

LEACH-G: an Optimal Cluster-heads Selection Algorithm based on LEACH

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Abstract—As a classic clustering algorithm, LEACH is widely used in wireless sensor networks. Due to the random cluster head selection process, LEACH does not guarantee optimization for the number and position of cluster heads. In order to further optimize LEACH, an optimal energy-efficient cluster-heads selection algorithm LEACH-G for LEACH protocol is presented. We calculate the optimal number of cluster heads based on energy model for LEACH algorithm, and further set forth on LEACH-G algorithm for optimal cluster heads. We use NS2 simulation platform to compare LEACH-G with LEACH. By calculating the optimal number of cluster-heads, the energy consumption of the sensor nodes in LEACH-G algorithm can be more evenly distributed in the wireless sensor networks to avoid too much energy consumption of single node to untimely death, which affect the network life cycle. Compared with LEACH protocol, the simulation results demonstrate that LEACH-G algorithm can effectively reduce the energy consumption and increase the system lifetime.

Index Terms—WSN, LEACH, Cluster head

I. INTRODUCTION

LEACH (Low Energy Adaptive Clustering Hierarchy) is a classic clustering algorithm, which is widely used in wireless sensor networks. LEACH randomly selects cluster head node circularly to balance energy of each sensor node in the whole network. In the original LEACH algorithm, it only manages cluster-head nodes by taking classification of cluster, and cluster-head nodes can consume energy in the process of data transmission between with the base station. Due to the random cluster head selection process, LEACH does not guarantee the optimization for the number and position of cluster heads [1]. Because cluster-head nodes in wireless sensor networks may be far away from the base station, or there exists many obstacles in deployment environments of wireless sensor networks to affect the data transmission performance, they would consume excessive energy in the process of the massive data transmission, which may lead to their earlier death and even shorten network lifetime [2]. System lifetime is one of the most important design factors in wireless sensor network [3-8]. So, how to optimize the number of clusters is an essential problem in wireless sensor networks.

The number of clusters is an expected value. In the practical sensor network environment, as the randomness

and instability of the computational method, it will cause the instability of cluster-head nodes, which will influence the performance of the wireless sensor networks. Meanwhile, the LEACH protocol will select cluster-head nodes randomly, thus the number may deviate from the most optimal cluster number. When the number of cluster is too few, the network will lose the concept of layers. Too much energy consumption of cluster heads will cause early death of nodes; when the number of cluster is too excessive, it will cause transmission data overload of the base station, which will affect the entire network energy consumption, thus reducing the life cycle of the WSN. LEACH does not consider the number of cluster head, monitoring areas and other factors, the network greatly consumes huge reduce the life cycle of the network [9]. In order to further optimize the classical level routing protocol LEACH, and the key is how to improve LEACH cluster head selection algorithm to prolong the network lifetime and success rate of data transmission.

To overcome the deficiency of LEACH, many scholars have launched research in this field [10-13]. A sliding window is set up to adjust the electing probability and manage to keep stable the expected number of the cluster heads, and this method can balance the energy consumption and extend the network lifetime better[14]. To correctly quantify the lifetime, a utility based lifetime measurement framework called Weighted Cumulative Operational Time (WCOT) is proposed [15]. LEACH is analyzed for mobility, and the model evaluates data loss after construction of the clusters due to node mobility, and sets a topology update interval to balance the energy and data loss ratio [16]. An energy-aware distributed dynamic clustering protocol (ECPF) is proposed, and simulation results demonstrate that ECPF performs better than LEACH, HEED, and CHEF in terms of extending network lifetime and saving energy [17]. The predictability of the network lifetime to enable the High Energy First (HEF) clustering algorithm to work in a hard lifetime environment is studied [18]. A novel energy efficient and unequal clustering algorithm for large scale wireless sensor network is proposed to balance the node power consumption and prolong the network lifetime as long as possible [19]. Power-aware routing in wireless sensor networks focuses on the crucial problem of extending the network lifetime of WSNs, which are limited by low-capacity batteries [20]. An energy

