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# An Energy-Balanced Clustering Routing Algorithm for Wireless Sensor Network

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## Abstract

In this paper, we consider a network of energy constrained sensors deployed over a region. Each sensor node in such a network is systematically gathering and transmitting sensed data to a base station (via cluster-heads). This paper focuses on reducing the power consumption of wireless sensor networks. Firstly, we proposed an Energy-balanced Clustering Routing Algorithm called LEACH-L, which is suitable for a large scope wireless sensor network. Secondly, optimum hop-counts are deduced. Lastly, optimum position of transmitting node is estimated. Simulation results show that our modified scheme can extend the network lifetime by up to 80% before first node dies in the network. Through both theoretical analysis and numerical simulations, it is shown that the proposed algorithm achieves higher performance than the existing clustering algorithms such as LEACH, LEACH-M.

**Keywords:** Wireless Sensor Network, LEACH, Energy Efficient, Multiple-Hop

## 1. Introduction

Wireless Sensor Networks (WSNs) can collect reliable and accurate information in distant and hazardous environments, and can be used in National Defence, Military Affairs, Industrial Control, Environmental Monitor, Traffic Management, Medical Care, Smart Home, etc. The sensor whose resources are limited is cheap, and depends on battery to supply electricity, so it's important for Routing to efficiently utilize its power.

In this paper, we propose an advanced multiple-hop routing protocol named LEACH-L, whose features can be described as follows: when the cluster-heads are close to, they directly communicate with Base station (BS); when they are far in distance, they telecommunicate by multiple-hop way, and the shortest transmission distance is limited. The sensors in different areas use different frequencies and gaps to communicate with BS. In the last part, the authors respectively simulate LEACH [1], LEACH-M [2], and LEACH-L on the Matlab. The simulation experiments indicate that: LEACH-L can prolong the whole network lifetime.

## 2. Related Works

Various issues in the design of wireless sensor networks such as the design of low-power signal processing architectures, low power sensing interfaces, energy efficient wireless media access control and routing protocols, have been areas of extensive research in recent years. LEACH is one of the first hierarchical routing approaches for sensors networks, which attempts to improve energy and routing efficiency of such networks. The idea proposed in LEACH has been an inspiration for many hierarchical routing protocols, although some protocols have been independently developed.

In [2], the author puts forward energy-LEACH and multihop-LEACH protocols called LEACH-M. Energy-LEACH protocol improves the choice method of the cluster head, makes some nodes which have more residual energy as cluster heads in next round. Multihop-LEACH protocol improves communication mode from single hop to multi-hop between cluster head and sink. Simulation results show that energy-LEACH and multihop-LEACH protocols have better performance than LEACH protocols.

In [3], a radio irregularity model is proposed aiming at location and topology control. The simulated results show that radio irregularity has a relatively larger impact on the routing layer than the MAC layer. It also shows that radio irregularity leads to larger localization errors and makes it harder to maintain communication connectivity in topology control.

In [4], author addresses the problem of clustering in WSNs, subject to upper bounds on the maximum latency, the energy consumed by intermediate nodes, and clusters size. Those constraints are necessary for the reliability of the system and for extending its lifetime.

In [5], author proposes a novel energy efficient clustering scheme for single-hop wireless sensor networks. A novel cost function is introduced to balance the load among the cluster heads and prolongs the network lifetime significantly against the other clustering protocols such as LEACH.

In [6], an Energy-Efficient Unequal Clustering is proposed for multihop sensor network. Simulation results show that the unequal clustering mechanism balances the energy consumption well among all sensor nodes and achieves an obvious improvement on the network lifetime.

In [7], a novel multicast protocol, uCast is proposed for energy efficient content distribution in sensor networks. The uCast support a large number of multicast sessions, especially when the number of destinations in a session is small.

In [8], a novel energy-efficient protocol is proposed, called Route Maintenance based-on Energy Threshold and extends the lifetime of nodes and enhance the efficiency of the entire network.

