



# An Energy Efficient Clustering Algorithm Based on Annulus Division Applied in Wireless Sensor Networks

Zhenhua Zhou<sup>1</sup> · Yugang Niu<sup>1</sup>

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## Abstract

Energy efficiency and energy balance are two important performance indexes in wireless sensor networks which determine the lifetime of networks. This paper proposes a protocol, termed as annulus division based energy-efficiency clustering protocol (ADEC), in which the monitor area is divided into several annuluses with different width. By considering the distance between sensor nodes and the base station, sensor nodes are firstly classified into different levels. Then, cluster heads selection and clusters formation are conducted independently in each annulus. Moreover, data transmission pathes are established among annuluses, and a strategy of cluster heads rotation and cluster adjustment is proposed. A key feature of this proposed algorithm is that the clustering is conducted in each annulus independently, such that a large amount of energy can be saved. Finally, the simulation results illustrate the effectiveness of ADEC in terms of energy efficiency and energy balance.

**Keywords** Wireless sensor networks · Clustering · Annulus division · Energy efficiency

## 1 Introduction

With the development of microelectronics and communication technology, wireless sensor networks have achieved great development and have been applied to a wide range of scenarios, including environmental monitoring, disaster warning, and target tracking in battlefield [1–3]. Unlike traditional wireless networks, wireless sensor networks have many key features, such as limited energy, communication range etc [4]. Because nodes deployed in wireless sensor networks cannot be replaced in most cases, the energy consumption is an important indicator to evaluate a communication protocol [5]. A good communication protocol can reduce and balance energy consumption in the network, which can extend the life cycle of the network as much as possible.

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✉ Yugang Niu  
acniuyg@ecust.edu.cn

Zhenhua Zhou  
qdzhouzhenhua29@163.com

<sup>1</sup> Key Laboratory of Advanced Control and Optimization for Chemical Process (East China University of Science and Technology), Ministry of Education, Shanghai 200237, China

Clustering is an effective means to reduce energy consumption [6]. In clustering networks, nodes are divided into cluster head nodes and cluster member nodes. The cluster member nodes are mainly responsible for sensing the monitoring information in the network and sending them to the corresponding cluster head. The cluster head is responsible for the aggregation of the received sensing information, and then, sends them to the base station in a single-hop or multi-hop manner. The clustering process is usually composed of two parts: cluster heads election and clusters formation [7]. In order to ensure the optimal energy consumption, the selection of cluster heads usually considers the remaining energy of nodes and the distance away from the base station. In the non-uniformly distributed network, the node density should be also considered. When building a cluster, factors such as the number of member nodes in the cluster and the total transmission distance within the cluster are taken into consideration to ensure the energy balance of the network [8]. When there are nodes, especially, cluster head nodes dying, an effective method to save energy is to partition the network in advance, in order to change the network structure as little as possible.

Cluster-based routing can greatly reduce energy consumption during data transmission phase [9]. In a large-scale network, cluster heads transmitting data in a single hop way will consume a lot of energy, which may severely shorten the life cycle of the network. Multi-hop routing can improve the energy performance of the network effectively [10].

A good network protocol should also have good scalability [11]. When nodes in the network die or new nodes join in, it should have the ability to flexibly adjust the network structure on the premise that it consume the least energy. Therefore, cluster heads rotation and cluster structure adjustment strategies are necessary.

The main content of this article is composed of the following parts. In Sect. 2, some related works are reviewed. The system model and some assumptions are introduced concisely in Sect. 3. In Sect. 4, the main contents of ADEC are described in detail, including methods of annulus division, cluster heads selection, clusters formation, routing establishment and cluster structure adjustment. The main simulation results are given and discussed in Sect. 5. Finally, the main ideas of this paper are summarized in chapter 6.

## 2 Related Works

Recently, there have been numerous papers on clustering protocols in wireless sensor networks. This section will review some of these articles.

