# An Energy-saving clustering routing algorithm for wireless gas meter reading system

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## Abstract

IoT gas meters are usually powered by batteries, and energy supply is limited. How to achieve energy conservation has become an urgent problem for wireless meter reading. Aiming at the energy consumption problem in wireless gas meter reading, considering the stability, load balancing and adaptability, an energy-efficient clustering routing algorithm with energy balance is proposed. The algorithm considers many factors, such as the optimal number of cluster heads(CHs), the residual energy of nodes and the distance to the base station nodes, to ensure that CHs are evenly distributed and that the nodes in the region do not take on too many forwarding tasks to form dead zones. The simulation results show that the energy-saving routing algorithm proposed in this paper improves the performance of load balancing, maximum lifetime of the system and the number of data transmission packets.

## Keywords

Wireless gas meter reading; Energy efficient routing; Clustering algorithm; Load balancing.

## 1. Introduction

In order to better dispatch gas supply according to user consumption and ensure people's normal gas demand, it is necessary to introduce more intelligent technical means in gas dispatching and supply system. Remote meter reading technology is the current research hotspot[1]. The remote meter reading technology effectively solves the drawbacks that the traditional manual meter reading accuracy is difficult to guarantee, and simplifies the cumbersome process of manual meter reading, and improves the efficiency of meter reading and the accuracy of data. Compared with the traditional manual meter reading, the remote meter reading system has the following advantages: 1) providing real-time meter reading possibility, meter reading parameters can be freely configured; 2) unified data storage form, standardizing data management mode, and statistical analysis for later application lay a good data resource basis; 3) The accuracy of meter reading is greatly improved compared with manual meter reading, and the cost of meter reading is greatly reduced. Based on the intrinsic safety considerations of the gas industry[2], smart gas meters cannot use external power supplies, resulting in limited energy for the smart gas meters. The wireless meter reading network is a special wireless sensor network. Each smart gas meter is an node in wireless sensor network. How to reduce the energy consumption of the node can be considered from two aspects: 1) the energy saving of the node itself; 2) the node Energy saving of network transmission. Research shows that reasonable scheduling of node forwarding can effectively reduce the energy consumption of a single node, thus extending the life cycle of the entire network[3]. In the current network energy-saving protocol, clustering routing protocol is the focus of research, mainly consisting of two stages: cluster formation and stable transmission. The stable transmission time is usually several times that of the previous period, so as to compensate for the energy consumed during the cluster formation phase.

This paper summarizes the advantages and disadvantages of various typical routing algorithms, and proposes an energy-efficient routing algorithm for wireless gas meter reading systems. The main problems are solved as follows: 1) The previous routing algorithm does not give an exact optimal CH number in the CH election process, and obtains an optimal CH number for each round of CH election by establishing a node transmission energy consumption model; 2) The CH election standard is single, and does not take into account the remaining energy of the node, the distance of the neighbor node, and the distance from the CH to the sink node.

## 2. Related Works

LEACH (Low-energy adaptive clustering hierarchy) protocol is a widely used IoT distributed clustering routing protocol[4]. In the clustering phase, each node randomly generates a value between 0 and 1 and compares it with the threshold $T(n)$. If it is less than the threshold, the node will become the CH in this round. It will broadcast the message to the surrounding node as CH. If the generated value is greater than the threshold, it will be determined according to the broadcast message strength of the received CH to join the cluster.

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

*p* is the CH expectation ratio, *n* is the current round, and *G* is the node set of CH that has not been elected in the nearest *1/p* round.

EACHP[5] (Energy Aware Clustering Hierarchy Protocol) is a clustering routing protocol based on clustering factor weighting by Baratii et al. It considers the clustering factors such as the residual energy of the node, the number of neighbor nodes, the distance between the node and the sink node, and the distance between adjacent nodes. The coefficient of the parameter determines how much each part affects the network's energy consumption. However, it does not consider the interaction between the clustering influence factors. At the same time, the communication radius of the neighbor nodes is only roughly set to a fixed value, and there is no further analysis and optimization according to the network attributes.

In [6], considering the residual energy of the node and the distance between the node and the sink node, a NEWLEACH protocol is proposed. Considering that the CH energy is consumed in the clustering process, a receiving and fusion data with the largest remaining energy is selected in the cluster during the steady state transmission process. Although the load balancing problem is considered to some extent, it is possible to cause the steady state transmission to consume excessive energy. In [7], an ICH-LEACH protocol is proposed. In the steady state process, when CH and the sink node are far away, the intermediate CH is used for transmission. Literature [8] proposes that the whole network will not be clustered after the first completion of the transmission is completed. After the current residual energy of CH is less than the threshold, CH is reselected in the cluster.