LEACH-C uses a centralized algorithm to form clusters [9]. A non-autonomous cluster-head selection is again the main disadvantage of this algorithm. Moreover, it requires the location information of all nodes in the network. However, location information in mobile wireless networks is only available through GPS or a location-sensing technique, such as triangulation which requires additional communication among the nodes.

In [10], DCHS algorithm is proposed. In this algorithm, in order to extend the lifetime, a parameter En_current/En_max is introduced. Nevertheless, it has a crucial disadvantage: After a certain number of rounds the network is stuck, although there are still nodes available with enough energy to transmit data to the base station, so DCHS algorithm need be improved.

## 3. LEACH-L Algorithm

In order to explain our idea, we fist define some parameters as follows.

The $E_{elect}$ is consumed energy per bit.

The $\varepsilon_{fs}$ and $\varepsilon_{mp}$ are consumed energy per bit and per area respectively.

The $d_o$ is a distance, which decide the parameter value both $\varepsilon_{fs}$ and $\varepsilon_{mp}$.

The $E_{DA}$ is the energy required for data aggregation.

The $p$ is a cluster-head section probability, used during cluster creation.

The round is the time, which all cluster members communicate with cluster heads and cluster heads communicate with BS.

### 3.1. Problem Formulation

This paper proposes a modification of LEACH cluster-head selection algorithm to reduce energy consumption. For a microsensor network, we make the following assumptions:

- The base station (BS) is located among the sensors and is stationary.
- All nodes in the network are homogenous and energy-constrained.
- All nodes are able to reach BS in one hop.
- Nodes have location information.
- Propagation channel is symmetric.

Cluster-heads perform data compression.

This paper presents an improvement to the LEACH's cluster-head selection algorithm by introducing distance-based factor, called LACH-L. In LEACH-L, the clusters are re-established in each round. Each of these rounds consists of a set-up and a steady-state phase. New cluster heads are elected in each round and as a result the load is well distributed and balanced among the nodes in the network. Moreover, each node transmits to the closest cluster-head to split the communication cost to the sink. Only the cluster head has to report to the sink and may consume a large amount of energy, but this happens periodically for each node. During the set-up phase cluster-heads are determined and the clusters are organized. During the steady-state phase data transfers to the base station occur.

We use a simplified model shown in **Figure 1** for the radio hardware energy dissipation. Both the free space ($d^2$ power loss) and the multi-path fading ($d^4$ power loss) channel models are used in the model, depending on the distance between the transmitter and receiver. Transmission ($E_{Tx}$) and receiving costs ($E_{Rx}$) are calculated as follows [9]:

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

where $d$ is the distance between the transmitter and the receiver.

Where is:

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

The following equation shows the amount of energy required to receive each message.

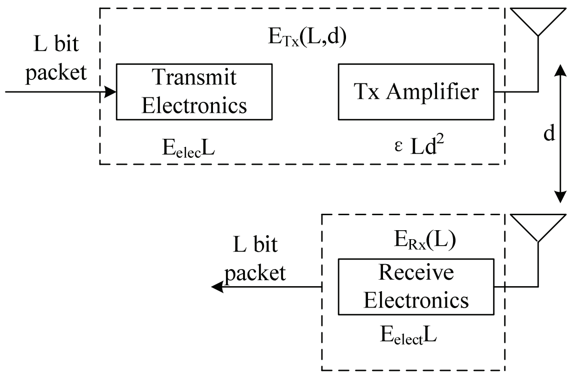


**Figure 1. Radio energy dissipation model.**

$$E_{Rx}(L) = E_{elect}L \quad (3)$$

with $L$ as the length of the message in bits, d as the distance between transmitter and receiver node. A sensor node also consumes $E_{DA}$ amount of energy for data aggregation. We assumed that the sensed information is highly correlated, thus the cluster-head can always aggregate the data gathered from its members into a single length-fixed packet.

## 3.2. Problem in Single-hop Routing

When the scope of WSN gets larger, the diversity of energy consumption among cluster-heads of LEACH as well gets larger.

Let's suppose that there are cluster-heads $S(i)$ which is r far from the BS and $S(j)$ which is 3r far from the BS.

