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# Routing Protocol for Wireless Sensor Networks Based on Virtual Force Disturbing Mobile Sink Node

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## Abstract

One of the main goals of wireless sensor networks (WSNs) is to utilize the energy of sensor nodes effectively and maximize the network lifetime. Thus, this paper proposed a routing protocol for WSNs based on virtual force disturbing mobile Sink node (VFMSR). According to the number of sensor nodes in the cluster, the average energy and the centroid factor of the cluster, a new cluster head (CH) election fitness function was designed. At the same time, a hexagonal fixed-point moving trajectory model with the best radius was constructed, and the virtual force was introduced to interfere with it, so as to avoid the frequent propagation of sink node position information, and reduce the energy consumption of CH. Combined with the improved ant colony algorithm (ACA), the shortest transmission path to Sink node was constructed to reduce the energy consumption of long-distance data transmission of CHs. The simulation results showed that, compared with LEACH, EIP-LEACH, ANT-LEACH and MECA protocols, VFMSR protocol was superior to the existing routing protocols in terms of network energy consumption and network lifetime, and compared with LEACH protocol, the network lifetime was increased by more than three times.

***Keywords:*** Mobile Sink node, Network energy consumption, Route optimization, Wireless sensor network.

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## 1. Introduction

With the application of various sensors in different fields, a self-organized communication network between sensors — WSNs has become a research hotspot. At present, WSNs have been widely used in military, intelligent housing, environmental monitoring, transportation and other fields. Because there are many sensor nodes, WSNs are different from traditional networks in architecture, addressing mode, communication mode, routing structure and so on [1-3]. Because the sensor nodes in WSNs have the characteristics of random arrangement and wireless communication, it is difficult to ensure that all sensor nodes have the same characteristics in any case [4], and the energy of sensor nodes is limited, so it can not carry out long-term data transmission [5]. Therefore, how to save energy in WSNs, make WSNs work for a long time under the condition of limited energy, provide valuable information for a long time, increase the reliability of information, and prolong the network lifetime have become the key problem of WSNs [6,7].

Routing protocol, as one of the key technologies to reduce energy consumption and prolong the lifetime of WSNs, has been widely used in WSNs. According to the routing characteristics, routing algorithms for WSNs can be classified into flat routing and clustering routing [8]. In flat routing, all sensor nodes have the same status and function. Although flat routing is simple and robust, it is only suitable for small-scale networks because of large information redundancy. Sensor nodes far away from destination node need high energy to send information to destination node. Under the condition of limited energy, if the sensor node carries out long-distance data transmission every time, the energy will be quickly consumed, which will lead to the decline of service quality [9]. In clustering routing, sensor nodes are classified into several clusters. In each cluster, CH will be elected to collect and fuse data information of member nodes in the cluster, reducing data redundancy and data volume, and achieving the purpose of reducing network energy consumption. **Fig. 1** shows the hierarchical routing of WSNs.

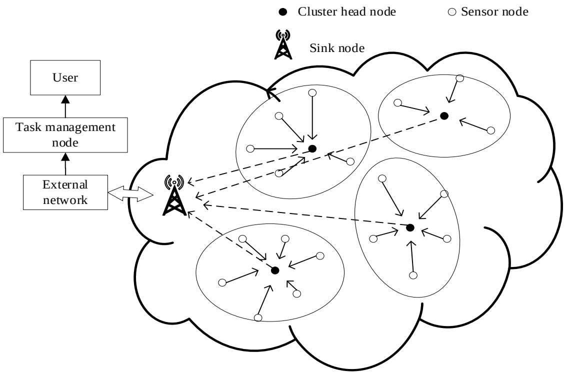


**Fig. 1.** Clustering routing structure of WSNs

In the traditional routing scheme, the sink node are fixed, and most of the data information is transmitted to Sink node in a multi hop way. As a result, sensor nodes deployed around Sink nodes consume too much energy as relay nodes of more CHs, forming energy holes and affecting data transmission [10]. The mobile sink node is used to gather the data in the monitoring area and change the position of the relay nodes around the Sink node, which helps to alleviate the problem that the peripheral sensor nodes have been used as relay nodes when the Sink node is fixed, alleviate the energy hole problem and improve the network service quality. However, it also brings new challenges to data transmission. The designed mobile sink node path should not only consider the location of the CHs and the remaining energy, to achieve the effect of saving energy and balancing energy consumption, but also consider taking up as little as possible of computing, storage and communication resources, so as to avoid the frequent spread of Sink node location causing excessive energy consumption of sensor nodes receiving information frequently, which greatly damages the energy-saving goal.

Aiming at the problems of energy limitation and short network life cycle of sensor nodes in WSNs, this paper proposed a routing protocol based on virtual force disturbing sink node movement. Based on LEACH, this protocol improved the election formula of CHs according to the centroid position and sensor node energy, and studied the fixed-point movement of Sink node according to the planned hexagon vertex and center point under the traction of virtual force. After the location of CHs and Sink node were determined, the improved ACA was introduced to plan the shortest path between CHs for multi hop data transmission. The improved ACA in this algorithm studied the propagation distance, propagation direction, size and transition probability of ants in the whole search process, enhanced the global search ability of ACA, reduced the energy consumption of CHs effectively, extended the lifetime of the network, and achieved the energy-saving goal of WSNs in the communication process.

This paper arranges the rest as follows: the second section introduces the related work of this paper; The third section introduces the system model of this paper; The fourth section introduces the algorithm proposed in this paper. The fifth section carries on the simulation analysis of the protocol proposed in this paper. The sixth section summarizes the previous work and also proposes the outlook for the future.

## 2. Related Work

Research showed that clustering routing protocol can increase the network scalability and prolong the network lifetime. The typical LEACH protocol is the first hierarchical structure protocol of homogeneous WSNs based on clustering [11], and it is also one of the most concerned protocols in the field of WSNs research. In LEACH protocol, the system is divided into smaller clusters. The protocol uses the idea of clustering to transmit the data of common sensor nodes to the CH of each cluster, and reduces the amount of data transmission to Sink node by fusing redundant information, so as to reduce energy consumption [12]. Although LEACH can extend the network lifetime, it still has some shortcomings. Because it does not pay attention to the residual energy and the location of the node when selecting the CHs, the common node with less energy and far away from the Sink node is selected as the CH, and the distribution of the CHs is uneven [13]. LEACH protocol realizes the single hop routing from CHs to Sink node, but it is not suitable for networks with large monitoring area. Moreover, it is based on fixed Sink node routing protocol, and it does not consider the sensor network of mobile Sink node in practical application.