In LEACH [2], each node generates a random number between 0 and 1. If the number is less than the threshold, the node will become the cluster head in current round. The rotation of cluster heads can balance the energy consumption among the network. Sensor nodes choose the nearest cluster head to form the clusters. However, cluster heads in LEACH communicate with the base station directly, which will consume a large number of energy, especially in large-scale networks. TEEN [12] sets hard threshold and soft threshold to control the information transmission in wireless sensor networks. Only when the perception data exceeds the hard threshold, will the data be sent to the base station. Soft threshold is used to reduce redundancy. On the basis of TEEN, nodes in APTEEN [13] can send the sensing messages to the base station periodically, and can adapt to abrupt changes in time, which is very suitable to time critical scenarios. Sensor nodes in ERA [14] calculate their waiting time for competing to be cluster heads according to their residual energy. However, in the process of cluster heads selection, the distance to the base station and the

node density should be considered in heterogeneous networks. DSBCA [15] takes node density and distance between the base station into consideration. In the cluster heads selection phase, a node is chosen randomly to trigger the process, and the cluster radius is set based on residual energy and distance to the base station. Finally, the node with the highest weight in the radius will be the actual cluster head. EBCAG [16] gives each node a gradient value according to its minimum hops to the base station. The gradient value will decide the radius of clusters and cluster members' head nodes. Wang, et al. [17] selects the cluster heads based on each sensor node's energy level and the minimisation of the associated additional energy. The selected cluster heads communicate with the sink node directly or relay on the nearest neighbour cluster head. Cluster member nodes transmit data to the corresponding head node in single-hop way without limiting the size of clusters, which may result in large energy consumption with clusters, especially in large scale deployment scenario. In [18], authors proposed a cluster method based on a probability parameter, which depends on the number of nodes haven't been selected as cluster heads. This protocol can solve the uneven selection result of cluster heads, nevertheless, the residual energy of nodes is not taken into consideration, which will select nodes with only trace energy as cluster heads. EEOC [19] defines a new kind of nodes in clustering network called boundary nodes, which are in the overlapping areas among clusters. Boundary nodes take the responsibility to forward data, so it can reduce the energy consumption of cluster heads. Algorithm in [20] uses genetic algorithm to determine the optimal number of cluster heads in the network and then forms clusters with K-means method. In [21], the whole network is split into several levels, and each level has the same width of  $d_0/2$ . Then the transmission of data will be conducted within any two successive levels. MSPT [22] designs three steps in the procedure of establishing data transmitting routine. First, each cluster member node selects two nearest node until a path to cluster head is established. The second step is calculating the energy cost table of the each path formed in step one by considering total energy, energy range, energy ratio and energy percentage. According to the energy cost table, each node determine the actual data transmitting path. MSPT uses the same method to establish routing intra-cluster and inter-cluster, which may significantly extend the time to determine the routine, especially in large scale networks and increase complexity.

In recent years, many intelligent optimization algorithms have been also applied to clustering in wireless sensor networks. For example, the PSO method was utilized in [23, 24] the clustering process. EAUCF [25] sets distance between sensor nodes and the base station and residual energy as fuzzy variables to decide the competition radius of candidate cluster heads. DUCF [26] sets nodes' residual energy, connectivity degree and distance between the base station as fuzzy variables to select cluster heads and control the radius of cluster heads.

### 3 System Model

#### 3.1 Network Model

In this work, a circular monitor area with radius  $R$  is considered. The base station is in the middle of the network and  $N$  sensor nodes are deployed randomly. The network model satisfies the following hypotheses:

- (1) There is no limit to the energy and communication range of the base station;

- (2) All the sensor nodes and the base station are stationary and are location aware;
- (3) Each node has the same initial state and a unique node ID;
- (4) The communication range of nodes can be adjusted by means of power control;
- (5) The network link is symmetrical, and the energy consumption of communication between two nodes is equal.