When $r \ge d_0$, the energy consumption of $S(i)$ is listed as

$$E_{Tx}(k,r) = kE_{elect} + k\varepsilon_{mp}r^4$$

The energy consumption of *S*(*j*) is written as

$$E_{Tx}(k,r) = kE_{elect} + 81k\varepsilon_{mp}r^4$$

In the formula, when the circuit consumption is the same, the energy consumed by transmit amplifier of *S*(*i*) is 8l times as much as that of *S*(*j*) so WSNs in large scope should adopt multiple-hop routing protocols.

## 3.3. Introducing Multiple-Hop Routing

The data collected by myriad sensors flow to a small number of BS, which leads to the energy of sensors which near to basic be used up quickly and leads to the break of networks, so the question existing in many-to-one networks is viewed as the hot spot [11]. Meanwhile, only considering the shortest route will result in the geographic superiority of individual sensor embodied in the multiple routes, and this is proved in LEACH-M. Besides, multiple-hops routing cuts down the communication consumption, but increases the circuit energy consumption. In order to go on the research, let's suppose that there is a linear network model, as shown in **Figure 2.**

The cluster-head which is nr far from the BS, if direct communication protocol is adopted, so the total energy consumed by network is:

$$E_{direct} = E_{Tx}(k,nr) = E_{Tx-elect}(k) + E_{Tx-amp}(k,nr)$$

If multiple-hop transmission is adopted, the total energy consumed by network is:

$$\begin{aligned} E_{multihop} &= nE_{Tx-elect}(k) + (n-1)E_{Tx-elect}(k) \\ &\quad + nE_{Tx-amp}(k,nr) \\ &= (2n-1)kE_{Tx-elect} + nE_{Tx-amp}(k,r) \end{aligned}$$

This paper adopts the parameters of **Table 1** in the fifth chapter. There are following conclusions:

When $r \ge d_0$, so

$$E_{direct} - E_{multihop} =$$
$$n^4r^4k\varepsilon_{mp} - 2(n-1)kE_{elect} - nr^4k\varepsilon_{mp}$$

When $nr \le d_0$, so

$$E_{direct} - E_{multihop} =$$
$$n^2r^2k\varepsilon_{fs} - 2(n-1)kE_{elect} - nr^2k\varepsilon_{fs} < 0$$

When $r < d_0$, $nr \ge d_0$, so

$$E_{direct} - E_{multihop} =$$
$$n^4r^4k\varepsilon_{mp} - 2(n-1)kE_{elect} - nr^2k\varepsilon_{fs} < 0$$

When $r > \frac{d_0}{n}\left(\frac{d^2 + 40000n^2(n-1)}{4n^2d^2}\right)^{\frac{1}{4}}$, so

$$n^4r^4k\varepsilon_{mp} - 2(n-1)kE_{elect} - nr^2k\varepsilon_{fs} > 0$$

When $r \le \frac{d_0}{n}\left(\frac{d^2 + 40000n^2(n-1)}{4n^2d^2}\right)^{\frac{1}{4}}$, so

$$n^4r^4k\varepsilon_{mp} - 2(n-1)kE_{elect} - nr^2k\varepsilon_{fs} \le 0$$

Therefore, when the nodes are close to the BS, directly communicate routing can exhibition a good result; when the transmission distance is long, under limiting each transmitting distance the multiple-hop strategy can reduce the energy consumption of WSN.

## 3.4. Communication Conflicts

The communication between the cluster-heads and the BS should adopt Collision Avoidance when the network becomes large and the number of sensors increase, or it will give rise to the occurrence of conflicts when the cluster-heads are sending data. Therefore, sensor networks in large scope should adopt certain strategies to reduce the

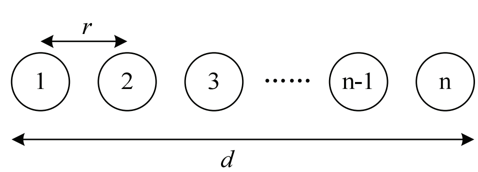


**Figure 2. Linear network model.**

 

occurrence of conflicts.

