An Energy-balanced Cluster Head Selection Method for Clustering Routing in WSN

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Abstract

Clustering technology used in routing protocols can reduce energy consumption and prolong the lifetime of wireless sensor networks. Cluster head selection is one of the most important parts in clustering routing. An Energy Prediction based selection method based on LEACH (LEACH-EP) is proposed in this paper. Its core is to maintain the structure of clusters unchanged in *K* rounds. In the first round, cluster heads are selected according to LEACH, and then selected based on energy prediction in the remaining *K*-1 rounds. LEACH-EP reduces the updates of clusters' structure and delays the dead time of nodes. Theoretical energy consumption analysis proves the effectiveness of LEACH-EP. Besides, the simulation with OMNeT++ shows that LEACH-EP delays dead time of the first node efficiently and it achieves an improvement on the effective network lifetime. At the same time, it is more conducive to energy balance.

Keywords: Energy balance, Cluster head selection, Clustering routing, LEACH, Wireless sensor networks

1 Introduction

A Wireless Sensor Network (WSN) consisting of numerous micro sensor nodes powered by batteries can form a self-organization network. As a new mode of information acquisition and processing, it has been widely used in military, environment, healthcare [1-6], industry, vehicular ad hoc network [7] and so on. In terms of healthcare, the aging of world population has pushed the need for designing new, more pervasive, and possibly cost effective healthcare systems. In this field, distributed and networked embedded systems, such as WSNs, are the most appealing technology to achieve continuous monitoring of aged people for their safety, without affecting their daily activities [1]. WSNs have witnessed rapid advancement in medical applications from real-time remote monitoring and computer-assisted rehabilitation to emergency response systems [2].

Since the energy of sensor nodes is limited and hardly be charged, how to save the energy of nodes to extend the network lifetime has been a research hotspot. Routing protocols, as an important part of WSNs, affect the energy consumption of nodes directly. In order to prolong the network lifetime, we should design effective routing protocol. Based on network structure, routing protocols in WSNs can be divided into flat routing and clustering routing. Owing to a variety of advantages, clustering is becoming an active branch of routing technology in WSNs [8]. At the same time, clustering routing is more efficient than flat routing in terms of energy consumption.

Low-Energy Adaptive Clustering Hierarchy (LEACH) [9] is a kind of clustering routing algorithm firstly proposed by Heinzelman et al. For the purpose of energy saving, it cuts down the number of nodes communicating with Base Station (BS) and reduces the transmission quantity of data by data fusion technique. The algorithm uses "round" as a work cycle, and it randomly selects new cluster heads (CHs) in each round, aiming at energy consumption distributed on all nodes in the network. However, there are some disadvantages of LEACH. Firstly, the CH selection method is instability in terms of the number and location of nodes [10], which is not conducive to energy balance. Though some literatures, such as [11], proprose pre-determined node deployment strategy to blance energy consumption, this kind of methods need large manpower cost to deploy sensors and could not suitable for general scenario. Secondly, the CH selection method doesn't take into account the rest energy of nodes; therefore nodes with low energy will be rapidly exhausted act as CHs. Thirdly, CHs send information to sink node by single hop transmission,

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and too much energy will be consumed by long distance communication. So LEACH is not suitable for large scale networks [12].

In recent years, researchers have made improvements on LEACH and many new clustering routing algorithms based on LEACH have been proposed. For example, DCHS [13], TEEN [14] and APTEEN [15] are designed based on the clustering idea borrowed from LEACH. Clustering routing needs to update cluster structure frequently, while random or unreasonable CH selection methods will lead to uneven network energy consumption. To address this situation, some research work have been done in this paper, and the main contributions includes:

(1) We propose an Energy Prediction based selection method based on LEACH (LEACH-EP). This method maintains the structure of clusters unchanged in K rounds, and chooses new CHs according to energy prediction, which is more conducive to energy balance.

(2) Theoretical energy consumption analysis demonstrate the effectiveness of LEACH-EP, and the simulation results show that LEACH-EP delays the dead time of the first node efficiently and it achieves an improvement on the effective network lifetime. At the same time, it works better when the value of K is relatively small.

The remainder of this paper is organized as follows. Section 2 presents and analyzes some advanced clustering routing algorithms at different aspects. Section 3 provides some models and hypotheses associated with experiments. Section 4 makes a detailed explanation and analysis for the proposed CH selection method based on energy prediction. Section 5 provides comparative experiments with LEACH to reflect the performance of LEACH-EP and analyzes the value of K in the method. Finally, we conclude the paper with the discussion on our future work in Section 6.

2 Related Work

The selection of CHs, the formation of clusters and the routing of clusters are three important parts of clustering routing. In recent years, researchers have proposed many clustering routing algorithms at different aspects.