In this paper, based on the LEACH protocol, a LEACH-ES protocol based on multi-parameter weighted optimization is proposed to optimize the energy consumption of the whole network, extend the life cycle of the network, and consider the amount of data transmitted during the network life cycle.

## 3. A multi-parameter weighted energy-saving routing algorithm (LEACH-ES)

### 3.1 System model

Suppose the network consists of N nodes, which are randomly distributed in a square area of *M*M* size. The Sink node will be in a fixed position outside the *M*M* area. All nodes have a unique ID to identify the identity; each node's transmission distance is consistent, avoiding the generation of hidden nodes and exposed nodes; the node can adjust its transmission power according to the distance of the data receiving end. The neighbor node of each node is a set of nodes whose distance from the node is less than *R*, and *R* is the distance of the neighbor node. The node cannot move by default.

The node wireless communication model adopted in this paper is shown in Figure 1. The energy consumed by the transmitting end is:

$$E_{emit} = \begin{cases} kE_{elec} + k\varepsilon_{fs}d^2 & d < d_0 \\ kE_{elec} + k\varepsilon_{amp}d^4 & d > d_0 \end{cases} \tag{2}$$

$k$ is the length of the transmitted message, $E_{elec}$ is unit energy consumption of the transmitting/receiving circuit, $\varepsilon_{fs}$ free space model coefficient, $\varepsilon_{amp}$ is the multipath fading model coefficient, when the distance between the transmitting node and the receiving node is greater than $d_0$ using the multipath fading model, Otherwise use the free space model, .

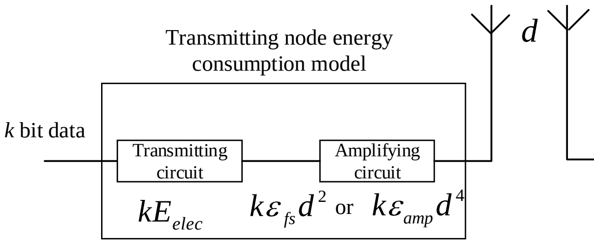


Fig.1 Wireless communication model

### 3.2 The number of cluster heads

Assume that the nodes in the cluster of the entire network are evenly distributed, and the number of CHs is *n*. The average number of nodes in the cluster can be *N/n*, and the number of member nodes(CMs) in each cluster is $(N-n)/n$. The transmission is divided into a cluster formation phase and a stable transmission phase according to a clustering protocol. The cluster formation phase consists of three parts: CH declaration, CM clustering process, and CH broadcast slot table. In this process, the energy consumed by the CH can be expressed as:

$$E_{CH\_declare} = k_1E_{elec} + k_1\varepsilon_{amp}R^4 \tag{3}$$

The receiving energy consumption of CMs is:

$$E_{CM\_declare} = k_1E_{elec} \tag{4}$$

After CM receives the completion, CM needs to send the cluster message to the CH, and its energy consumption is:

$$E_{CM\_join} = k_2E_{elec} + k_2\varepsilon_{fs}d_{CH}^2 \tag{5}$$

$d_{CH}^2$ is the distance between CM and CH. The receiving energy consumption of the CH is:

$$E_{CH\_join} = k_2E_{elec} \tag{6}$$

After receiving the clustering message of all CMs, CH node allocates a slot message to the nodes in the cluster. The energy consumption of CH is:

$$E_{CH\_comfirm} = k_3E_{elec} + k_3\varepsilon_{fs}d_{CH}^2 \tag{7}$$

The receiving energy consumption of CMs is:

$$E_{CM\_comfirm} = k_3E_{elec} \tag{8}$$

All energy consumption during the cluster formation phase can be expressed as:

$$E_{setup} = n(E_{setup\_CH} + E_{setup\_CM}) \tag{9}$$

Since $E_{elec}$, $\varepsilon_{fs}$, and $\varepsilon_{amp}$ are constants, the $R$ of the $k_1\varepsilon_{amp}R^4$ term in $E_{setup\_CH}$ is the node neighbor node radius. Assume that the three process CHs and CMs propagate message lengths are equal in this phase, that is $k_1 = k_2 = k_3 = k$.