### 3.5. Estimating Hop-Counts

CHs can send their data via just one (high-energy) transmit of data to the base station or via a multi-hop scheme where each data message must go through *n* (low energy) transmits and *n* receives. Depending on the relative costs of the transmit amplifier and the radio electronics, the total energy expended in the system might actually be greater using multi-hop routing than direct transmission to the base station.

To illustrate this point, consider the linear network shown in **Figure 1**, where the distance between the nodes is *r*. If we consider the energy expended transmitting a single *l*-bit message from a node located a distance *nr* from the base station using the direct communication approach via one hop and Equations (1) and (3), we have:

$$E_{Tx} = l\varepsilon_{fs}\left(\frac{n-1}{\beta}r\right)^2 + lE_{elect} \tag{4}$$

Where $\beta$ is the number of hops. Thus, the total energy is:

$$\begin{aligned} Etot &= \beta E_{TX} + \beta E_{RX} \\ &= 2l\beta E_{elect} + l\varepsilon_{fs}\frac{(n-1)^2 r^2}{\beta} \end{aligned} \tag{5}$$

And the optimum number of hops is computed as below:

$$\frac{dE_{tot}}{d\beta} = 2lE_{elect} - l\varepsilon_{fs}\frac{d^2}{\beta_{opt}^2} = 0$$

$$\Rightarrow \beta_{opt} = d\sqrt{\frac{\varepsilon_{fs}}{2E_{elect}}} = \frac{d}{100}$$

This shows that, when transmission energy is on the same order as receive energy, which occurs when transmission distance is short, direct transmission is more energy-efficient than multi-hop routing. Thus we use direct transmission communication among CHs and the base station.

### 3.6. Selecting Optimum Transmitting Node

To illustrate this point, consider the linear network shown in **Figure 3.**

Where $r_1 < d_0$ is distance between BS and node 1, $d_0 < r_2 < 2d_0$ is distance between node 2 and node 1, $r$ is distance between BS and node 2. We select node 1 to transmit data, when node 2 transmits data to BS. From

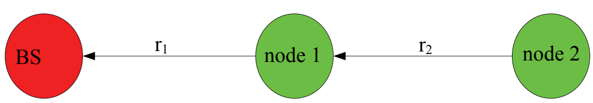


**Figure 3. Relay node network model.**

**Figure 2**, we have

$$r_2 = r - r_1 \tag{6}$$

When node 2 transmits data to node 1, the energy consumption is written as

$$E_{node1} = k\varepsilon_{fs}r_1^2 + kE_{elect}$$

$$E_{node2} = k\varepsilon_{fs}(r_1^2 + r_2^2) + 2kE_{elect}$$

The total energy consumption is as follows

$$E_{tot} = 2k\varepsilon_{fs}(r_1^2 + r_2^2) + 3kE_{elect} \tag{7}$$

We replace (6) into (7),

$$E_{tot} = 2k\varepsilon_{fs}((r-r_2)^2 + r_2^2) + 3kE_{elect}$$

And the optimum node position is computed as below:

$$r_2 = r/2$$

In a similar way, when $r_{31} = r/3$ and $r_{32} = 2r/3$, the energy consumption is minimum, etc.

According above computation, optimum transmitting distance is

$$d_{opt} = \frac{d}{\beta_{opt}} \times (\beta_{opt} - 1)$$

Given coordinate of S(i) be (x, y), optimum node coordinate is listed as

$$\begin{cases} x_{opt} = \dfrac{x}{\beta_{opt}} \times (\beta_{opt} - 1) \\ y_{opt} = \dfrac{y}{\beta_{opt}} \times (\beta_{opt} - 1) \end{cases} \tag{8}$$

## 4. Simulation Results

This paper makes Matlab as experiment platform, and goes on imitation in two scenes respectively. The parameters of imitation experiments see the following **Table 1**, in which the first ten parameters are same to the document.