According to the clustering idea of LEACH, many LEACH-based methods appeared. Multi-hop LEACH (LEACH-M) [16] uses the same algorithm and mechanism with LEACH to form clusters. At the same time, CHs record information about location and energy of all nodes in the network. During the data transmission stage, CH chooses the nearest node with lager energy as the next hop. The algorithm requires CHs record information about all nodes and calculate distance between them, which makes a big network energy costs. LEACH-Centralize (LEACH-C) [17] is a kind of centralized head selection algorithms. For LEACH-C, each node reports its location and energy to BS directly. BS assesses the average residual energy of network based on that information, and optimizes the CH selection according to simulated annealing algorithm. This process allows the number of nodes is substantially equal in each area and achieves energy balance, but it costs much energy on communication. Li *et al.* [18] proposed a new improved clustering routing method based on LEACH (LEACH-N). According to LEACH-N, how to select CHs from numerous nodes relies on residual energy of nodes in clusters. This strategy can guarantee the rationality during selecting CHs. Moreover, the network robustness can be enhanced and the lifetime of the network can be prolonged. Simulation results indicate the algorithm behaviors better performance than LEACH in the following three aspects, the number of life nodes, energy consumption and data transmission.

Power-Efficient Gathering in Sensor Information Systems (PEGASIS) [19] is a greedy chain protocol that is near optimal for a data-gathering problem in sensor networks. In PEGASIS, each node communicates only with a close neighbor and takes turns transmitting to the BS, thus reducing the amount of energy spent per round. PEGASIS outperforms LEACH by eliminating the overhead of dynamic cluster formation, minimizing the distance non leader-nodes must transmit, limiting the number of transmissions and receives among all nodes, and using only one transmission to the BS per round. Nodes take turns to transmit the fused data to the BS to balance the energy depletion in the network and preserves robustness of the sensor web as nodes die at random locations. Tang *et al.* [20] proposed a routing algorithm called Chain-Cluster based Mixed routing (CCM), which makes full use of the advantages of LEACH and PEGASIS, and provide improved performance. It divides a WSN into a few chains and runs in two stages. In the first stage, sensor nodes in each chain transmit data to their own chain head node in parallel, using an improved chain routing protocol. In the second stage, all chain head nodes group as a cluster in a self-organized manner, where they transmit fused data to a voted CH using the cluster based routing. Experimental results demonstrate that their CCM algorithm outperforms both LEACH and PEGASIS in terms of the product of consumed energy and delay, weighting the overall performance of both energy consumption and transmission delay.

Hierarchical clustering is effective to prolong the lifetime of WSNs. Gautam and Pyun [21] proposed a new hierarchical routing protocol called Distance Aware Intelligent Clustering (DAIC), with the key concept of dividing the network into tiers and selecting the high energy CHs at the nearest distance from the BS. The distance aware CH selection method adopted in the proposed DAIC protocol can also be adapted to other hierarchical clustering protocols for the higher energy efficiency. Ji *et al.* proposed [22], an energy effective routing protocol based on low-energy adaptive clustering hierarchy algorithm. The proposed protocol focuses on some defects of the traditional LEACH, and improves the energy efficiency and other QoS parameters by excluding the node with improper geographic location to be the CHs. In the protocol, the optimum measuring range of head nodes is designed to be a criterion of CH selection, and every CH can be selected according to the node density threshold in the measuring area, which is confirmed by the node distribution situation and communication requirement. In order to minimize the energy consumption caused by large distance of CHs from the BS, Gautam [23], the authors proposed Dynamic clustering and Distance Aware Routing protocol (DDAR) for WSN which takes into account of node distance for selecting CH, dynamic approach of selecting the CH nodes, and two level hierarchy of clustering with Super Cluster Head (SCH) node near to the BS. However, due to multi-hop forwrading for inter-cluster communication, it is easy cause uneven energy comsumption and lead to energy-hole problem [24].

To approach the problem of uneven distribution of CHs, Younis and Fahmy [25] proposed Hybrid Energy- Efficient Distributed Clustering (HEED) algorithm. The algorithm is different from LEACH in CH selection criteria and mechanisms for cluster-head competition. The residual energy is used to select initial CHs set randomly, and the communication costs within clusters are used to determine which cluster a node should belong to. The clustering algorithm of HEED requires repeated message iterations with much communication costs. Li *et al.* [26] proposed an Energy Efficient Uneven Clustering routing protocol (EEUC). Candidate CHs construct clusters of varying sizes according to uneven scope for competition. The cluster near BS is smaller than the far ones, so it can reserve energy to transfer data within clusters. Jiang *et al.* [27] proposed a Distributed Energy Balanced Unequal Clustering routing protocol (DEBUC), which adopts an unequal clustering mechanism in combination with an inter-cluster multi-hop routing. Through a time based competitive clustering algorithm, DEBUC partitions all nodes into clusters of unequal size, in which the clusters closer to the BS have smaller size. The CHs of these clusters can preserve some more energy for the inter-cluster relay traffic, and the “hot-spots” problem can be avoided. For inter-cluster communication, DEBUC adopts an energy-aware multi-hop routing system to reduce and balance the energy consumption of the CHs. Compared to equal clustering, unequal clustering is more conducive to energy balance, but it’s more complex to implement simultaneously.

3 Models and Hypotheses

In order to confirm our idea and complete experiment successfully, the models we mainly used in this paper includes network model, energy consumption model and assessment model for energy balance.