efficient clustering algorithm with optimum parameters is used for reducing the energy consumption and prolonging the system lifetime [21]. A HAMS protocol is proposed to optimize the network lifetime and save energy for wireless sensor networks. This scheme extends LEACH protocol to enable the cooperative MIMO transmission between the sink and clusters [22]. Among traditional wireless sensor routing algorithm like LEACH, period uncertainty of periodic cluster head and unbalanced energy consumption between clusters come into being. Aiming at problem of unbalanced energy consumption between wireless sensor clusters, uneven clustering strategy is used in this research [23]. An improved application method of quadratic-standard form based on LEACH protocol is presented in intelligent space to use calculation method of cluster head election threshold, considering the factor of node residual energy [24]. Many intelligent algorithms such as ant colony algorithm [25] and other swarm intelligence methods [26] are used to optimize route selection among cluster-head nodes in wireless sensor networks. A cluster head optimization strategy for wireless sensor network is proposed by using UMDA. The novel routing protocol is named UMDA_LEACH. Simulation results show that UMDA_LEACH has better performance than LEACH protocol [27]. A centralized routing protocol CBCDACP where the base station centrally performs the cluster formation task is introduced [28]. Compared with LEACH and LEACH-C, simulation results show that CBCDACP can improve system energy efficiency and life time in terms of different simulation performance metrics over its comparatives. In order to reduce the energy dissipation of transmitting data at each sensor, a novel energy efficient data clustering method to improve energy efficiency for cluster-based wireless sensor networks is presented [29]. Simulation results show that EEGC obviously reduces the energy consumption of the sensors and extends network lifetime to be longer than LEACH for life rate. Moreover, the total transmission data of EEGC is much more than LEACH protocol. A two layer hierarchical tree routing protocol with location-based uniformly clustering strategy in Wireless Sensor Network is proposed [30], which can gives a good compromise between energy consumption and delay. Simulation results show that TRPLUS performs better than LEACH in terms of energy delay cost metric. A modified protocol based on LEACH protocol called Adaptive and Energy Efficient Clustering Algorithm for Event-Driven Application in Wireless Sensor Network is introduced [31], which aims to prolong the lifetime of a sensor network by balancing energy usage of the nodes.

In this paper, an optimal energy-efficient cluster heads selection algorithm for LEACH protocol is presented, namely LEACH-G. In section 2, LEACH algorithm is briefly introduced. In section 3, we calculate the optimal numbers of cluster heads based on energy model for LEACH algorithm. Then, we further set forth on LEACH-G algorithm for optimal cluster heads selection in section 4, and give simulation results and analysis is section 5.

II. LEACH ALGORITHM

In the process of LEACH running cycle, the cluster reconstruction executives cyclic, the reconstruction process can be described as the concept of round. Each round can be divided into two phases: phase of establishment and phase of stable data transmission. The process of establishing cluster is divided into four stages: the first node selection, cluster of the first node, establishment of radio and cluster scheduling mechanism formation. The specific choice of cluster head node is: sensor network will calculate a threshold according to some factors, so when electing each round of cluster head of nodes, each sensor node will choose a random value ranged from 0 to 1. If the value of a sensor node is less than the threshold, then this node is chosen to be the first node in the cluster.

The formula of $T(n)$ is as follows:

$$T(n) = \begin{cases} \frac{p}{1-p*(r \bmod \frac{1}{p})} & \text{if } n \in G \\ 0 & \text{others} \end{cases} \quad (1)$$

Where p is the ratio of the number of cluster nodes in the network to the total number of nodes; r is the current election rounds; G is the $1/p$ recently. Then, elected cluster head node broadcasts a message about the first node cluster to the entire network. The rest nodes of the network decide to join which cluster according to signal strength of received information, and notify the corresponding cluster head node, completing the establishment of the cluster.