In order to solve these problems, researchers have made improvements from the following aspects:

In a previous study, Anupkumar M B [14] proposed a new EIP-LEACH model. The protocol selects the CHs based on the residual energy of the current node, and each round of the process still includes the clustering stage and the stable stage. The main difference between EIP-LEACH protocol and LEACH protocol is to select CHs according to energy influence parameters and then change the election threshold. The results showed that this protocol is more effective than LEACH protocol. However, EIP-LEACH protocol does not pay attention to the average energy of sensor nodes and the data transmission distance between CHs and Sink node, resulting in uneven CHs election and too fast energy consumption. In a previous study. Tripathi M [15] proposed a LEACH-C protocol based on cluster. LEACH-C is a stable protocol using the centralized clustering algorithm. Only nodes with higher energy than average energy can be qualified as CHs. In LEACH-C protocol, Sink node has a global understanding of the location and energy of all nodes in the network, and can choose a better CH to reduce the energy required for data transmission [16]. However, the definition of LEACH-C optimal CHs is a NP complete problem, which fails to control the network overhead, and the dead nodes appear earlier [17]. In a previous study, Chandana M [18] proposes a distributed adaptive routing algorithm (ANT-NET), which only selects one optimal path to transmit data. Ants collect network information through indirect communication, and use this information to establish network state model and pheromone table to minimize energy consumption. In a previous study, Wang L [19] proposed an improved routing protocol based on energy optimization (ANT-LEACH). The protocol finds an optimal energy path between CHs and Sink node. However, in the path with the largest number of ants, most nodes will soon die. Although the energy consumption is reduced, most sensor nodes will die quickly in the path with the largest number of ants [20].

The above protocols are based on fixed Sink node, and the impact of mobile Sink node on the network is not studied. However, in the current practical application, it is necessary to move Sink node to maintain energy balance. Therefore, some scholars began to study the application of mobile sink nodes in WSNs.

In a previous study, Lin C J [21] proposed HCDD routing protocol, the protocol is a routing algorithm based on clustering. Sink node will select a CH nearest to itself as its "assistant". The "assistant" CH is responsible for broadcasting inquiry requests, collecting other CHs data and collecting its own cluster information [22]. However, the HCDD protocol uses the maximum and minimum distance clustering algorithm to construct the CHs, which leads to the CHs far from the "assistant" node consumes more energy and is not conducive to energy saving. In a previous study, Nazir B [23] proposed a mobile Sink based routing protocol (MSRP). In this protocol, only when the Sink node moves within the transmission distance threshold of the CHs, the CHs can transmit data to the Sink node. Therefore, it is only suitable for networks that can tolerate delay. Moreover, because the Sink node of the protocol adopts random mobility, it can not guarantee that the Sink node can access all CHs in a certain period of time, resulting in incomplete data reception and insufficient network service. In a previous study, Wang J [24] proposes a mobile receiver based energy-saving clustering algorithm (MECA). In this algorithm, the movement track of Sink node is fixed. The whole sensor monitoring area is divided into several equal areas and CHs will be selected in each area. To prolong the lifetime of a WSNs, the selected CH is responsible for gathering the data information in the cluster and sending it directly to the mobile Sink node after collection.

To sum up, the improved protocol based on the traditional clustering routing protocol often elects the CHs based on the remaining energy and distance, but it is easy to cause the uneven distribution of the CHs, and some nodes are far away from the CHs, resulting in excessive energy consumption, which is difficult to effectively extend the network life. For the routing algorithm of mobile Sink node, the demand for part of the data at the same time is not considered, which may lead to incomplete information received by Sink node and serious errors in background data analysis.

In view of the above problems, this paper constructed a hexagon fixed-point moving model by constraining the path of Sink node movement. The CHs position was relocated by considering the number of CHs, the remaining energy and the size of cluster members.

According to the position information of CHs and Sink node, a virtual force is defined. By adding the virtual force to disturb the mobile Sink node, the Sink node could be located effectively. In the data transmission stage, the improved ACA was introduced to make the sensor data multi hop transmission between clusters according to the CHs size in the specified ring area, which further improves the network lifetime.

## 3. System Model

### 3.1 Network Model

This paper assumes $N$ sensor nodes in the network are randomly distributed in a square area with an area of $M \times M\ m^2$, and the following assumptions are made:

(1) The energy of Sink node is unlimited.
(2) All sensor nodes are isomorphic and their positions cannot be changed.
(3) Each node in the WSNs can access the Sink node.
(4) The energy of all sensor nodes is limited.

### 3.2 Energy Consumption Model

The energy consumption model used in this paper is the same as that in reference [19]. The energy consumed by the sending data node transmitting $b$ bits data to the receiving data node at a distance of $d$ consists of transmitting circuit loss and power amplification loss. If the distance $d$ between the sending data node and the receiving data node is less than the threshold value $d_0$ set by us, the free-space model will be adopted in this paper, otherwise, the multipath fading model will be adopted.

The energy consumed for sending information is shown in equation (1):

$$E_{TX}(b,d)=\begin{cases} b*E_{elec}+b*\varepsilon_{fs}*d^2 & d<d_0 \\ b*E_{elec}+b*\varepsilon_{mp}*d^4 & d\geq d_0 \end{cases} \tag{1}$$

The threshold value $d_0$ is calculated by equation $d_0=\sqrt{\varepsilon_{fs}/\varepsilon_{mp}}$ , $\varepsilon_{fs}$ and $\varepsilon_{mp}$ are the signal power amplification coefficients in free space and multipath fading channel models respectively. Where $E_{elec}$ is the energy lost by the transmitting circuit.