**Figure 4** and **Figure 5** are the network's life cycle in two scenes. In the scene 1, the Fist Node Death time (**FND**) of LEACH-L is 2.5 times more than that of LEACH, and the Half Nodes Death (**HND**) time of LEACH-L is about 1.1 times more than that of LEACH. In the scene 2, LEACH-L's FND and HND are 12 times and 1.8 times as much as that of LEACH. Besides, the last node dead time of LEACH and LEACH-M are longer than that of LEACH-L. The reason is that LEACH-L makes power equally distribute among all sensors, therefore, in the pre-period, the network's activity nodes and cover areas of LEACH-L are greatly larger than that of LEACH-M and LEACH.

**Figure 6** and **Figure 7** are the sum of data packets which is the cluster-heads sending to the BS in two different scenes. In the scene 1, before HND, the sum of data packets transmitted by LEACH-L is 1.3 times as much as that of LEACH and 1.4 times as much as that of LEACH–

**Table 1. Simulation parameters.**

| | scene 1 | scene 2 |
|---|---|---|
| The scope | 300 × 300 m | 500 × 500 m |
| The number of sensors | 900 | 2500 |
| The location of BS | (150,150) | (250,250) |
| The initial energy | 0.5 J | 0.5 J |
| $E$ | 1 J | 1 J |
| The length of packets | 4000 | 4000 |
| $E_{TX}$ | $5 \times 10^{-8}$ | $5 \times 10^{-8}$ |
| $E_{RX}$ | $5 \times 10^{-8}$ | $5 \times 10^{-8}$ |
| $\varepsilon_{fs}$ | $10^{-11}$ | $10^{-11}$ |
| $\varepsilon_{mp}$ | $1.3 \times 10^{-15}$ | $1.3 \times 10^{-15}$ |
| $E_{DA}$ | $5 \times 10^{-9}$ | $5 \times 10^{-9}$ |
| $P$ | 0.1 | 0.1 |
| $M$ | 0.1 | 0.1 |
| $D$ | 70 m | 70 m |
| *Restriction_distance* | 30 m | 70 m |
| Max_distance | 87 m | 87 m |

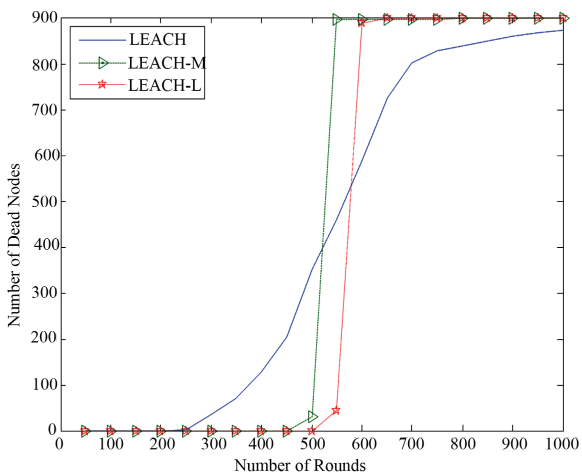


**Figure 4. Dead nodes over rounds in 300 × 300 m.**

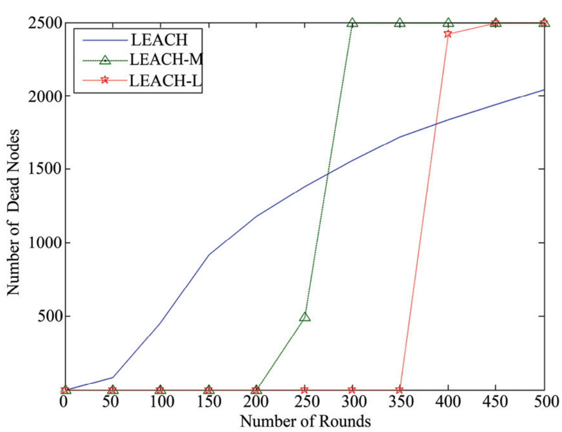


**Figure 5. Dead node over rounds in 500 × 500 m.**

M. In the scene 2, before HND, the data transmitted by LEACH-L is 2.4 times that of LEACH and 2.1 times that of LEACH-M.

**Figure 8** is relation between energy consumption and round among LEACH, LEACH-M, LEACH-L in 300 × 300 scene. From **Figure 8**, it is known that LEACH-L can save energy consumption of network when LEACH-L is compared with LEACH-M and LEACH. After a while, it saves energy in LEACH and LEACH-M better than LEACH-L. In about the 400th round, total energy consumption of network in LEACH-L is more than LE-ACH and LEACH-M, because some nodes in LEACH and LEACH-M are dead with time going.