The energy consumption during the cluster formation phase can be obtained as follows:

$$E_{setup} = k*[N\varepsilon_{fs}d_{CH}^2 + n\varepsilon_{amp}R^4 + (4N-2n)E_{elec}] \tag{10}$$

In the stable transmission phase, CMs send information to CH in their respective time slots, and CH node sends the fused data to the sink node after one cycle. The energy consumption at this stage consists of the energy emitted by CMs $E_{CM\_emit}$, the energy received by CHs $E_{CH\_rev}$, the energy consumption of CHs $E_{CH\_fusion}$, and the energy consumed by CHs to the Sink node $E_{CH\_emit}$. The energy consumption in the steady state transmission phase can be obtained as:

$$\begin{aligned} E_{stable} &= (\frac{N-n}{n})*(k_D E_{elec} + k_D\varepsilon_{fs}d_{CH}^2) \\ &+ (\frac{N-n}{n})*(k_D E_{elec}) + \frac{N}{n}*(k_D E_{DA}) \\ &+ cc*k_D(E_{elec} + \varepsilon_{amp}d_{BS}^4) \end{aligned} \tag{11}$$

Where: $cc$ is CH data fusion rate, $k_D$ is the node packet size (here assumed to be 10k), and finally the single wheel consumes energy:

$$E_{total} = E_{setup} + n*E_{stable} \tag{12}$$

$d_{CH}^2 = \dfrac{M^2}{2\pi n}$ is available from [9], so $E_{total}$ is

$$\begin{aligned} E_{total} &= k[N*E_{elec}*(24+10*cc) - 22*n*E_{elec} \\ &+ \varepsilon_{fs}*\frac{M^2}{2\pi n}*(11N-10n) + n*\varepsilon_{amp}*R^4 \\ &+ 10*cc*n*(\varepsilon_{amp}*d_{BS}^4) + 10N*E_{DA}] \end{aligned} \tag{13}$$

The value of $n$ when the network energy consumption is the smallest is:

$$n = M*\sqrt{\frac{11N\varepsilon_{fs}}{2\pi[\varepsilon_{amp}(R^4 + 10cc*d_{BS}^4) - 22E_{elec}]}} \tag{14}$$

It is easy to find that the optimal number of CHs is proportional to the number of nodes in the network and the length of the network area. In the above formula, there is also a parameter R that affects the number of optimal CHs of the network, which is the neighboring node communication radius of the nodes in the clustering network, that is, the maximum adjacent node distance of CH. When the communication radius of the largest neighbor node of CH increases, the number of CMs affected by it increases at the same time, and the energy consumption of communication within the cluster increases. However, considering the increase of the communication radius of the largest neighbor node Reduce the number of optimal CHs in the network.

When the nodes in the network die, there are no nodes in the communication range of some nodes, then these nodes will become CHs, which will directly communicate with the Sink node, increasing the network energy consumption. Therefore, it is necessary to optimize the communication radius of the neighboring nodes after the network reaches a certain level.

### 3.3 Weighting parameter

Generally, when selecting a CH, the energy-saving algorithm only considers a single performance parameter of the node, and does not compare the node with the performance average of the node at that time. Analysis of the impact factors affecting network transmission efficiency in clustered networks can effectively extend the network life cycle.

The residual energy of the nodes in the clustering network determines the remaining life cycle of the node. The general idea is that when the remaining energy of the node is low, the transmission task of the node will be reduced. Otherwise, the load of the node will be appropriately increased, and the remaining energy belongs to the performance index of the node. By determining the ratio of the remaining energy of the node to the initial energy, the energy consumption of the node can be determined. No additional communication overhead, sacrificing less accuracy but achieving higher equalization is more acceptable for energy-sensitive wireless gas meter reading systems.

At the same time, in the process of forwarding CH to the sink node, the distance between CH and the sink node will greatly affect the energy consumption of CH. This distance is considered as the forwarding performance index of the node. Generally, we think that the distance between CH and the sink node is greater than the threshold $d_0$. According to the multipath weakening model of the wireless communication energy consumption model, the energy consumption difference of CH to the sink node in a region of 100m*100m Up to 10 times. Therefore, the distance between CH and the sink node needs to be considered in the process of selecting CH in the clustering network.

From equation (11), we can see that the energy consumption in the steady state transmission phase is related to the distance between the neighbor nodes of CH. In the wireless gas meter reading system, not only the overall energy saving of the network but also the load of the nodes in the network should be balanced. The number of neighbor nodes of the node and the average distance of the neighbor nodes of the node reflect the degree of load and the energy consumption of communication within the cluster when the node acts as CH.