### 3.2 Energy-Consuming Model

The energy consumed by each node depends on the hardware circuit, the data size, and the transmission distance. The energy consumption model can be classified into free space and multi-path channel according to the distance between the sender and the receiver nodes. This work uses the same model as in [27] and the energy needed for transmitting  $l$  packets data over distance  $d$  is

$$E_T(l, d) = \begin{cases} l \times E_{elec} + l \times \epsilon_{fs} \times d^2, & d \leq d_0 \\ l \times E_{elec} + l \times \epsilon_{mp} \times d^4, & d > d_0 \end{cases}, \quad (1)$$

and the energy needed for receiving  $l$  packets data is

$$E_R = l \times E_{elec}, \quad (2)$$

where  $E_{elec}$  is the energy consumed per bit for running the hardware circuit of each node,  $\epsilon_{fs}$  and  $\epsilon_{mp}$  are the energy needed by the amplifier in free space and multi-path channel models respectively,  $d_0 = \sqrt{\epsilon_{mp}/\epsilon_{fs}}$  is the threshold to distinguish the two energy consumption models.

## 4 Protocol Details

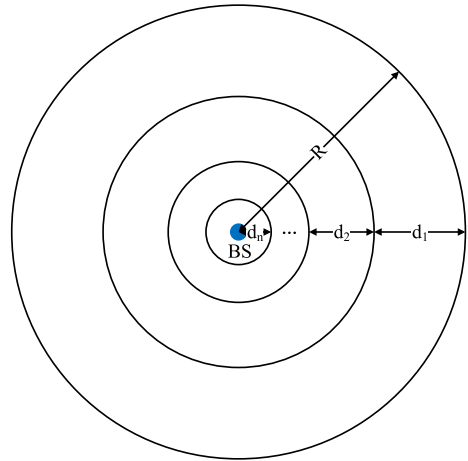
In this work, the monitor area is divided into annuluses based on the distance between sensor nodes and the base station, so the nodes in the network can be classified into several levels and the nodes in the same annulus have the same node level. The clustering will only happen among the nodes in the same level. In this way, when any cluster head dies, re-cluster will only be conducted in the corresponding annulus and it is unnecessary to change the cluster structure of the whole network such that a great amount of energy can be saved.

The main process of the protocol includes annuluses division, cluster heads selection, data transmission paths establishment and clusters adjustment.

### 4.1 Annuluses Dividing

In clustering network as in Fig. 1, cluster heads closer to base station undertake more data forwarding tasks, such that their energy will be expended much more quickly. To balance the energy consumption in the network, the radius of clusters near the base station is set smaller and the clusters far away from the base station have larger radius. To achieve this goal, the circle monitor area is divided into several annuluses with different width according to the distance to the base station, and the outer circle has larger width. To save energy, the largest annulus width is set to  $d_0$ , and the width of the  $i$ th annulus( $d_i$ ) can be calculated according to the expression (3). When the radius of undivided

**Fig. 1** Annulus division of the monitoring area



circle( $r_{ud}$ ), which can be calculated according to (4), is smaller than  $d_0/2$ , the remaining nodes will communicate with the base station directly, and all of them are cluster head nodes with node level 1.

$$d_i = \alpha \frac{R - \beta \sum_{j=1}^{i-1} d_j}{R} d_0 \tag{3}$$

$$r_{ud} = R - \sum_{j=1}^i d_j \tag{4}$$

The number of nodes in  $i$ th annulus( $numofnode_i$ ) can be represented as

$$numofnode_i = \frac{\left(R - \sum_{j=1}^{i-1} d_j\right)^2 - \left(R - \sum_{j=1}^i d_j\right)^2}{R^2} N \tag{5}$$

### 4.2 Cluster Heads Selection

After dividing the monitor area into  $n$  annuluses, cluster heads will be elected in each annulus, respectively. The main factors considered in this process are residual energy and node density. The node density will be denoted by node degree (the number of neighbour nodes) in this work. The distance has been considered in the process of annuluses dividing. The nodes with more residual energy have a larger chance to be cluster heads. At the same time, the area with higher node density will generate more sensing information, so the radius of cluster in these area should be smaller and nodes in these areas are more likely to be cluster heads.

Based on the residual energy and node degree, the weight of each node to compete as cluster head is calculate as

$$w_i = \frac{E_i \cdot Nn_i}{E_{ave_j} \cdot Nn_{ave_j}} \tag{6}$$

where  $E_i$  and  $Nn_i$  are residual energy and node degree of node  $i$ ,  $E_{ave_j}$  and  $Nn_{ave_j}$  are the average residual energy and average node degree of  $j$ th annulus.

According to the weight of becoming cluster heads, the waiting time of competing to become cluster heads is given as

$$T_{wait}^i = e^{\frac{1}{w_i + \sigma}} + \delta \tag{7}$$

where  $\sigma$  is the adjustment factor and  $\delta$  is the time of transmitting data over  $d_0/2$ .

In each annulus, each node will wait for CH\_message in the waiting period. If a node don't receive any CH\_message, it will announce itself as cluster head and broadcast CH\_message in the range of its competing radius. Considering the coverage rate and energy efficiency, the competing radius( $r_c$ ) should be larger than the width of the corresponding annulus  $d_i$  and smaller than  $d_0/2$ .  $r_c$  of each cluster head can be calculated according to expressions (8) and (9):

$$r'_c = \mu \frac{E_i \cdot Nn_{max}}{E_0 \cdot Nn_i} (Rmax - Rmin_i) + Rmin_i \tag{8}$$

where  $Rmax$  equals to  $d_0/2$  and  $Rmin_i$  equals to  $d_i$ .

$$r_c = \begin{cases} d_i, & r'_c < Rmin_i \\ r'_c, & d_i \leq r'_c < \frac{d_0}{2} \\ \frac{d_0}{2}, & Rmax \leq r'_c \end{cases} \tag{9}$$

The nodes receiving CH\_message will quit the competition of cluster heads, and become cluster members.

All of the nodes with level 1 play the role of cluster heads and communicate with the base station directly.

### 4.3 Cluster Formation

In the process of clusters formation, each ring is considered independently, and each member node only belongs to cluster heads in the same annulus. To ensure the balance of energy consumption among clusters of the same level, the number of cluster members and transmission distance within each cluster are mainly considered.

After the cluster heads are elected, they will broadcast CH\_message within its  $r_c$ , and these normal nodes receiving the CH\_message will become the cluster members of the corresponding cluster heads. The formation procedure of clusters will continue until all the nodes in the network are divided into clusters. This step is called as preliminary clustering.

There is no doubt that the size of clusters formed after preliminary clustering differs from each other greatly, which is adverse to the balance of energy consumption. To deal with this shortcoming, the clusters will be adjusted.

Based on the number of cluster heads and sensor nodes in the annulus, the average number of sensor nodes in each cluster can be calculated. Each cluster head compares its own number of member nodes with the average number of cluster members. If the number of member

nodes is larger than the average number, the cluster heads will get rid of the redundant nodes according to the distance. The nodes with the longest distance away from the cluster head will be dismissed and they need to search for new cluster to join in. The culled nodes look for the closest cluster head whose number of members is less than the average number in the range of  $d_0$ . If there is no desirable cluster head, the node will still belong to the original cluster. The adjustment is conducted in each annulus independently.

#### 4.4 Transmission Path Establishment

To save the energy of each node, they transmit data to the nearest forwarding node. The cluster members communicate with their corresponding cluster heads directly, and the cluster heads send data to the closest cluster heads in inner annulus, while the nodes in innermost annulus communicate with the base station directly.

#### 4.5 Cluster Heads Rotation

With the operation of the network, the energy of cluster heads will be consumed faster. When the residual energy of a cluster head is less than the threshold, it can't play the role of relay node and can't take the responsibility of aggregating data. To maintain the operation of the network, a method of cluster heads re-selection is proposed in the following.