The energy consumed by sensor nodes to receive $b$ bits information is shown in equation (2) :

$$E_{RX}(b)=b*E_{elec} \tag{2}$$

The total energy consumption in the network is shown in equation (3):

$$E_N=\sum_{i=1}^{N}E(i) \tag{3}$$

$N$ is the total number of nodes, and $E(i)$ is the energy consumption of data transmission and fusion of each sensor node.

The radio energy loss model is depicted in **Fig. 2**:

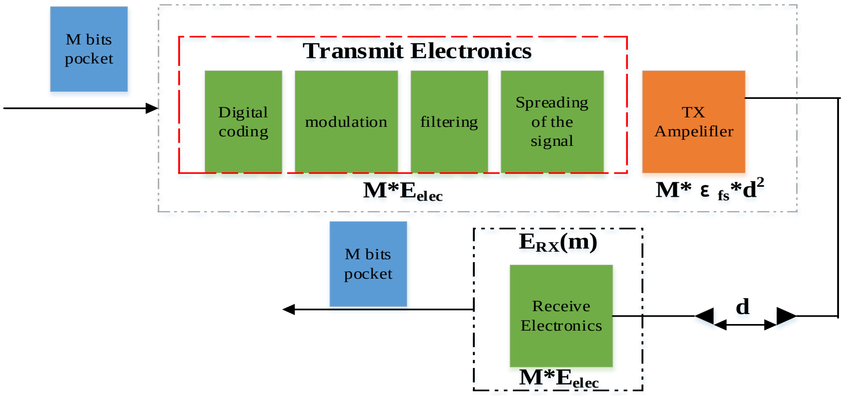


**Fig. 2.** Radio energy loss model

# 4. Proposed VFMSR Routing Algorithm

## 4.1 CH Election Strategy

In general, WSNs mainly include two kinds of nodes, which are ordinary nodes and Sink nodes. The Sink node needs to process the information of the whole network and send it to the external network, which is not limited by energy. If each common sensor node that is far away from Sink directly communicates with it, the energy of the common node will be consumed rapidly and serious data blocking will occur, which will reduce the transmission efficiency of the network. Therefore, this paper first clusters the sensor nodes in the network. The LEACH protocol distributes energy load according to randomness and probability, and reconstructs and selects CHs periodically. If the energy loss caused by data transmission can be borne by more nodes, the network lifetime can be extended. In the CHs election process, the common node selects the nearest CH node to join, and sets the threshold value of being selected as the CH node to zero to avoid the node being selected as the CH node again. The calculation method of threshold *T(s)* is shown in equation (4).

$$T(s)=\begin{cases}\dfrac{p}{1-p(r \bmod \frac{1}{p})} & \forall s\in G\\[2ex] 0 & others\end{cases} \tag{4}$$

Where $p$ is the proportion of the selected CHs, $r$ is the current round, $s$ is the sensor node, $G$ is the node set that has not been selected as the CHs in the latest $1/p$ round, and in LEACH protocol, each node s is at least once every $r=1/p$ round as the CH. During data transmission, the data fused by the CHs comes from the incoming data of the sensor node of the upper layer, and the data is transmitted to the Sink node through single-hop transmission.

In order to achieve the goal of balancing network energy consumption, the LEACH algorithm makes each node in the network act as the CHs in turn, extending the lifetime of the network. However, the selection of CHs in LEACH protocol is completely random, and it is easy to choose nodes with a distant location and less energy than CHs, which will affect the network lifetime.

Therefore, in this paper, the initial energy of all sensor nodes is set to $E_0$, and the total energy of sensor nodes in this paper is shown in equation (5).

$$E_{all} = \sum_{i=1}^{n_{alive}} E_r \tag{5}$$

$$E_{ave} = \frac{E_{all}}{n_{alive}} \tag{6}$$

$$p_i = \frac{p * N * E_r * E_r}{E_{all} * E_{ave}} \tag{7}$$

$E_{ave}$ is the average residual energy of current network. $n_{alive}$ represents the number of sensor nodes alive， and $E_r$ is the residual energy of the current node.

From the (5), (6) and (7), The selection probability of CHs involves many factors, which makes the selection of CHs more reasonable and balanced, thus balancing the energy consumption of the whole network and prolonging the service lifetime of the network.

In this paper, according to (4), $p_i$ is introduced into (4), and the probability threshold equation (8) of CHs selection in network is obtained.

$$T(s)=\begin{cases} \dfrac{p_i}{1-p_i(r \bmod \dfrac{1}{p_i})} & \forall s \in G \\ 0 & others \end{cases} \tag{8}$$

After the CH election is completed according to (8), each common node adds to the nearest CH one after another through the received CHs control command. After the clustering is completed, the CH is re-screened in the cluster according to the clustering formula, and the clustering formula is equation (11). The minimum value of *C(i)* is taken as the new CH. After the CH is re-selected, the common sensor nodes join the cluster according to the latest CH position for data transmission.

$$X_{cen} = \frac{\sum_{i=1}^{n_{CH}} x_i}{n_{CH}} \tag{9}$$

$$Y_{cen} = \frac{\sum_{i=1}^{n_{CH}} y_i}{n_{CH}} \tag{10}$$

$$C(i) = d_{tocen} * (\frac{1}{E_r}) \tag{11}$$

Where ($X_{cen}$, $Y_{cen}$) is the centroid of the temporary cluster, ($x_i$, $y_i$) is the location coordinate of the nodes in the cluster, *C(i)* is the preferred threshold of the new cluster, and $d_{tocen}$ is the distance between the sensor node and the center of mass of its cluster.

Through the above strategy, the CH election can avoid the CH distributed at the edge of the region, in case the data transmission distance is too large, resulting in excessive energy consumption, further extending the network lifetime.

## 4.2 Multi hop Strategy

Some studies have shown that [25-27], in the communication mode between the CH and the Sink node, if the single-hop direct communication is adopted, the CH node far away from the Sink node will die quickly due to too large transmission distance, resulting in too high transmission energy consumption. Therefore, the multi-hop routing is more conducive to saving data transmission energy. However, if the number of hops is too much, the energy consumption will be more. Therefore, choosing the appropriate number of hops will also reduce the energy loss of CHs.