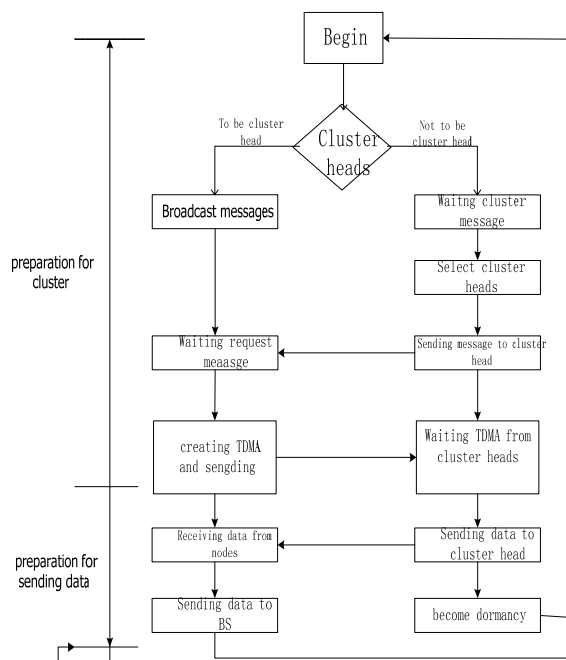


Figure 1. Flow chart of LEACH protocol

Finally, cluster head nodes use TDMA sequence to distribute timing data into each node. Data transmission begins in the stable stage. The sensor nodes send data to cluster head node, then all of collected data into the cluster-head node integrated with information, and then the cluster-head node transfers integrated information to the BS (base station). The flow chart of the algorithm LEACH protocol is in Figure 1.

III. MODELING ON OPTIMAL NUMBERS OF CLUSTER HEADS

A. Energy Model for LEACH Algorithm

First Radio Model is the channel model for LEACH. This model has the following characteristics: sensor nodes are exactly uniform and limited energy; energy consumptions of nodes are same in any direction; base station node is still and far away from WSN. Usually, free space attenuation channel mode and multipath fading channel model are used to calculate energy consumption in the process of routing data transmission. We choose the channel mode according to the distance between the transceivers. When the distance between the transceivers is less than d_0 , free space attenuation channel mode is appropriate, or else multipath fading channel model. The energy consumption of the sensor node in the process of sending 1 Kbit data is:

$$E_{TX}(k, d) = E_{elec} \times k + \varepsilon_{amp} \times k \times d^r \quad (2)$$

The energy consumption of the sensor node in the process of receiving 1 Kbit data is:

$$E_{RX}(k) = E_{elec} \times k \quad (3)$$

In the above formula 2 and formula 3, E_{elec} is circuit energy consumption in the process of sending and receiving data, ε_{amp} is magnification times of signal amplifier. Energy consumption of radio signal transmission is proportional to the distance d^r . If transmission distance is short, $d < d_0$ and $r = 2$; else if transmission distance is long, $d > d_0$ and $r = 4$.

The energy consumption sending 1Kbit data from a non-cluster-head node to a cluster-head node is:

$$E_{TX}(k, d) = E_{elec} \times k + \varepsilon_{amp} \times k \times d^2 \quad (4)$$

The energy consumption sending 1Kbit data from a cluster-head node to a base station node is:

$$E_{TX}(k, d) = E_{elec} \times k + \varepsilon_{amp} \times k \times d^4 \quad (5)$$

In each cluster of WSN, the distance between non-cluster-head node and cluster-head node is $d_{toCH} < d_0$, and the distance between cluster-head node and base station node is $d_{toCH} > d_0$.

B. Optimal Numbers of Cluster Heads

Research shows that the number of cluster nodes has a strong effect on both the life cycle and energy consumption of the network. The original LEACH cluster head selection algorithm depends on the random number which is generated by the sensor node, and instability of random number leads to the instability of the number of the sensor nodes. The calculated optimal cluster K_{opt} is an expected value, but in the real number of the cluster heads in real WSN environment may be far from expectation K_{opt} .