3.1 Network Model

The network studied here is distributed within an $M \times M$ square area, and it consists of N randomly distributed sensor nodes. The application scenario is cyclical collection, and the network features are assumed as follows.

(1) BS locates outside the observation area, both BS and nodes are no longer change positions after being deployed;

(2) All nodes with data integration capability are homogeneous and have roughly equal initial energy;

(3) Each node has a unique identification;

(4) Data fusion technology is used to reduce the amount of data;

(5) All nodes can communicate with BS directly;

(6) According to the distance from receivers, nodes can freely adjust the transmission power to save energy;

(7) Links are symmetric. The distance between sender and nodes can be calculated based on sender’s transmission power.

3.2 Energy Consumption Model

We employ the first-order radio communication energy consumption model used in literature [9]. The model mainly consist of transmit electronics, power amplifier and receive electronics, it is shown in Figure 1.

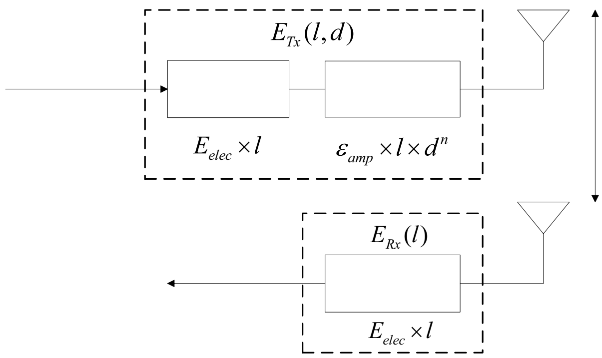

Figure 1. First-order radio communication energy consumption model

The energy consumed by transmitting l bit data over distance d consists of the loss of transmission circuit and power amplification, it can be calculated by Equation (1).

$$E_{Tx}(l,d) = \begin{cases} lE_{elec} + l\varepsilon_{friss-amp}d^2 & (d < d_0) \\ lE_{elec} + l\varepsilon_{two-ray-amp}d^4 & (d \geq d_0) \end{cases} \quad \textbf{(1)}$$

Here, E_{elec} denotes the loss energy when transmit one bit data, d_0 denotes the threshold value of distance. The power attenuation is dependent on the distance between the transmitter and receiver. If transmission distance d is less than d_0, the loss of power amplifier uses free space model, otherwise it uses multipath fading model. $\varepsilon_{friss\text{-}amp}$ and $\varepsilon_{two\text{-}ray\text{-}amp}$ are parameters used in the power amplification loss model and depends on the sensitivity and noise factors of the receiver.

The energy consumed by receiving l bit data is calculated by Equation (2).

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

Data fusion can reduce the amount of data transmission and save the energy of network. In a cluster, the same information data will be detected. We assume that CH receives l bit data from each member node, and compresses all received data into an l bit size. E_f denotes the energy consumption used to fuse one bit data. The energy consumed by fusing l bit data is calculated by Equation (3).

$$E_{fuse}(l) = E_f \times l \tag{3}$$

3.2 Assessment Model for Energy Balance

In probability theory and mathematical statistics, the deviation between random variable and its expectation is measured by variance. In case of same sample, larger variance represents greater volatility of data. According to this feature, we introduce the variance into WSN, and use it to evaluate the energy consumption of network nodes.

Definition 1. The average energy of nodes and residual energy variance: We assume that in a network with N nodes, $E_{i\text{-}rest}$ ($E_{i\text{-}rest} \geq 0$) denotes the residual energy of the i-th node.

Let $E_{average}$ denotes the average energy of all nodes, then it can be calculated by Equation (4).

$$E_{average} = \frac{1}{N}\sum_{i=1}^{N} E_{i-rest} \tag{4}$$

Let S^2_{energy} denotes the variance of residual energy, and it can be calculated by Equation (5).

$$S^2_{energy} = \frac{1}{N}\sum_{i=1}^{N}(E_{i-rest} - E_{average})^2 \tag{5}$$

The smaller S^2_{energy} is, the more uniform energy consumes. Otherwise it means that there is a big difference in energy consumption.

4 An Energy-balanced Cluster Head Selection Method Based on Energy Prediction

Clustering routing has many advantages, such as managing topology conveniently, using energy efficiently and fusing data simply. The basic idea of clustering is fusing data for cluster nodes through CHs and reducing the amount of data transmission through transfer mechanism. It reduces the energy consumption of communication, and achieves the purpose of saving energy in network. The current number of clustering routing algorithms represents insights into the selection of CHs, the information of clusters and the clustering routing. But there are few people concerned the defect in frequent updates of clusters' structure. To solve this problem, we proposed an energy-balanced CH selection method based on energy prediction for clustering routing.

4.1 Basic Idea

LEACH takes "round" as work cycle. In each round, it includes establishment phase and stabilization phase. At establishment phase, CHs are generated randomly and they form clusters dynamically. At stabilization phase, it is mainly for data transmission. In each round, CHs should be reselected and the structure of clusters should be rebuilt, so frequent updates cost much energy. In this paper, we made improvements on the thinking of "round" and proposed an energy-balanced CH selection method based on energy prediction. Its core is to maintain the structure of clusters unchanged in K rounds. In the first round, CHs are selected according to LEACH, and then they are selected based on energy prediction in the remaining K-1 rounds. The advantage of this approach is that the clusters' structure will not change in the later K-1 rounds, what we need to do is select a suitable CH in each cluster. This approach can save energy efficiently for frequent updates of clusters' structure, and it is conductive to energy balance.