In the classical cluster routing protocol, the influence of the size of the CHs node on the transmission energy consumption is generally not taken into account. Multiple forwarding will seriously consume the energy of the CHs near the base station and cause its energy consumption to be too fast. In order to reduce the phenomenon that too much forwarding leads to the rapid death of nodes, this paper constructs an inter cluster relay forwarding strategy based on the CH size.

According to the area of the monitoring area, the multi hop area is divided into three parts, and the Sink node is located in the center of the multi hop region. the multi hop partition calculation method is shown in **Table 1**, *L* represents the side length of the region and *l* represents the radius of the ring. When the CH is located in the region 1, the CH will successively find the CH closest to it in the region 2 for transmission. The same is true for the data transmission from the CH in the region 2 to the region 3, and finally the data is transmitted to the Sink node. But at the same time, the energy consumption of single hop and multi hop should be considered. If the energy loss of transmitting data in the form of single hop is the least, single hop should be used. As shown in node A, B and S in **Fig. 3**, if the energy from node A to node S is less than that from node A to node B to node S, single hop is adopted, otherwise multi hop is adopted. However, considering that the CH nodes close to Sink node relay for many times to reduce the complexity of the network, when the total number of CH nodes in region 2 and region 3 is greater than 3 and the number of CH reaches a specific proportion in region 1, this paper can find the optimal path and relay forwarding. Otherwise, data forwarding will not be carried out, but the CH nodes directly transmit the data to Sink node. According to the actual environment, some nodes may send data directly to Sink node rather than to their CHs to consume less energy. The relay forwarding strategy model is shown in **Fig. 3**.

**Table 1.** Calculation of cluster head distribution interval

| **Distribution interval** | **value** |
|---|---|
| Region 3 | $0 < l \leq (1/6)L$ |
| Region 2 | $(1/6)L < l \leq (1/3)L$ |
| Region 1 | others |

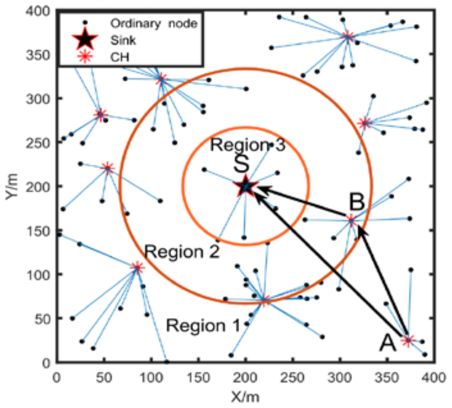


**Fig. 3.** Relay forwarding policy model

### 4.3 Ant Colony Algorithm Model

ACA optimization routing is a transmission method with rich characteristics, effectively solves the transmission path problem between nodes and prolongs the life cycle of WSNs. ACA is more suitable than genetic algorithm (GA), cuckoo algorithm (CS), bee colony algorithm and particle swarm optimization (PSO) [28-30]. Although the ACA has high computational cost, the path found by ACA is relatively optimal. Therefore, this paper uses the improved ACA for multi hop transmission. ACA takes pheromone as the optimization direction and uses positive feedback mechanism to complete the optimization process. In the process of ant foraging, pheromone is an important factor affecting ant behavior. Ants will choose the path with higher pheromone concentration, and the pheromone concentration on the shorter path will increase with the number of visits by ants. On the contrary, the path with lower pheromone concentration will be abandoned gradually. Finally, ants will choose the shortest path [31].

Using ACA to optimize WSNs, the main steps include the following four steps.

(1) Suppose the number of ants searching for path is $m$, and the search direction is random. At the initial time, the pheromone strength of each path is the same. The pheromone concentration on the path $< i , j >$ at time $t$ is $\tau_{ij}(t)$, $\tau_{ij}(0) = C$, $C$ is a constant.

(2) In the process of finding the path, the process of all ants from one path to another is random, and the transition probability is expressed by Equation (12)

(3)

$$p_{ij}^{k}(t)=\begin{cases}\dfrac{[\tau_{ij}(t)]^{\theta}[\eta_{ij}]^{\beta}}{\sum_{h\in Allowed_k}[\tau_{ij}(t)]^{\theta}[\eta_{ij}]^{\beta}} & h\in Allowed_k\\ 0 & h\notin Allowed_k\end{cases} \tag{12}$$

$$\eta_{ij}=\frac{1}{d_{ij}} \tag{13}$$

$$d_{ij}=\sqrt{(x_i-x_j)^2+(y_i-y_j)} \tag{14}$$

$p_{ij}^{k}(t)$ represents the probability of the $k$th ant moving from node $i$ to node $j$ at time $t$. $\theta$ is the pheromone concentration heuristic factor parameter, $\beta$ is the expectation heuristic factor parameter. among $\tau_{ij}(t)$ represents the pheromone concentration from node $i$ to node $j$ at time $t$. $\eta_{ij}$ represents the heuristic function value corresponding to the ant moving from node $i$ to node $j$. this value indicates that the smaller the distance between the two sensor nodes, the greater the probability of ant transferring from the two sensor nodes. $h$ represents all possible next hop nodes. $Allowed_k$ represents the next hop node set that the $k$th ant can explore.

(4) After the ants have completed the optimization process, pheromones are updated along the ant's path. The pheromone updating formula is Equation (15):

$$\tau_{ij}(t+n)=(1-\rho)\times\tau_{ij}(t)+\Delta\tau_{ij} \tag{15}$$

$$\Delta\tau_{ij}=\sum_{k=1}^{m}\Delta\tau_{ij}^{k} \tag{16}$$

Where, $\rho$ denotes the pheromone persistence coefficient $0<\rho<1$, $\Delta\tau_{ij}$ represents the increment of pheromones on the $<i , j>$ path in this iteration.

(4) Repeat steps (2) and (3) to return a path set with the strongest pheromone concentration. For each conversion of the cluster node, steps (1) to (4) are repeated.