Assume that N nodes distribute in the $M \times M$ area and the optimal number of cluster heads is K , which means the sensor nodes are distributed in K clusters and each cluster have N/K nodes. Assume that each cluster has a cluster-head node and $\frac{N}{K} - 1$ cluster nodes; each node has the same processing power and communication ability, and transmitted power can be controlled. We put forward the optimal cluster head number in the algorithm, the energy consumption of the whole network is divided into three parts:

1) The first part: energy consumption in the stage of cluster head selection

Energy consumption of Cluster head node is as follows. In formula 6, the first portion represents the energy consumption of broadcast information which is transferred by cluster head node; the second portion is the energy consumption when $\frac{N}{K} - 1$ non-cluster-head nodes in the same cluster receive data from cluster head node; the third portion is the energy consumption when the cluster head node broadcast message of the CDMA and TDMA.

$$E_{CH-elec} = \{E_{elec} + l\varepsilon_{fs}d_{toCH}^2\} + \{(\frac{N}{K} - 1)E_{elec}\} + \{(\frac{N}{K} - 1)(E_{elec} + l\varepsilon_{fs}d_{toCH}^2)\} \quad (6)$$

Because the sensor network distributes equally, we put $E(d_{toCH}^2) = (\frac{M^2}{2K\pi})$ into the above formula 6, and it can be expressed as follows:

$$E_{CH-elec} = (\frac{2N}{K} - 1)E_{elec} + l\varepsilon_{fs} \frac{M^2}{2k\pi} \frac{N}{K} \quad (7)$$

The energy consumption of the non-cluster-head node can be expressed in formula 8. In formula 8, the first portion is the energy consumption when receiving broadcast message from cluster head node; the second portion is the energy consumption when responding to message from cluster head node; the third portion is the energy consumption when receiving the confirmation message from cluster head node.

$$E_{non-CH-elec} = lE_{elec} + \{lE_{elec} + l\epsilon_{fs}d_{toCH}^2\} + lE_{elec} \quad (8)$$

Put $E(d_{toCH}^2) = (\frac{M^2}{2K\pi})$ into the above formula 8, it can be simplified as:

$$E_{non-CH-elec} = 3lE_{elec} + l\epsilon_{fs} \frac{M^2}{2k\pi} \quad (9)$$

2) The second part: energy consumption in the stage of data transmission

In data transmission stage, the energy consumption of a cluster head node can be expressed as formula 10. In formula 10, the first portion is the energy consumption when receiving from all non-cluster-head nodes; the second portion is the energy consumption from data fusion; the third portion is the energy consumption which is transmitted data from cluster head node to base station. Formula 10 can be simplified as formula 11.

$$E_{CH-data} = \{(\frac{N}{K}-1)lE_{elec}\} + \{lE_{DA} \frac{N}{K}\} + \{lE_{elec} + l\epsilon_{amp}d_{toBS}^4\} \quad (10)$$

$$E_{CH-data} = \frac{N}{K}lE_{elec} + lE_{DA} \frac{N}{K} + l\epsilon_{amp}d_{toBS}^4 \quad (11)$$

The energy consumption of non-cluster-head node in the process of data transmission is as follows:

$$E_{non-CH-data} = lE_{elec} + l\epsilon_{fs} \frac{M^2}{2k\pi} \quad (12)$$

3) Total energy consumption

Therefore, the total energy consumption in a cluster is expressed as formula 13. In the formula 13, the first portion is the energy consumption in the stage of cluster-heads selection; the second portion is the energy consumption in the stage of data transmission. The total energy consumption of K clusters can be expressed as formula 14:

$$E_{cluster} = \{E_{CH-elec} + (\frac{N}{K}-1)E_{non-CH-elec}\} + \{E_{CH-data} + (\frac{N}{K}-1)E_{non-CH-data}\} \quad (13)$$

$$E_{total} = kE_{cluster} = k(E_{CH-elec} + (\frac{N}{K}-1)E_{non-CH-elec}) + k(E_{CH-data} + (\frac{N}{K}-1)E_{non-CH-data}) \quad (14)$$