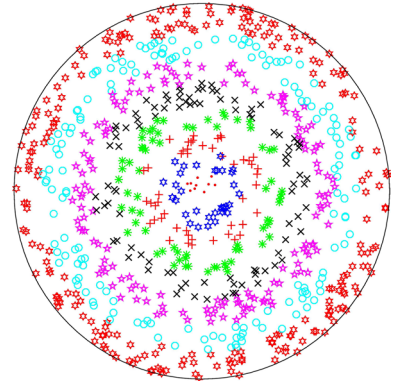
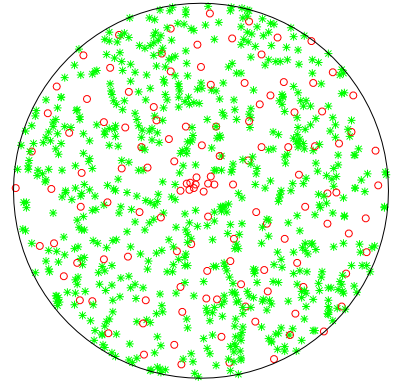
When the residual energy of any cluster head is less than the threshold, the cluster head will be replaced by the node with the highest residual energy in the cluster. The new cluster head will be the forwarding node of the cluster heads whose forwarding node is the dead node, and the cluster head that was the forwarding node of the dead cluster head becomes the forwarding node of the new cluster head.

This rotation won't change the structure of the network and is only conducted in one annulus, so energy can be saved.

At the same time, if there is a node that can't find any forwarding node, the structure of the whole network will be re-established. The process of cluster heads selection, clusters formation and transmission paths establishment will be carried out again.

Key contributions of the proposed protocol ADEC are:

- (1) Each cluster is independent in the process of cluster and re-cluster, which can reduce energy consumption in the formation of clusters;
- (2) The monitor area is divided into several annuluses of different width according to the distance between cluster heads and the base station, which can balance energy consumption of cluster heads effectively;
- (3) To balance energy consumption of all sensor nodes, the residual energy and node density are taken into consideration in the process of cluster formation;
- (4) A cluster adjustment mechanism is proposed to balance energy consumption among clusters;
- (5) The cluster head rotation method within clusters can greatly save the energy consumption caused by whole cluster structure adjustment.

**Fig. 2** Annuluses division result**Fig. 3** Distribution of cluster heads and member nodes

## 5 Simulation and Analysis

In this section, some simulation results are demonstrated, including the division of the monitor area, cluster heads election result and the behavior of the clustering network. We compared the performance of ADEC, EEOC and LEACH from the aspects of the number of surviving nodes and the average residual energy of surviving nodes.

Figure 2 shows the division of the circle monitor area. The sensor nodes are distributed randomly in the network, and ring width gradually increases from inside to outside. The result is in line with our expectations.

Figure 3 shows the distribution of cluster heads and cluster members. All the nodes with level 1 are set as cluster heads and they communicate with the base station directly. The simulation result shows that ADEC can make the cluster heads distributed evenly in the network, it's beneficial to the energy balance of sensor nodes.

The main design objective of this protocol is to improve the energy efficiency of the network and prolong the lifetime. We further verify the performance of the network from the aspects of the number of surviving nodes and average residual energy. The number of surviving nodes is an important performance index indicating whether the network can operate normally. If there are few nodes alive, the coverage rate will be poor and the sensor network loses its function. At the same time, the more sensor nodes die, the worse energy efficiency and energy balance performance the network has. The average residual energy



can also illustrate the energy efficiency. The more residual energy in the network means the less energy consumed by the network.