In case of unchanged clusters' structure, we can also use the residual energy of cluster members to make energy prediction, but it doesn't take the distance between nodes and BS into account. In this situation, nodes far from BS may be selected as CHs, and they will run out energy quickly, which is bad for energy balance. So we adopt the front method we proposed to select CHs.

4.2 Specific Steps

Predicting energy of nodes requires the distance between nodes and BS, so we design a preparation phase to make sensor nodes acquire and store the distance. After the preparation phase, nodes enter the normal working phase.

Preparation phase. At preparation phase, BS broadcasts messages to the entire monitoring area. Sensor nodes calculate the distance between themselves and BS based on the strength of received signal [28]. The equations are shown as follows.

$$d_{ib} = s \cdot (P^r)^{-1/2} \tag{6}$$

$$s = c \cdot (P^s)^{1/2} 4\pi f \tag{7}$$

In the equations, d_{ib} denotes the distance between node i and BS b, s denotes a constant value used for the communication range, P^r denotes the received signal strength, P^s denotes the sender signal strength, c denotes the speed of light and f denotes the communication frequency.

The biggest advantage of calculating distance by the strength of signal is acquiring distance without the help of GPS. It saves the unnecessary energy consumption and reduces the cost of sensor nodes. The distances between nodes and BS have two uses: (1) To adjust the transmit power when the node become a CH; (2) To calculate the energy consumption by transmitting data..

Working phase. At working phase, it is still makes “round” as work cycle, but it will remain the clusters’ structure unchanged in the recent K rounds. The procedure is shown in Figure 2.

In Figure 2, each round is divided into establishment phase and stabilization phase. At establishment phase, CHs are selected by specific method and they form clusters dynamically. At stabilization phase, it is mainly for data transmission. The stabilization phase can be divided into several frames, and the cluster members transmit data to CH during their own timeslots in each frame. The method A denotes the standard CH selection method used by LEACH, and method B denotes the improved CH selection method based on energy prediction. It takes K rounds as a whole. When one K rounds is over, a new K rounds is begin. At establishment phase of the first round, CHs are selected according to LEACH, and then enter stabilization phase to transmit data. In the remaining K-1 rounds, CHs are selected based on energy prediction, and then enter stabilization phase to transmit data.

The specific steps of building phase in first round are shown as follows.

(1) Generating CHs randomly. In the phase of clusters’ formation, each node automatically generates a random number between 0 and 1. For a node, if the number is less than the threshold $T(n)$, it will become the CH of the current round. The equation of $T(n)$ is shown as follows [9].

$$T(n)=\begin{cases}\dfrac{p}{1-p\times\left[r\bmod(1/p)\right]}, & n\in G\\ 0, & others\end{cases} \quad \textbf{(8)}$$

In Equation (8), p denotes the ratio of CHs, r denotes the current number of rounds, and G denotes nodes set which has not been selected as CHs in the last $1/p$ rounds;

(2) CHs broadcast messages that they become CHs;

(3) Non-CHs receive messages from CHs. They choose the strongest signal source as CH, and inform the CH the information of join. The information contains something about nodes, such as ID, residual energy and the distance to BS;

(4) After CHs have received all the request information of nodes, they will use TDMA technology allocate time slots for the cluster nodes and inform the appropriate node.

The specific steps of stabilization phase in first round are shown as follows.

(1) Non-CHs send the detected data to CHs in their own time slot, and go to sleep in other time slots to save energy;

(2) CHs fuse data from cluster members, and send the processed data to BS.

In the remaining K-1 rounds, the specific steps to select CHs and inform clusters are shown as follows.

(1) In each cluster, CH makes energy prediction for cluster members; it means that calculating the residual energy after the node finish communication as a CH. We use the following equation to calculate the predicted residual energy E_{rest}.

$$E_{rest}=E_{current}-E_{receive}-E_{fuse}-E_{transmit} \quad \textbf{(9)}$$

In Equation (9), $E_{current}$ denotes the current energy of node, $E_{received}$ denotes the energy consumption that node receives data, E_{fuse} denotes the energy consumption that node fuses data, $E_{transmit}$ denotes the energy consumption that node transmits data.