**Figure 9** is relation between energy consumption and round among LEACH, LEACH-M, LEACH-L in 500 × 500 scene. From **Figure 9**, it is known that LEACH-L can save 50% energy consumption of network in the 100th round when LEACH-L is compared with LEACH-M and LEACH. In about the 400th round, total energy consumption of network in LEACH-L is more than LEACH and

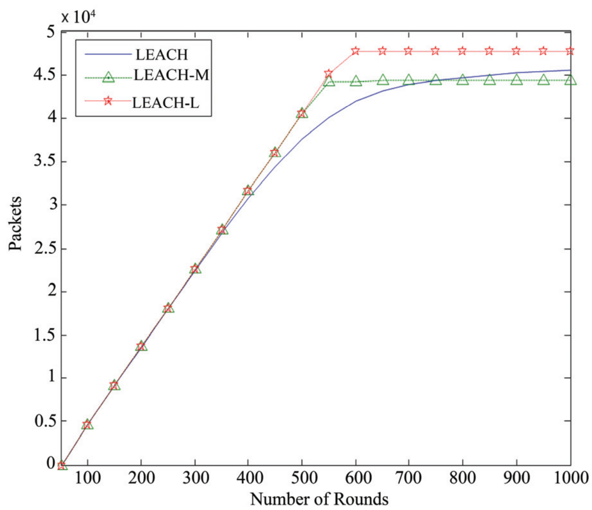


**Figure 6. Received packets over rounds in 300 × 300 m.**

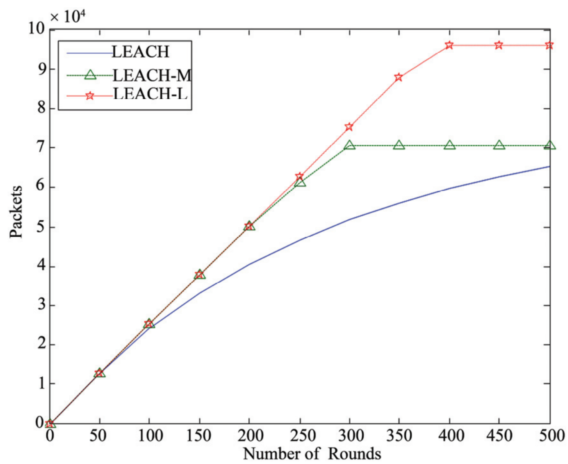


**Figure 7. Received packets over rounds in 500 × 500 m.**

 