Put the above formula into formula 14, then differentiate to K, and $\frac{dE_{total}}{dk} = 0$. The optimal number of cluster heads is calculated as:

$$K_{opt} = \sqrt{\frac{N}{2\pi}} \sqrt{\frac{\epsilon_{fs}}{\epsilon_{amp}d_{toBS}^4 - E_{elec}} M} \quad (15)$$

IV. LEACH-G ALGORITHM FOR OPTIMAL CLUSTER HEADS SELECTION

LEACH-G algorithm can be divided into three stages:

1) Stage of clusters establishment

According to the above optimal cluster-heads number K_{opt} derived the formula 15, all nodes in an area will be clustered using distance relationship to make the real number of clusters equal with the expected cluster-heads number K_{opt} . The specific process is as follows:

- Step1.** Decide the number of clusters K according to the optimal number of cluster-heads.
- Step2.** The base station broadcasts a short message.
- Step3.** Once network node receives the message from base station, it will return its own current information, such as position and node ID number, to base station.
- Step4.** According to the time slice of node messages return to base station, base station choose a maximum-return-time node as a cluster head. Then, base station sends ID of the cluster head to all sensor nodes in the WSN.
- Step5.** The cluster head broadcast a short message in the WSN again.
- Step6.** When sensor node receives the short message from the cluster head, it returns its node information the cluster head.
- Step7.** The cluster head choose $N/K-1$ minimum-return-time nodes as its cluster member nodes according to length of information time slice from responded nodes. Meanwhile, cluster member nodes will send a message including cluster ID and node ID within the cluster to base station. If a node joins to a cluster, it cannot join to other cluster.
- Step8.** Cluster head choose another maximum-return-time node as the next cluster head according to the time slice of node messages, and send the next cluster ID and the next cluster head node ID to base station.
- Step9.** Repeating steps from 5 to 8 until the number of clusters is equal K_{opt} .
- Step10.** When the number of selected cluster is equal to K_{opt} , sensor nodes within each cluster to select their cluster heads.

Figure 2 is flow chart of Cluster Establishment Stage.

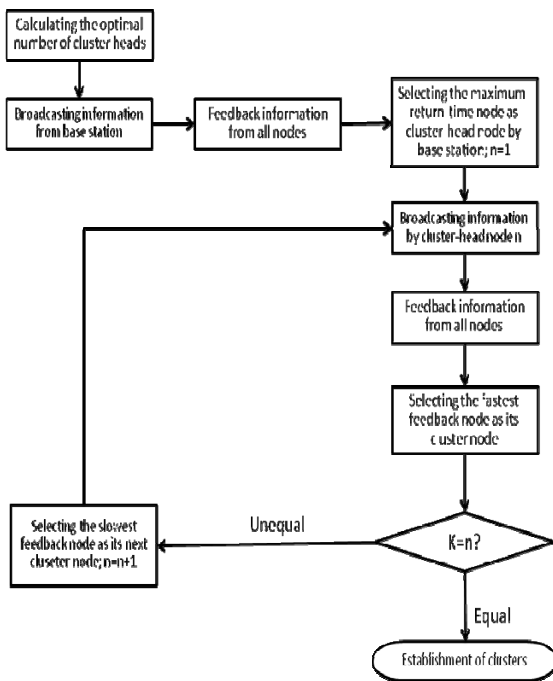


Figure 2. Flow Chart of stage of clusters establishment

2) Stage of sequential establishment

This stage mainly charges cluster-heads reselection after clusters are formed, and creates TDMA sequence for each node. Each node will broadcast an ADV message. If the residual energy of a node is sufficient, its transmission speed for information broadcast is faster than that of a node with insufficient residual energy. So, we can select cluster head node in terms of its residual energy. Then, each node can transmit data stably by creating TDMA sequence.