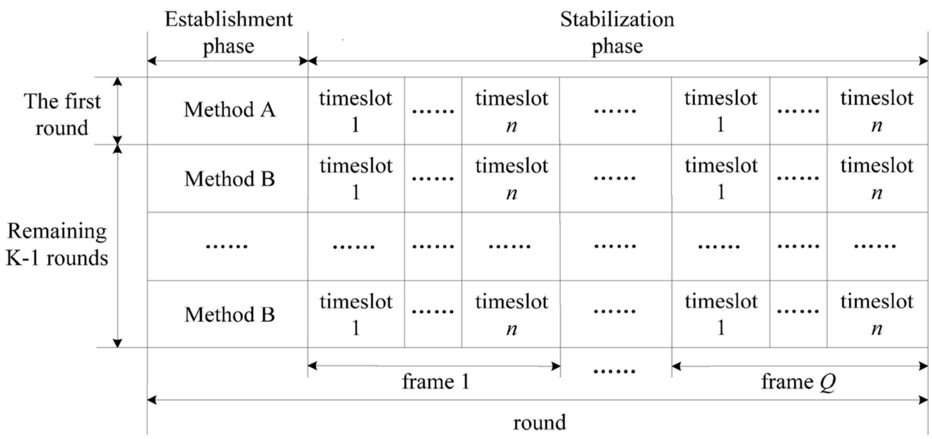

Figure 2. Working phase of nodes’

(2) Predict nodes' residual energy, and choose the node with maximum energy as the new CH. If the node is the old CH, then building phase is over, and enters stabilization phase. Otherwise, the old CH broadcast messages that CH is change, the messages contain *ID* of the new CH. At the same time, the old CH replace the time slot of new CH in stabilization phase, and the other nodes' time slots are not change.

(3) When cluster members receive message that CH is change, they check the *ID* part of message. If the *ID* is the same with itself, the node will be the new CH, and it broadcast messages that it becomes the new CH. When the other nodes receive the messages, they check the *ID* part of messages, and confirm the node is CH. Then they enter stabilization phase.

The whole process is shown in Figure 3.

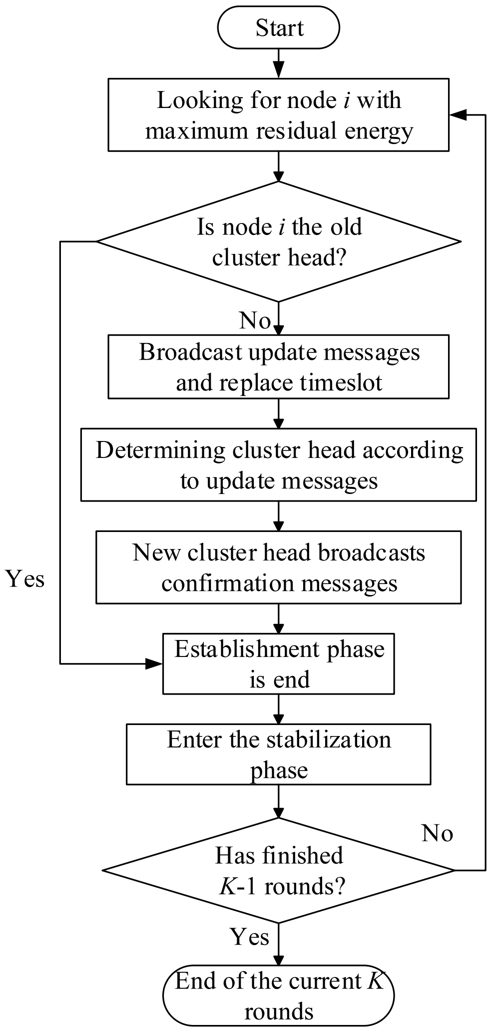

Figure 3. *K*-1 rounds cluster head selection based on energy prediction

In the *K*-1 rounds CH selection based on energy prediction, the old CH replace the time slot of new CH in transmission phase, and the other nodes maintain their time slots unchanged. Even if a node is dead because of running out of energy, the rest nodes will not change their time slots. Because when it runs to the dead node's time slot in stabilization phase, the rest nodes are all in sleeping state; this will not make effect on the whole transmission of data. After keeping clusters' structure unchanged in *K* rounds, clusters need be rebuilt. New CH can allocate time slots according to new cluster members without the influence of dead node. The main steps of CH selection based on energy prediction are shown in Process 1.

Process 1:

```
WHILE (round <= K)
  FOR n = 0 to clusterNodes DO
    EnergyRemain = energyCurrent – energyWillCost
    IF energyRemain > energyMax THEN
      CHeadId = n
    End IF
  End FOR
  IF CHeadId == myId THEN
    fuseData(data)
    WHILE (framesSend < frames)
      sendData(myCHead, myslot)
  ELSE
    replaceSlot(oldCHead, newCHead)
    fuseData(data)
    WHILE (framesSend < frames)
      sendData(myCHead, myslot)
  End IF
End WHILE
```

In the process, *energyWillCost* denotes the energy consumption that the node as a new CH costs in the first round, function *fuseData* denotes the process that CHs fuse the data from cluster members, function *sendData* denotes the process that CHs transmit data to BS in stabilization phase, function *replaceSlot* denotes that old CH replaces the time slot's location of new CH in previous stabilization phase.

The biggest advantage of LEACH-EP is that it reduces the frequent operations to update clusters' structure, which reduces the energy consumption in some degree. At the same time, the CH selection based on energy prediction is conducive to energy balance.

5 Experiment and Analysis

5.1 Simulation Environment

OMNeT++ [29] based on discrete event is a free and open network protocols simulation software which plays an important role in the field of network simulation, it is an extensible, modular, component-based C++ simulation library and framework, primarily for building network simulators, and it is suitable for communication model simulation, protocol simulation, hardware architecture verification, complex software systematic performance assessment and other discrete event driven application simulation.