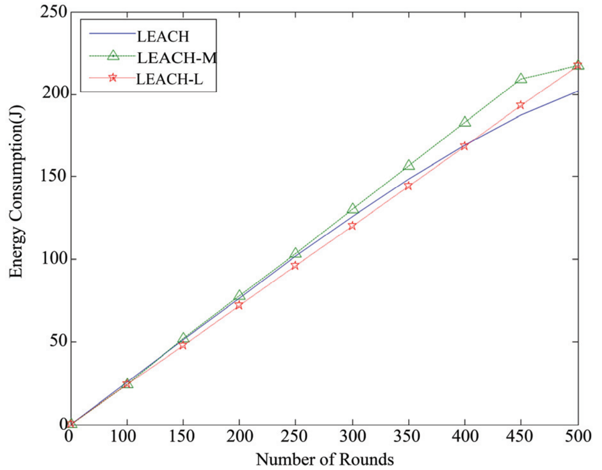


**Figure 8. 300 × 300 energy consumption among LEACH, LEACH-M and LEACH-L.**

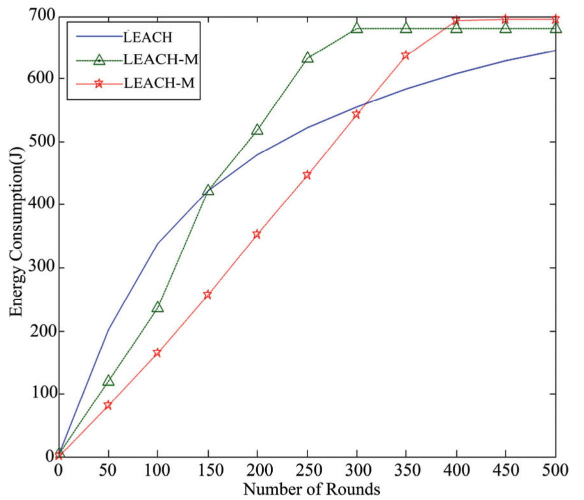


**Figure 9. 500 × 500 energy consumption among LEACH, LEACH-M and LEACH-L.**

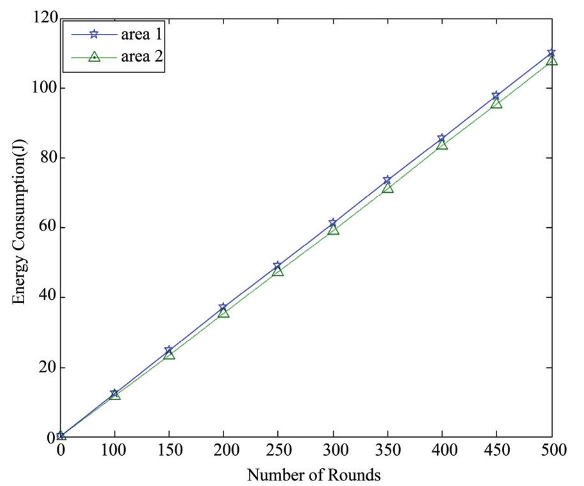


**Figure 10. 300 × 300 energy consumption of LEACH-L in different areas.**

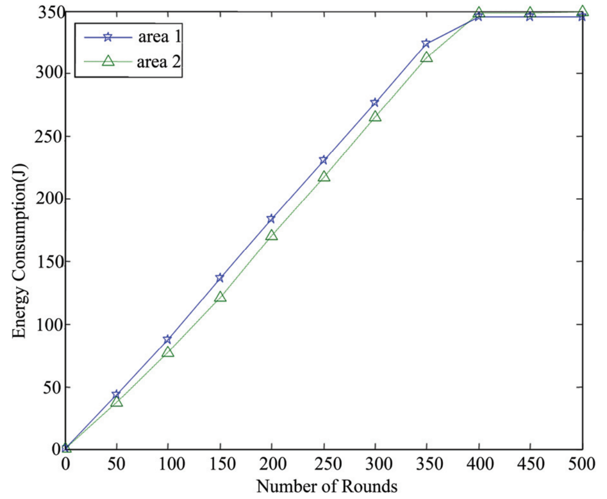


**Figure 11. 500 × 500 energy consumption of LEACH-L in different areas.**

LEACH-M, because some nodes in LEACH and LEACH-M are dead with time going.

**Figure 10** is relation between energy consumption and rounds in different area in LEACH-L. It is obvious that in two areas energy consumption is balancing in 300 × 300 scene.

**Figure 11** is relation between energy consumption and rounds in different area in LEACH-L. It is obvious that in two areas energy consumption is balancing in 500 × 500 scene.

## 5. Conclusions

We have proposed a routing protocol named LEACH-L. The experiments demonstrate that in the larger scope sensor networks, Comparing with LEACH and LEACH-M which is the multiple-hop protocol only considering the distance, LEACH-L can balance network load, reduce the network's energy consumption, enhance the network's data collecting precision and extend the network's life cycle, certainly, LEACH-L demands each sensor node to record its own location information and the information of candidate routing cluster-heads, increasing the storage requirements of sensor nodes. But, compared with balancing the nodes' surplus energy and prolonging the life time of network, LEACH-L is valuable.

## 6. Acknowledgements

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