The key pseudo-code about cluster-head selection is described as follows:

```

Cluster Form
{
  //In each cluster
  If(EResidual==Biggest){
    EResidual.flag=Cluster_Head;
    Broadcast ADV(CH_ID,GROUP_ID_CH)
  }
  If(Node_GROUP_ID_CH== GROUP_ID_CH){
    Non_CH not Broadcast ADV(CH_ID,GROUP_ID_CH)
    Non_CH send Join_Message(NODE_ID,CH_ID)
    //when receiving Join_Messag
    CH send(TDMA)
  }
}
  
```

3) Stage of stable transmission

Once each non-cluster-head node has collected data in the cluster, it sends data to cluster head in terms of TDMA sequence. In other time, it can enter sleeping state to save energy. After each cluster head node has received data, it processes related data fusion and sends data

fusion to the base station. Having reached a round of data transmission, all sensor nodes get rid of their cluster flag, so as to next round of clustering, cluster-head selection and data transmission.

V. SIMULATION RESULTS AND ANALYSIS

Energy is the key factor needed to consider in WSN. How much energy consumption directly affects the service life of WSN. We use NS2 simulation platform to compare LEACH-G with LEACH. First of all, setting up the related simulation environment, get useful and detailed simulation data about energy consumption and lifetime of each node in documents such as leach.energy, leach.alive files, leach.alive and leach.energy. In the process of simulation, we use awk to extract useful data from files leach.alive and leach.energy. In order to compare with LEACH and LEACH-G, we use the following indicators:

- 1) The number of survival nodes in the wireless sensor network.
- 2) The total residual energy of nodes.
- 3) Received data packets of base station.
- 4) Network lifetime.

The simulation parameters and node distribution files are same in the process of simulation between LEACH and LEACH-G protocol. The simulation parameters settings are listed in table 1.

TABLE I. SIMULATION PARAMETERS SETTINGS

Parameter Name	Default Parameter Value
Number of nodes	100
Initial energy	2J
Simulation area	100m*100m
Channel bandwidth	1Mb/s
Energy Consumption of Transmitting	50nJ/bit
Energy Consumption of amplifier	10pJ/bit/m ²
Energy Consumption of data fusion	50nJ.bit/signal
Packet size	100bytes

Figure 3 and figure 4 demonstrate statistical results from 60 rounds of random cluster division simulation between LEACH protocol and LEACH-G algorithm. Seen from figures, the number of clusters from LEACH widely ranges from 1 to 15, while that of LEACH-G basically ranges from 4 to 8. Due to LEACH protocol randomly forms cluster heads according to the given

threshold value, the number of clusters is not stable and widely distributed.

The LEACH-G protocol is improved to takes into consideration energy consumption of cluster-heads selection when calculating the whole energy consumption. Moreover, the optimal number of cluster-heads formula largely improves the cluster-heads selection algorithm. By calculating the optimal number of cluster-heads, the selective number of cluster-heads is more and more reasonable and stable, ranging from 4 to 8.