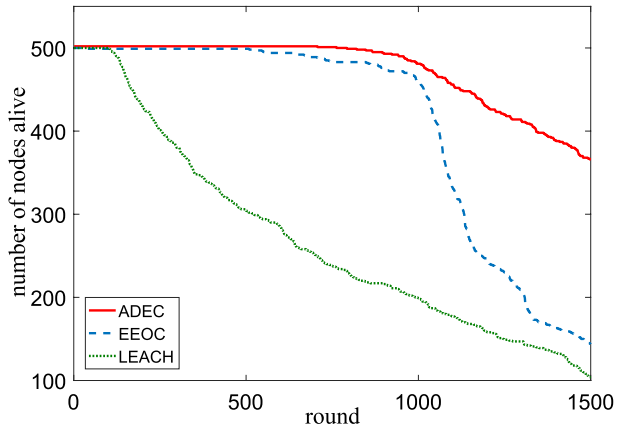
In the sequel, two sets of experiments are designed with the simulation parameters shown in Table 1

The first set of experiment is performed in a smaller monitor area with radius of 300. Figures 4 and 5 show the trend of the number of surviving nodes and average residual energy in the monitor area with the operation of the network respectively. From either the number of surviving nodes or the remaining energy, ADEC shows obvious advantages.

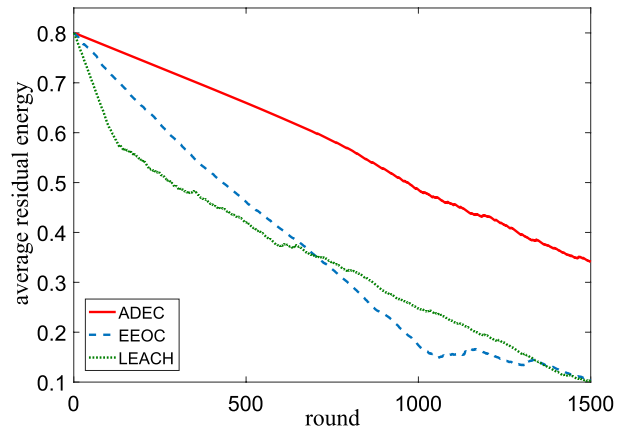
**Table 1** value of simulation parameters

Parameters	Values in experiment 1	Values in experiment 2
$R$	300	600
$N$	500	800
$E_0$	0.8	0.8
$\epsilon_{fs}$ (pJ/bit/m <sup>2</sup> )	10	10
$\epsilon_{mp}$ (pJ/bit/m <sup>4</sup> )	$1.3 \times 10^{-3}$	$1.3 \times 10^{-3}$
$E_{elec}$	50	50

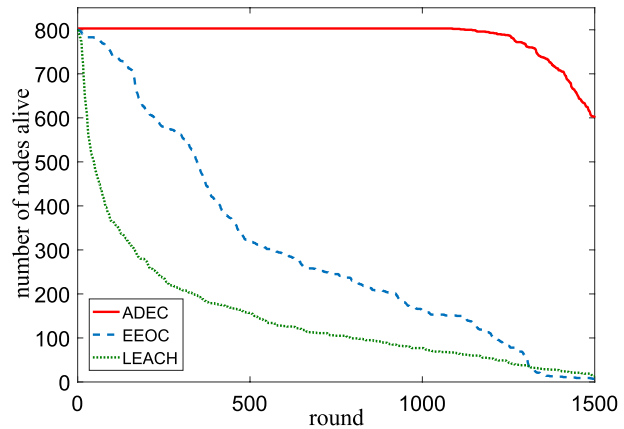
**Fig. 4** Number of surviving nodes in experiment 1



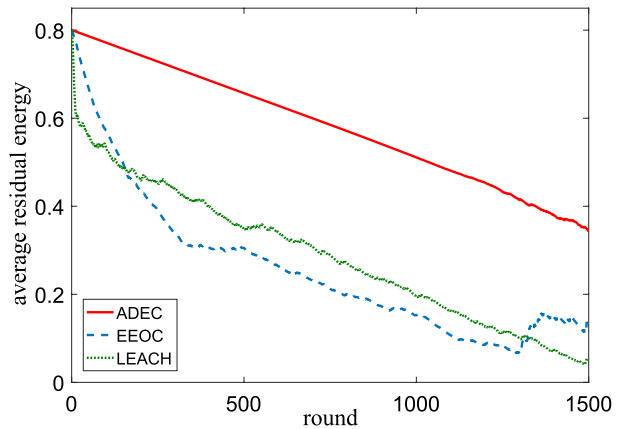
**Fig. 5** Average residual energy in experiment 1



**Fig. 6** Number of surviving nodes in experiment 2



**Fig. 7** Average residual energy in experiment 2



Compared with LEACH and EEOC, ADEC has much better performance, especially after the first 1000 rounds. In the first 1000 rounds, EEOC and ADEC don't show a big difference, however, after 1000 rounds, nodes in EEOC die in a fast rate. Few nodes die in network under ADEC in first 1000 rounds, and nodes die at a relatively slow rate after 1000 rounds. This means that the network can survive longer and have a good energy performance.

Besides, the trend of average residual energy indicates the good performance of ADEC. As far as average residual energy, none of EEOC and LEACH shows a greater preponderance, but the energy consumption rate of ADEC is always kept at a slower speed. A larger number of surviving nodes and more average residual energy means that less total amount of energy have been consumed.

The second set of experiment is performed in a larger monitor area with radius of 600. Figures 6 and 7 show the trend of the number of surviving nodes and average residual energy in the monitor area with the operation of the network respectively. The result is the same as the one in experiment 1, ADEC has a great advantage compared with EEOC and LEACH, furthermore, the advantage is more obvious in large-scale network. One of the reasons is that cluster heads in LEACH and EEOC communicate with the base station directly, it will consume a large number of energy and shorten the lifetime of the network.

The trend of the number of surviving nodes under LEACH decreases nearly exponentially, and there is almost no surviving node after 1500 rounds in the network under EEOC and LEACH. There is no sudden death of a large number of nodes in ADEC. As far as average residual energy of surviving nodes, it slowly falls in a linear pattern in ADEC, which means network operation under ADEC can run smoothly.

By comparing the results of the above two groups, the performance of ADEC shows great advantage, especially in large-scale network. There is no sudden decrease of the number of surviving nodes and average residual energy. At the same time, the number of surviving nodes and average residual energy decreasing at a slower rate indicates the network under ADEC can run in a steady state for a longer time. In general, ADEC can improve the energy efficiency and prolong the lifetime of the network whether in small-scale or large-scale monitor area effectively.

## 6 Conclusion

In this paper, a clustering method of dividing the monitor area into annuluses has been proposed. The main objective is to improve the energy efficiency of wireless sensor network and prolong the lifetime. At the same time, this protocol can balance energy consumption among the network effectively. Moreover, the network has a fine scalability.

In the simulation section, we have compared the performance of LEACH, EEOC and ADEC in terms of the number of surviving nodes and average residual energy in two different conditions. The simulation shows that either in small-scale or in large-scale network, ADEC has much better performance, especially in large-scale network. At the same time, it can reduce energy consumption and prolong the lifetime of network effectively. Moreover, the simulation result shows that the cluster heads selected by ADEC are distributed evenly around the network, which can balance the energy consumption.

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**Zhenhua Zhou** received the B.S. degree from Southeast University Chengxian College in 2016. He is currently pursuing a master's degree with the School of Information Science and Engineering, East China University of Science and Technology. His current research interest is clustering in wireless sensor networks.



**Yugang Niu** received the M.Sc. and Ph.D. degrees from the Nanjing University of Science and Technology, in 1992 and 2001, respectively. In 2003, he joined the School of Information Science and Engineering, East China University of Science and Technology, where he is currently a Professor of Control Science and Engineering. He is the Associate Editors of several journals, including *Information Science*, *Neurocomputing*, *Journal of the Franklin Institute*, *International Journal of Systems Science*, *IET Control Theory and Applications*. His research interests include stochastic systems, sliding mode control, Markovian jump systems, networked control systems, wireless sensor network, and smart grid.