In the traditional ACA, the parameters of pheromone concentration heuristic factor and expected heuristic factor are set to fixed values, the influence of this parameter on path selection and algorithm convergence is not considered, which leads to the long search time and slow convergence speed of the algorithm, and it is difficult to optimize in continuous space. When the scale of the problem is complex, the search space is large or the number of ants is too large, it’s hard to find a suitable solution in a short period. With the volatilization of pheromones, the probability of the unselected optimal solution to be selected later will become smaller, or even stop looking for the optimal path and fall into the local minimum prematurely. To solve these problems, the key parameters affecting the network lifetime are analyzed, and the basic ACA strategy is improved, so that the improved algorithm can find a reliable route, so as to achieve the purpose of extending the network lifetime. The parameters are adjusted to dynamically change with the number of CH nodes, which is calculated by equation (17) (18).

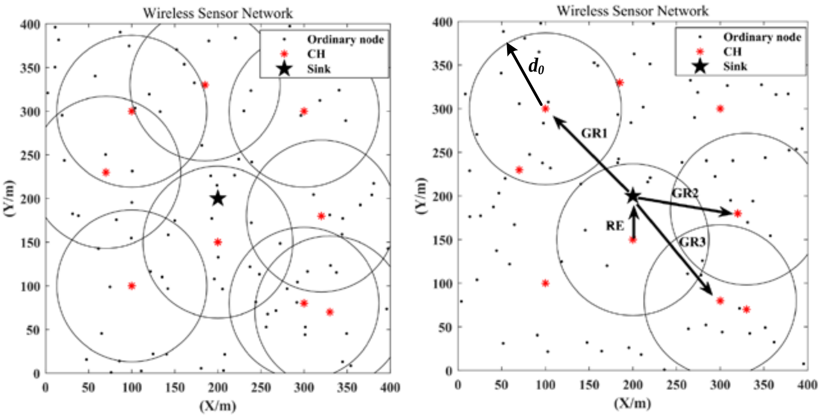
$$\theta = \mu * (1 + e^{\gamma * ci}) \tag{17}$$

$$\beta = \lambda * (1 + e^{\omega * ci}) \tag{18}$$

Where, $\gamma$, $\omega$ is a constant between [0,1], and $ci$ is the number of searches. $\mu$, $\lambda$ is the balance parameter.

### 4.4 Routing Protocol for Sink Node Mobility Based on Virtual Traction

Based on the above CH election strategy and inter cluster multi hop strategy, the purpose of energy saving is achieved. However, the distribution of CHs in the whole region is still random, and there is the possibility of uneven distribution. Therefore, Sink node are moved to the optimal direction in the case of energy saving. The hexagon fixed-point moving trajectory is designed to avoid the excessive energy consumption of CH caused by too many Sink node locating and frequently sending the location information of Sink node. This paper assumes that there are two kinds of forces between the Sink node and the CH node, namely repulsive force and attraction. When the distance between the CH and the Sink node is greater than its communication radius, it shows attraction, otherwise it shows repulsive force. Finally, Sink node will move under the action of virtual resultant force. When the force reaches equilibrium or reaches the maximum permission iterative number of times, the movement ends. According to the communication radius $d_0$, the boundary between attraction and repulsion is $d_0$, and the model diagram is shown in the **Fig. 4**.



(a) (b)

**Fig. 4.** Virtual force model

As shown in **Fig. 4**, The ring represents CH communication range. GR1, GR2 and GR3 represent the attraction of CH to Sink node respectively, and RE represents the repulsion of CH to Sink node. when the Sink node is within the communication radius of the CH, the CH will generate repulsive force RE on the Sink node, which will push the Sink away from itself, and the repulsive force will decrease with the increase of the distance between the two. When there is gravitational GR between CH and Sink node, Sink will be pulled to its own direction. As the distance between Sink node and CH gradually decreases, the attraction will be smaller and smaller, and it will reach the best point after moving many times.

$$F_{SUM}=\begin{cases} F_{GR}+F_{RE} & ,\quad 0<Cluster \\ 0 & ,\quad others \end{cases} \tag{19}$$

$$F_{GR}(i,Sink)=(d_{CH-Sink}(i,sink)-d_0,\theta(i,Sink))\quad ,d_{CH-Sink}(i,sink)>d_0 \tag{20}$$

$$F_{RE}(i,Sink)=(d_0-d_{CH-Sink}(i,Sink),\theta(CH,Sink))\quad ,d_{CH-Sink}(i,sink)<d_0 \tag{21}$$

$$F_{RE}(i,Sink)=F_{GR}(i,Sink)\quad ,d_{CH-Sink}(i,sink)=d_0 \tag{22}$$

$$F_{GR}=\sum_{i=1}^{N}F_{GR}(i,Sink) \tag{23}$$

$$F_{RE}=\sum_{i=1}^{N}F_{RE}(i,Sink) \tag{24}$$

In equation (19), $F_{sum}$ is the virtual resultant force between the CH and Sink node, $F_{GR}$ is the virtual attraction, $F_{RE}$ is the virtual repulsion, and *Cluster* is the number of CH nodes. $\theta(CH,Sink)$is the bearing angle of the force between the CH and Sink node, $d_{CH\text{-}Sink}(i, Sink)$ is the distance between the $k$th CH and the Sink node.

In order to avoid frequent spread of Sink node location and destroy energy saving target greatly, a hexagon structure model is designed, as shown in **Fig. 5**. The marks 1, 2, 3, 4, 5, 6 and 7 are the moving tracks of the mobile Sink node respectively. The reasonable hexagonal fixed-point mobile Sink node can minimize the energy dissipation among clusters and maximize the network lifetime.

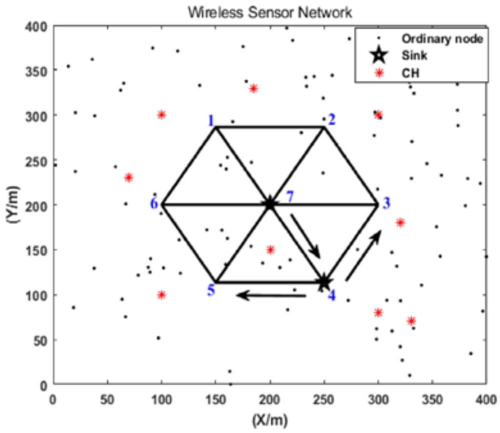


**Fig. 5.** Sink node fixed point mobile model

The virtual position of the Sink node is selected according to the resultant force on the Sink node. By calculating the distance between the virtual position and the vertex and center point of the hexagonal structure, the nearest point is selected as the position of the Sink node. And the Sink node moves from the previous position to the new position, as shown in **Fig. 5**, and the distance formula is shown in equation (25).

$$d_{F\sin ktoH\sin k} = \sqrt{(x_{F\sin k} - x_{H\sin ki})^2} + \sqrt{(y_{F\sin k} - y_{H\sin ki})^2} \qquad (25)$$

$(x_{Fsink}, y_{Fsink})$ represent the location of virtual Sink node, while $(x_{Hsinki}, y_{Hsinki})$ represent the fixed point positions of the hexagon structure model.

## 4.5 Algorithm Flow

The flow chart of the WSNs routing protocol based on virtual force disturbance of Sink node movement proposed in this paper is shown in **Fig. 6**, and the main steps are as follows.

(1) Parameter initialization. The number of nodes, coordinates, initial energy and area size of nodes in the initialization network are discussed.

(2) Select a temporary CH. Through the number, location and residual energy update of the nodes in the temporary cluster, a new optimal CH location is selected, after that, the clustering is done again.

(3) Determine the location of Sink node. Sink node are driven by virtual forces to move. According to the (19), (20), (21), (22), (23), (24), the position of Sink node is updated. The step of each iteration of Sink node is set to 10*m*. If the resultant force is 0 or reaches the maximum number of iterations, the node will jump out of the iteration.

(4) Ant colony path optimization. According to the number and location of CH nodes, whether to use multi hop mode to transmit data is determined, if the multi-hop method is adopted, the algorithm will be used to find the optimal path; otherwise, the algorithm will be skipped.

(5) Data transmission. If the number of CHs is 0 or the distance between node and CH is greater than that between node and Sink node, the data packet will be transmitted to the Sink node; Otherwise, the data will be transmitted to the CH. If the CH meets the multi hop transmission conditions, the data transmission is carried out according to the optimal path found in step (4), otherwise the data is directly sent to Sink node through the CH.

(6) Judge whether the energy of all nodes is exhausted. If so, the algorithm ends. Otherwise, return to step (2).

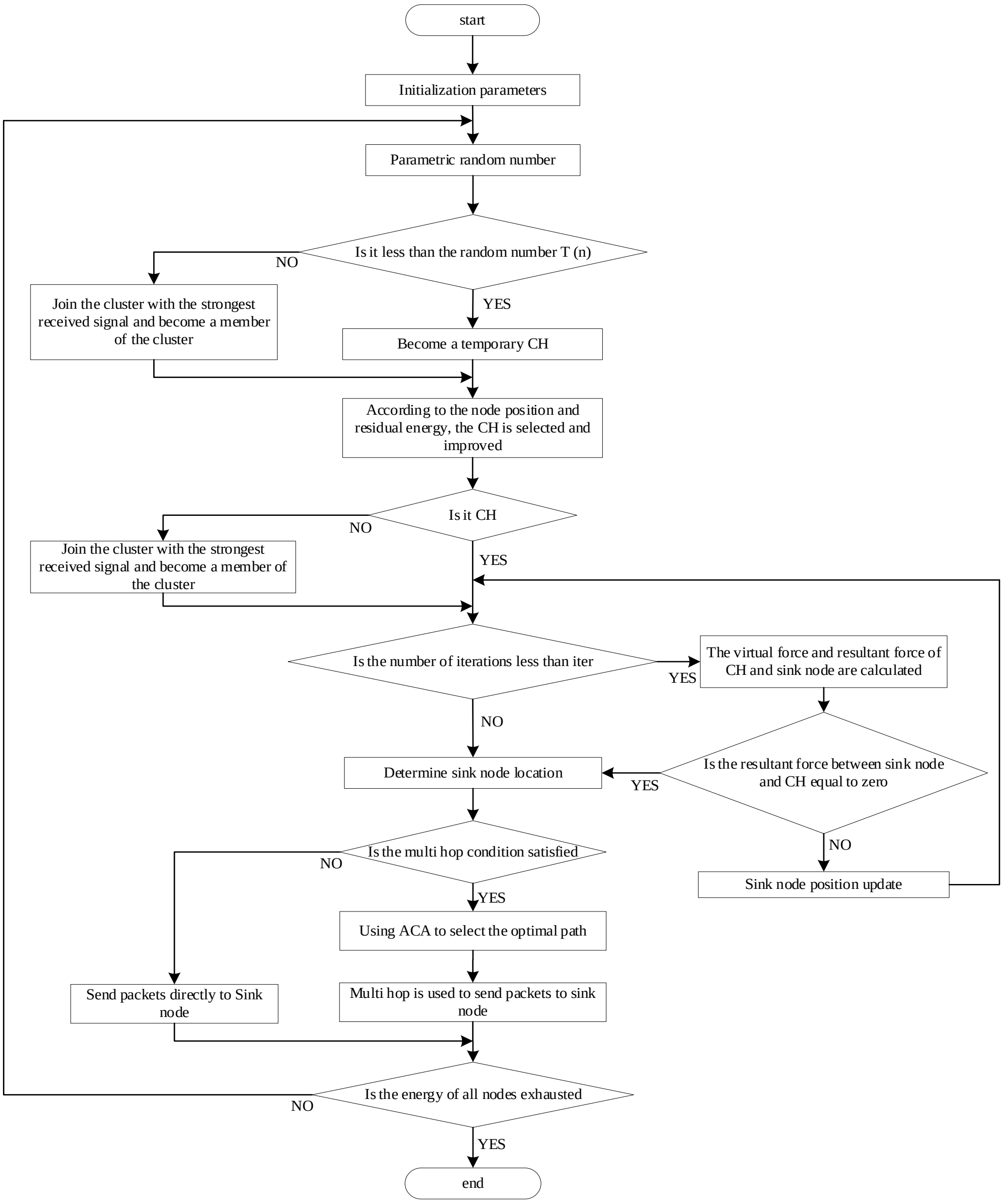


**Fig. 6.** Algorithm flow chart

# 5. Simulation Results and Analysis

To test the performance of the VFMSR algorithm, the VFMSR algorithm is compared with LEACH, EIP-LEACH, ANT-LEACH and MECA protocols about the cluster distribution, CH energy consumption, network residual energy and network lifetime. In the meantime, the influence of different number of nodes on network performance is studied.

The following simulation is achieved by MATLAB R2016a. The simulation parameters are shown in the **Table 2**.

**Table 2.** Simulation parameters

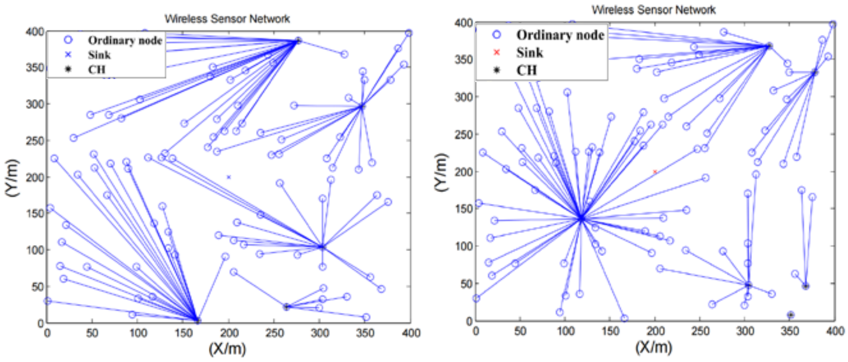
| parameters | value |
|---|---|
| Monitoring area | $400 \times 400(m^2)$ |
| Number of nodes | $N$=100, 200, 300 |
| Cluster head election probability | $p$=0.1 |
| Initial Sink node location | (50,50) |
| Energy consumption of data fusion | $E_{DA}=5nJ/bit$ |
| Energy consumption of transmission and reception | $E_{elec}=50nJ/bit$ |
| Energy of initial node | $E_0=0.5J$ |
| Transfer coefficient of amplifier (free space) | $\varepsilon_{fs}=10\mathrm{pJ/bit/m}^2$ |
| Transmission coefficient of amplifier (multipath space) | $\varepsilon_{mp}=0.0013pJ/bit/m^2$ |
| $\gamma$ | 0.125 |
| $\omega$ | 0.5 |
| $\mu$ | 5 |
| $\lambda$ | 0.1 |
| Packet size | $b=4000bits$ |

## 5.1 Experiment and Analysis of CH Distribution

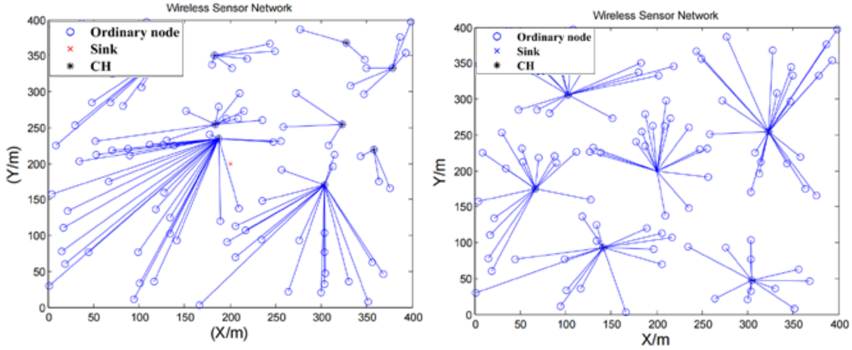
In this experiment, The VFMSR algorithm is compared with other three algorithms in the area of $400 \times 400m^2$, and the comparison diagram of CH distribution is shown in **Fig. 7**.

For LEACH, EIP-LEACH and ANT-LEACH, This is shown in **Fig. 7(a)**, **(b)** and **(c)**, the distribution of CHs is obviously uneven, resulting in maximum clusters and minimum clusters. At the same time, some CHs are far away from the cluster center, resulting in too long data transmission distance and too much energy consumption. This is because LEACH protocol, ANT-LEACH protocol and EIP-LEACH protocol are based on the mechanism of selecting CHs by rotation of nodes. The nodes currently selected as CHs will not participate in the selection of CHs before $1/p$ round. The difference between EIP-LEACH protocol and LEACH protocol, ANT-LEACH protocol in CH election is that EIP-LEACH protocol introduces residual energy and initial energy, which improves the chance for sensor nodes with high residual energy to become CH, and avoids the premature death of low-energy nodes. However, EIP-LEACH protocol does not pay attention to the distance between the CH and Sink node, resulting in the data transmission distance of the CH being too long and the energy consumption being too fast.

For the VFMSR algorithm, as shown in **Fig. 7(d)**, after the completion of the first selection of temporary clusters, the CH position is reconsidered to make the CH position more balanced, the data transmission distance between nodes in the cluster and the CH is reduced, and the energy consumption in the cluster is reduced.



(a) LEACH (b) EIP-LEACH

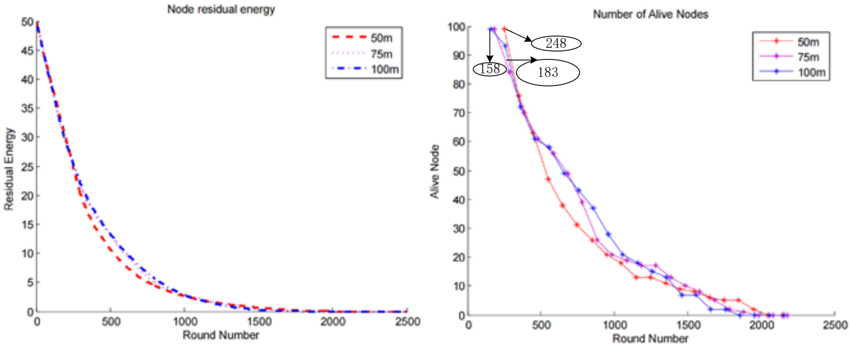


(c) ANT-LEACH (d) VFMSR

**Fig. 7.** Cluster head distribution comparison

## 5.2 Determination of Sink Node Moving Radius

In this experiment, the network performance is verified by changing the radius of the hexagon structure model. The tests are carried out when the moving radius of Sink node is 50m, 75m and 100m respectively, and compare the rounds of the first dead node, the remaining energy and the rounds of the final dead node. The relation between BS location and network is shown in **Fig. 8**.



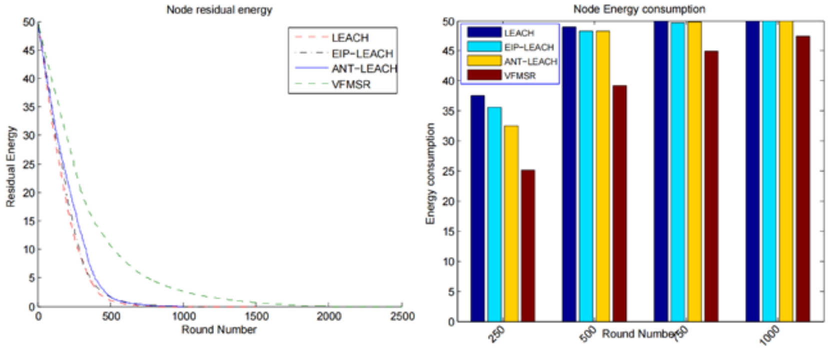
(a) Residual energy (b) Alive node

**Fig. 8.** Relation between BS location and network

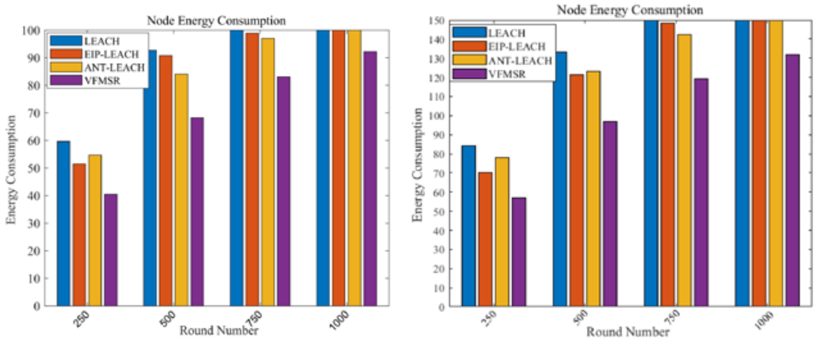
This is shown in **Fig. 8**, there is little difference in energy consumption in the three cases. Although the moving range is 75m and 100m, and the residual energy in the intermediate stage is higher than 50m, the first dead node appears earlier and the life cycle is shorter than 50m. To decrease the distance of Sink node and reduce the delay of data transmission in the actual situation, the experiment simulation is carried out with the hexagon radius of 50m.

### 5.3 Experiment and Analysis Based on Network

In the same round, the current total energy of the network is positively correlated with the working efficiency. Therefore, the current total energy of the whole network is an important performance index to measure the working efficiency of the network. The comparison between the current total network energy of the four algorithms and the energy consumption within the cycle is shown in **Fig. 9**. **Fig. 9 (a)** shows the residual energy curve of 100 sensor nodes, **Fig. 9 (b) (c) (d)** shows the energy consumption histogram of 100, 200, 300 sensor nodes in the monitoring area respectively.



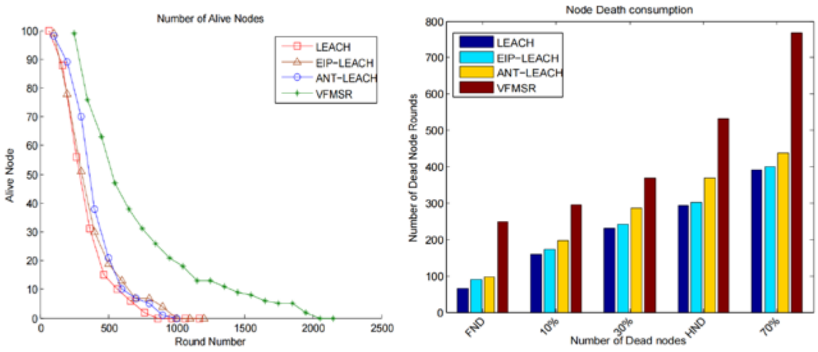
(a) Residual energy (100 nodes) (b) Energy consumption (100 nodes)



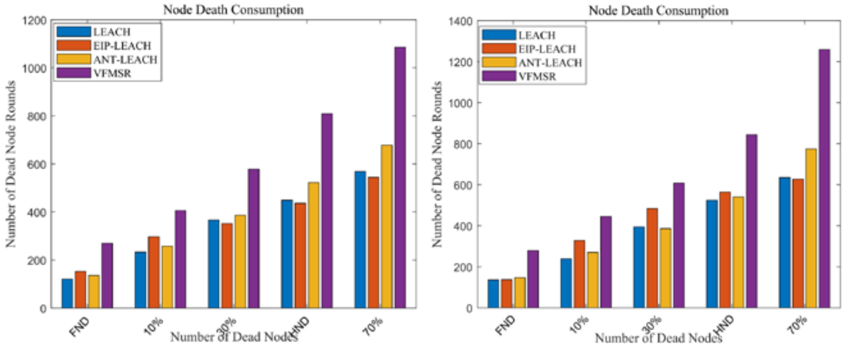
(c) Energy consumption (200 nodes) (d) Energy consumption (300 nodes)

**Fig. 9.** Node energy comparison diagram

As shown in **Fig. 9 (b)**, LEACH, EIP-LEACH and ANT-LEACH consume 74.1%, 71.28% and 64.96% of the total energy respectively when the network is executed to 250 rounds. When the network is executed to 500 rounds, the energy of LEACH, EIP-LEACH and ANT-LEACH is almost exhausted, and there is still high energy in this algorithm. Similarly, in the environment of 200 and 300 sensor nodes, as shown in **Fig. 9 (c) (d)**, the VFMSR algorithm consumes less energy than LEACH, EIP-LEACH and ANT-LEACH when the number of rounds is same. The main reason is that the VFMSR algorithm in this paper not only introduces the current energy of the node, but also considers the distance information from Sink node and the position of cluster members, which ensures the uniformity of CH distribution. More importantly, two virtual forces are defined to pull Sink nodes to move. The existence of these two virtual forces optimizes the location of Sink node to move, ensures that the CH can shorten the transmission distance as much as possible, and reduces the energy consumption. