network environment. Our future work is to increase the robustness of our proposed protocol.

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Authors

Jin Wang Dr. Jin Wang received the B.S. and M.S. degree in the Electronical Engineering from Nanjing University of Posts and Telecommunications, China in 2002 and 2005, respectively. He received Ph.D. degree in the Ubiquitous Computing laboratory from the Computer Engineering Department of Kyung Hee University Korea in 2010. Now, he is a professor in the Computer and Software Institute, Nanjing University of Information Science and technology. His research interests mainly include routing method and algorithm design, performance evaluation and optimization for wireless ad hoc and sensor networks. He is a member of the IEEE and ACM.

Liwu Zuo He obtained his B.S. degree in the Computer and Software Institute from Nanjing University of Information Science and technology, China in 2012. Now, he is working toward the M.S. degree in the Computer and Software Institute. His current research interests are in performance evaluation for wireless sensor networks, and healthcare with wireless body area networks. He is a student member of ACM and CCF.

Zhongqi Zhang He obtained his B.S. degree in the Eletronic and Information Engineering from Nanjing University of Information Science and technology, China in 2012. Now, he is working toward the M.S. degree in the Computer and Software Institute. His current research interests are in performance evaluation for wireless sensor networks, and healthcare with wireless body area networks. He is a student member of ACM and CCF.

Xiaoqin Yang She obtained her B.S. degree in Binjiang College from Nanjing University Nanjing University of Information Science and technology, China in 2011. Now, she is working toward the M.S. degree in the Computer and Software Institute in her Alma Master. Her current research interests are in performance evaluation for wireless sensor networks, and energy efficient routing protocol and algorithm design.

Jeong-Uk Kim Dr. Jeong-Uk Kim received his B.S. degree in Control and Instrumentation Engineering from Seoul National University in 1987, M.S. and Ph.D. degrees in Electrical Engineering from Korea Advanced Institute of Science and Technology in 1989, and 1993, respectively. He is a professor in SangMyung University in Seoul. His research interests include smart grid demand response, building automation system, and renewable energy.