Based on the above analysis, this paper proposes a LEACH-ES (LEACH-Energy-sensitive) algorithm based on improved LEACH protocol. LEACH-ES consists of four parts: node neighbor function, node energy function, node and sink node distance function and node neighbor node distance function. Each part has a $Q_n$ to determine its weight, among them $Q_1+Q_2+Q_3+Q_4=1$.

$$V_i(n)=Q_1*N_i(n)+Q_2E_i(n)-Q_3D(n)-Q_4d_i(n) \tag{15}$$

$n$ is the number of rounds of CH election, and $i$ is the node ID.

$$N_i(n)=1-\frac{neighbor(i)}{N} \tag{16}$$

In equation (16), $nerghbor(i)$ is the number of neighbor nodes of the node, and $N$ represents the total number of nodes in the network. Nodes can determine the regional density of nodes without frequently updating their routing table information.

$$E_i(n)=\frac{E_{curr}}{E_{init}} \tag{17}$$

The node energy function in equation (18) is the ratio of the current energy of the node to the initial energy. Through the node's current remaining energy percentage, you can know whether the node has the ability to serve as a CH.

$$D_i(n)=\frac{D_i}{D_{average}} \tag{18}$$

The distance function between the node and the sink node is the ratio of the distance between the node and the sink node and the distance between all the nodes and the sink node. This can determine the average network level of the distance between the node and the sink node, and thus the transmission energy between the node and the aggregation node can be optimized.

$$d_i(n)=\frac{\sum_{j\in neighbor(i)} d_{ij}}{num(neighbor(i))*R} \tag{19}$$

$neighbor(n)$ is a set of nodes with a maximum distance $d_0$ from the node $i$. Through $d_i(n)$, the energy consumption in a single cluster can be optimized. Through the above parts, the energy consumption optimization and load balancing of the entire network can be realized.

### 3.4 Algorithm flow

First, several nodes are randomly distributed in the determined area, and the sink node is not far from outside this area( $(d_0 \le D_{sink} \le 2d_0)$ ). The first part is the clustering preparation: after determining the position of the rear node, the sink node broadcasts a message to all nodes to let the node get the remaining distance $D_i$ from the Sink node, and then transmits the value to the Sink node. The sink node broadcasts the mean of the distance $D_{average}$ between the node and the sink node in the network to all nodes.

The second part is the node clustering process that is performed every round of clustering. At the beginning of the clustering, each node will get its own $V_i(n)$ according to equation (15), and each node will send its $V_i(n)$ to the node within its communication radius *R*. After a period of time, node *i* compares all the $V_k(n)$ it receives with its own $V_i(n)$ value. If the $V_i(n) > V_k(n)$ node announces itself as a CH. If the cluster application does not receive a response or does not receive When CH of other nodes announces the value, the node becomes CH itself. After CM sends the clustering request to CH, CH sends a TDMA time slot allocation result to CM according to the received clustering request for a period of time, and CM receives the TDMA time slot allocation result. The clustering process is over. After a period of steady state transmission, re-enter the clustering process, the flow chart is shown in Figure 2.

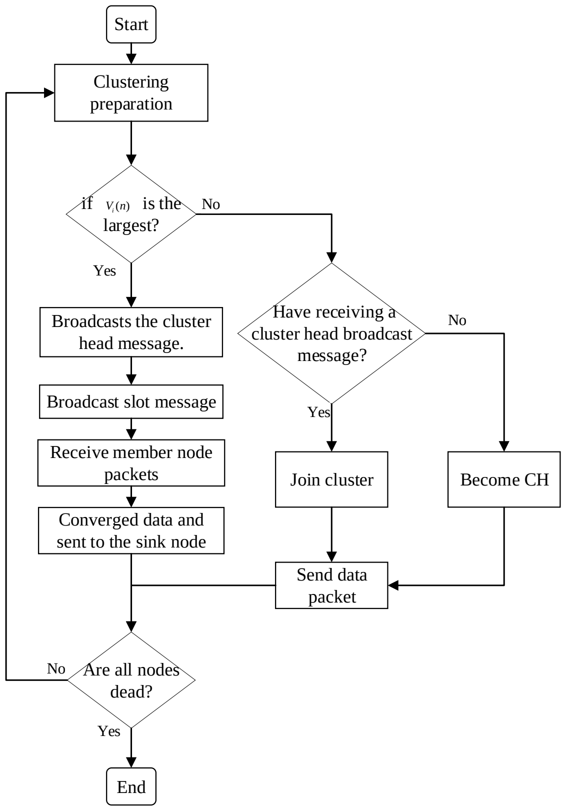


Fig.2 Clustering algorithm LEACH-ES flow chart

## 4. Simulation

### 4.1 Experimental environment and parameters

The simulation environment parameters used in this paper are shown in Table 1. The Matlab simulation software was used to simulate the network lifetime and packet transmission in the region.