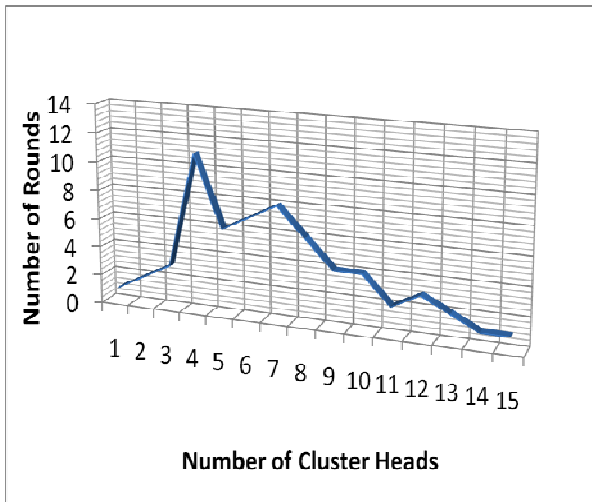


Figure 3. Quantitative distribution of cluster heads in Leach Protocol

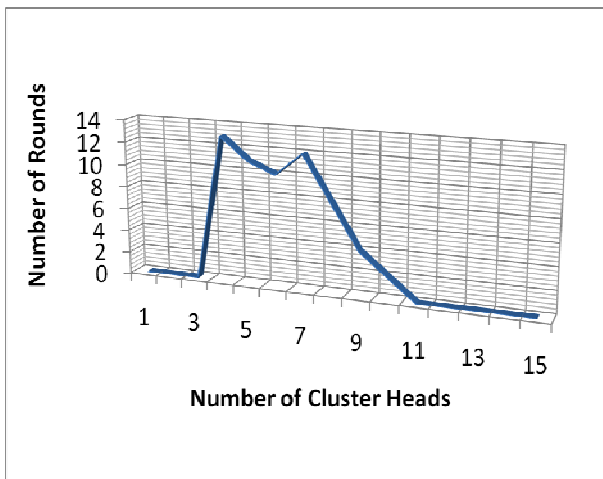


Figure 4. Quantitative distribution of cluster heads in Leach-G Protocol

Figure 5 shows comparison of network lifetime between LEACH and LEACH-G. Seen from figure 5, death time of the first node in LEACH-G algorithm is later than that in LEACH protocol; when all nodes run out of energy in LEACH protocol, nodes in LEACH-G can still run several rounds. Novel LEACH-G algorithm takes into consideration energy consumption in the stage of cluster-heads selection.

By calculating the optimal number of cluster-heads, the energy consumption of the sensor nodes in LEACH-G algorithm can be more evenly distributed in the WSN to

avoid too much energy consumption of single node to untimely death, which affect the network life cycle. This simulation only sets 100 sensor nodes, and if the number setting of nodes is more, LEACH-G algorithm will get better effect compared with LEACH protocol.

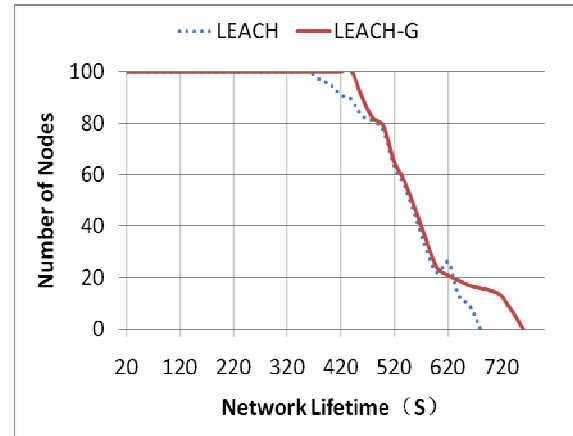


Figure 5. Comparison of network lifetime between LEACH and LEACH-G

VI. CONCLUSION

LEACH algorithm as a classic clustering algorithm is widely used in wireless sensor networks. In order to further optimize the classical level routing protocol LEACH, and the key is how to improve LEACH cluster head selection algorithm to prolong the network lifetime. An optimal energy-efficient cluster heads selection algorithm for LEACH protocol is presented, namely LEACH-G. We calculate the optimal numbers of cluster heads based on energy model for LEACH algorithm, and further set forth on LEACH-G algorithm for optimal cluster heads. Compared with LEACH protocol, the simulation results demonstrate that LEACH-G algorithm can effectively reduce the energy consumption and increase the system lifetime.

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