The simulation with OMNeT++ is running under Ubuntu 12.04 system, some parameters of the simulation environment are shown in Table 1.

Table1. Simulation parameters

Parameters	Value
Range of network	(0, 0)~(100, 100)m
Location of BS	(50, 125)m
Number of nodes	100
Proportion of CH	5%
Initial energy of node	(1±0.00001)J
E_{elec}	50nJ/bit
E_f	5nJ/bit
d_0	87m
$\varepsilon_{friss\text{-}amp}$	10pJ/(bit·m²)
$\varepsilon_{two\text{-}ray\text{-}amp}$	0.0013pJ/(bit·m⁴)
Packet size	4000bit
Q	5

From Table 1, we can see that the network is distributed in a 100m×100m area, and the BS is outside of it. The proportion of CHs is 5%, which is conductive to nodes' energy consumption.

5.2 Theoretical Energy Consumption Analysis

The energy consumption for each node includes $E_{received}$, E_{fuse} and $E_{transmit}$. Since the only difference between LEACH and LEACH-EP is how to select CHs, thus the amount of received data, fused data and transmitted data are equal respectively under both methods. Equation (1) indicates that $E_{transmit}$ is related to the amount of data and the distance between sender and receiver, Equations (2) and (3) shows that $E_{received}$ and E_{fuse} are only related to the amount of data. To simplify the problem, we ignore the little influence brought from data transmission among nodes. Considering the above situation, we can conclude that the differences in energy consumption mainly derived from data transmission from nodes to BS.

Suppose that the network runs S rounds and every node is alive. The distances between nodes and BS arranged in ascending are d_1, d_2, …, d_i, …, d_N. The node's ID correspond to d_i is n_i, and let c_i denotes the energy consumption when n_i transmit data as a CH. Since longer distance leads to bigger consumed energy, then we can get $c_i < c_{i+1}$ $(0 < i < N)$.

For LEACH, each node has equal opportunity to become a CH. Let e_i denotes the expected number that node n_i as a CH. Then $e_i = e_{i+1}$ $(0 < i < N)$, and Equation (10) is established.

$$\sum_{i=1}^{N} e_i = NpS \tag{10}$$

The energy consumption of LEACH can be calculated by Equation (11).

$$E_{leach} = \sum_{i=1}^{N} (e_i \cdot c_i) \tag{11}$$

For LEACH-EP, its aim is to achieve energy balance. Theoretically, the best situation is that each node's residual energy should be equal after S rounds. Thus if the distance between node and BS is big, the node should be less likely be a CH. Let e'_i denotes the expected number that node n_i as a CH. Then $e'_i > e'_{i+1}$ $(0 < i < N)$, and Equation (12) is established.

$$\sum_{i=1}^{N} e'_i = NpS \tag{12}$$

Let $e_X' > pS > e_{X+1}'$ (X is a constant), the energy consumption of LEACH-EP can be calculated by Equation (13).

$$E_{leach-ep} = \sum_{i=1}^{X} (e_i' c_i) + \sum_{j=X+1}^{N} (e_j' c_j) \tag{13}$$

Based on Equation (10) to Equation (13), we can get Equation (14):

$$\begin{aligned} & E_{leach} - E_{leach-ep} \\ &= \sum_{i=1}^{X} [(pS - e_i')c_i] + \sum_{j=X+1}^{N} [(pS - e_j')c_j] \end{aligned} \tag{14}$$

Since $e_X' > pS > e_{X+1}'$, and $0 < c_i < c_{i+1}$, we can get Equations (15), (16) and (17):

$$\sum_{i=1}^{X} [(pS - e_i')c_i] > \sum_{i=1}^{X} (pS - e_i')c_X \tag{15}$$

$$\sum_{j=X+1}^{N} [(pS - e_j')c_j] > \sum_{j=X+1}^{N} (pS - e_j')c_{X+1} \tag{16}$$

$$c_{X+1} = c_X + \Delta c \quad (\Delta c > 0) \tag{17}$$

Based on the Equation (15) to Equation (17), we can get Equation (18):

$$\begin{aligned} & \sum_{i=1}^{X} (pS - e_i')c_X + \sum_{j=X+1}^{N} (pS - e_j')c_{X+1} \\ &= \sum_{i=1}^{X} (pS - e_i')c_X + \sum_{j=X+1}^{N} [(pS - e_j')(c_X + \Delta c)] \\ &= \sum_{i=1}^{N} (pS - e_i')c_X + \sum_{j=X+1}^{N} (pS - e_j')\Delta c \\ &= \sum_{j=X+1}^{N} (pS - e_j')\Delta c \end{aligned} \tag{18}$$

Based on the Equation (14) to Equation (18), we can get that:

$$E_{leach} - E_{leach-ep} > \sum_{j=X+1}^{N} (pS - e_j')\Delta c \tag{19}$$

Equation (19) indicates that LEACH-EP achieves a better performance at energy saving than LEACH.

5.3 Simulation Results and Analysis

For WSNs, the quality of service (QoS) can be defined as the number of awakened sensors [30]. When the number of dead nodes reaches half, its performance will be greatly reduced and the remaining nodes will die quickly because of lack of energy. Therefore, we can make it that whether there are half nodes are survived as a standard to judge the network.

Definition 2. Efficient lifetime: If the number of surviving nodes is no less than half the initial value, we say that the network is in effective lifecycle. If the number of surviving nodes is less than half the initial value, we say that the network's effective lifecycle is over.

LEACH and LEACH-EP are compared in two aspects: network efficient lifetime and the variances of surviving nodes' energy. At the same time, we analyze how the value of *K* affects the efficient network lifetime.

Efficient lifecycle of network. Making energy even distributed on all nodes is one of the targets to design a good cluster routing algorithm. The later the first node dies, the more balanced the energy consumption is.

In case of *K* is 5 in LEACH-EP, we record 12 groups of valid data about LEACH-EP and LEACH. Let A denotes the number of rounds when the first node is dead in case of LEACH, B denotes the number of rounds when the first node is dead in case of LEACH-EP, C denotes the number of rounds when half of the nodes are dead in case of LEACH, and D denotes the number of rounds when half of the nodes are dead in case of LEACH-EP. The results about 4 different situations are shown in Table 2, and the average number of rounds are shown in Figure 4.

Table 2. Relationship between dead nodes and number of rounds

Group Number	A	B	C	D
1	26	30	74	79
2	45	43	75	80
3	26	42	76	79
4	31	51	75	78
5	43	56	74	80
6	40	60	73	80
7	19	58	76	80
8	28	55	73	80
9	37	54	75	77
10	41	57	74	80
11	42	43	76	80
12	33	51	74	80

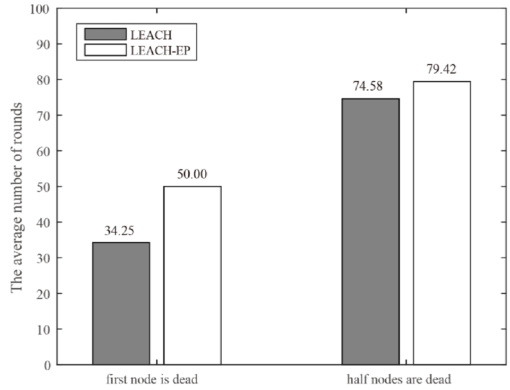

Figure 4. The average number of rounds

From Figure 4, we can see that the average rounds when the first node is dead in case of LEACH-EP is 50, it improves 45.8% compared to the case of LEACH. And the average rounds when half of nodes are dead in case of LEACH-EP is 79.42, it improves 6.4% compared to the case of LEACH.

Simultaneously, the relationship between dead nodes and the number of rounds is shown in Figure 5. From Figure 5, we can see that LEACH-EP delays the dead time of the first node efficiently and it achieves an improvement on the efficient network lifetime.

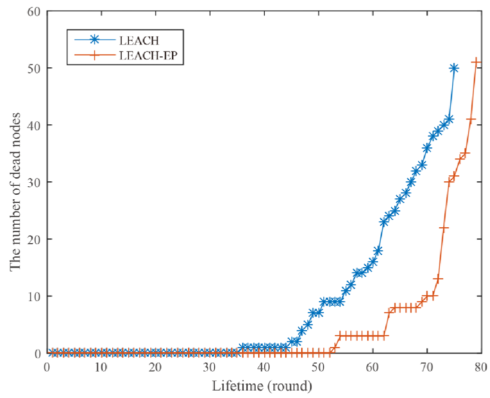

Figure 5. Relationship between dead nodes and the number of rounds

Energy balance. The dead time of first node can reflect from the side that whether the network energy is balance and the assessment model for energy balance can directly reflect nodes' energy consumption.

In case of *K* is 5 in LEACH-EP, we record 12 groups of valid data about LEACH-EP and LEACH. First, we extract the residual energy of surviving nodes in case of first node is dead and half of nodes are dead. Then we calculate the variance of rest nodes' energy based on assessment model for energy balance. In order to observe results conveniently, we extend the value of energy up to 10^6 times. Let E denotes the variance of nodes energy when the first node is dead in case of LEACH, F denotes the variance of nodes energy when the first node is dead in case of LEACH-EP, G denotes the variance of nodes energy when half of nodes are dead in case of LEACH, and H denotes the variance of nodes energy when half of nodes are dead in case of LEACH-EP. The results about 4 different situations are shown in Table 3, and the average variances are shown in Figure 6.

Table 3. The variances of surviving nodes' energy

Group Number	E	F	G	H
1	21017.6	16295.6	5973.17	781.295
2	20695.3	12167.5	4197.33	562.395
3	20696	21750.2	3891.15	241.551
4	24704.8	9822.63	5375.07	643.309
5	25493.3	5718.48	5795.6	362.911
6	24631.8	5142.61	6834.24	352.871
7	16583.1	7326.22	4134.9	670.519
8	23339	7925.31	6924.73	567.11
9	19682.1	7855.63	4479.58	430.544
10	25146.8	7446.55	4001.69	747.33
11	25558.5	9160.25	4503.87	902.691
12	25078.1	7560.68	4310.33	211.163

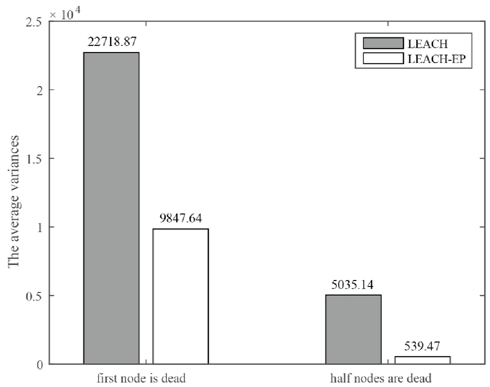

Figure 6. The average variances

From Figure 6, we can get that when the first node is dead in case of LEACH-EP, the variance of average nodes' energy is 9847.64, and it is 43.3% in 22718.9 in case of LEACH; when half of nodes are dead in case of LEACH-EP, the variance of average nodes' energy is 539.474, and it is 10.7% in 5035.14 in case of LEACH. Therefore, comparing to LEACH, LEACH-EP is more conductive to energy balance.

Analysis of *K*. In the design of LEACH-EP, *K* is not a constant, so we need to analyze how the value of *K* influences the efficient network lifetime. In the case of different *K*, we make 5 experiments under the same experimental condition. We record and average the data, results are shown in Figure 7.

From Figure 7, we can see that when the value of *K* is 100, the death time of first node is about 10 rounds, which means big *K* leads to quick death of some nodes. And when the value of *K* is no more than 50, the death time of first node is no less than 40 rounds, which is improved compared to 34.4 rounds of LEACH. The results show that LEACH-EP is more conductive to energy balance, and the influence is obvious when the value of *K* is relatively small.

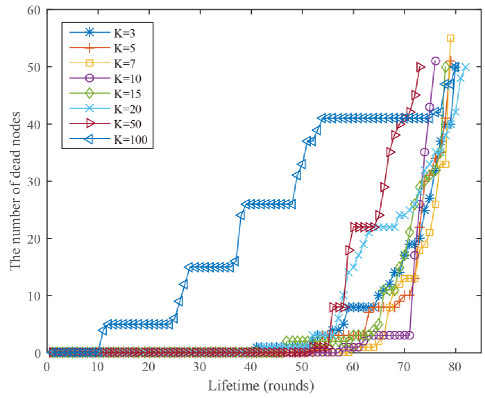

Figure 7. Relationship between dead nodes and the number of rounds

6 Conclusion

Clustering routing can reduce energy consumption of nodes effectively and prolong network lifetime. To approach the problems that clusters' structure update frequently and energy consumption of nodes distributed uneven, we proposed an advance CH selection method LEACH-EP. Its core is to maintain the structure of clusters unchanged in *K* rounds, and selects new CHs based on energy prediction. The simulation results show that LEACH-EP delays the dead time of the first node efficiently and it achieves an improvement on the effective network lifetime. At the same time, it is more conducive to energy balance when the value of *K* is relatively small.

In our study, the value of *K* is fixed in a single experiment, and it will not change during operation. In our next work, we will research on how the dynamic value of *K* influences the network lifetime and nodes' energy balance.

Conflict of Interests

The authors declare that there is no conflict of interests regarding the publication of this paper.

Acknowledgments

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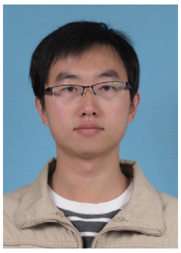

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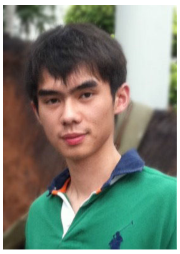

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Background

The aging of world population has pushed the need for designing new, more pervasive, and possibly cost effective healthcare systems. In this field, wireless sensor network is one of the most appealing technologies to achieve continuous monitoring of aged people for their own safety, without affecting their daily activities. Since the energy of sensor nodes is limited and hardly be charged, how to save the energy of nodes to extend the network lifetime has been a research hotspot.

Routing protocols, as an important part of WSN, affect the energy consumption of nodes directly. In order to prolong the network lifetime, we must design good routing protocol. CH selection is one of the most important parts in clustering routing. As a classical algorithm, LEACH is the cornerstone of some good methods, but it also has some disadvantages. For example, it selects new CHs in every round, and a node with low energy may be selected as the head, which will lead to bad energy balance. There have been many methods proposed in the literature attempt to solve the problem that the energy consumption is not even in the network. The different aspects they focused on can be divided into three kinds: the remaining energy of nodes, the location of nodes and the size of cluster. In this paper, the authors proposed an energy-balanced CH selection method based on LEACH. Its core is to maintain the structure of clusters unchanged in K rounds. In the first round, CHs are selected according to LEACH, and then they are selected based on energy prediction in the remaining *K*-1 rounds. The results show that the proposed method delays the dead time of the first node efficiently and it is more conducive to energy balance.