Tab.1 Simulation parameter setting

| Parameter | Value |
|---|---|
| Number of nodes | 100 |

| | |
|---|---|
| Network area ($m^2$) | 100*100 |
| Location of Sink Node($m$) | (50,150) |
| Initial energy (J) | 0.02 |
| $\varepsilon_{fs}$ (pJ/bit $m^2$) | 10 |
| $\varepsilon_{amp}$ (pJ/bit $m^4$) | 0.0013 |
| The size of control packet(bit) | 40 |
| The size of data packet (bit) | 4000 |
| $E_{DA}$ (nJ/bit) | 5 |
| $E_{elec}$ (nJ/bit) | 50 |
| Data fusion rate | 0.4 |

**4.2 Simulation and analysis**

4.2.1 Network life time

As can be seen from Figure 3, all nodes have died in the LEACH protocol in less than 800 rounds. All nodes in the EACHP protocol network died in the 991 rounds. Under the LEACH-ES protocol, the number of surviving nodes in the 1000 rounds is only 4 One. However, the network validity period of LEACH, EACHP and LEACH-ES is 694, 877 and 965, respectively. LEACH-ES is 28% and 9% higher than LEACH and EACHP respectively. At the same time, the first node death round (FND) of the network under the LEACH-ES protocol has a certain improvement compared with the LEACH protocol and the EACHP protocol, especially 34% compared with the LEACH protocol FND.

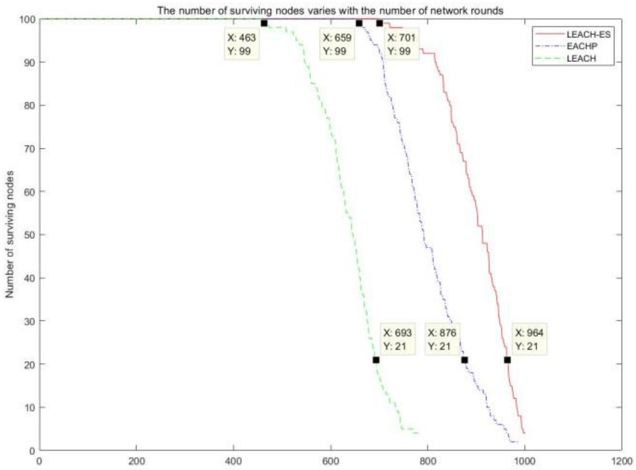


Fig.3 Number of surviving nodes

4.2.2 Packet throughput

In the wireless meter reading system, we are concerned about the amount of data packets transmitted, so we compare the number of packets transmitted by LEACH-ES, EACHP and LEACH before the 80% node mortality. The results are shown in Figure 4. From the above simulation results, it can be found that LEACH-ES is 28% and 9% higher than LEACH and EACHP in terms of network validity period. At the same time, the clustering effect of LEACH-ES is also ideal, and there is no instability of cluster network structure.

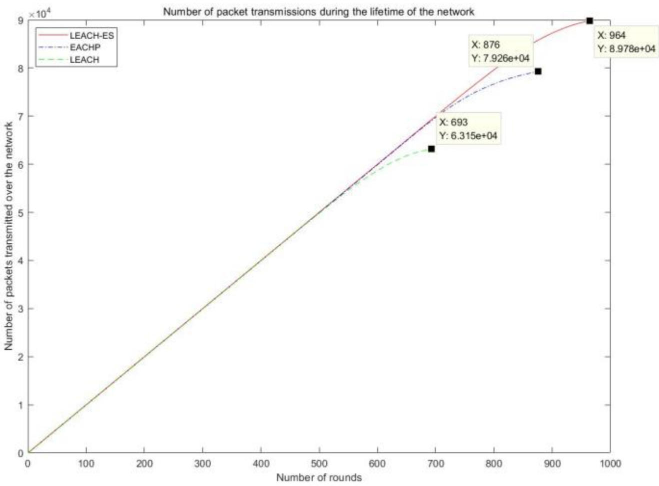


Fig.4 Packet throughput of the network validity period

## 5. Conclusion

This paper proposes an energy-efficient clustering algorithm for wireless meter reading systems, and compares the performance of LEACH protocol and EACHP protocol. The simulation results show that LEACH-ES is superior to LEACH and EACHP in network lifetime and network validity period. This paper not only compares the entire network life cycle, but also introduces the number of network death packets before the first node death round and 80% node mortality. Simulation experiments also prove that LEACH-ES is superior to LEACH and EACHP in load balancing.

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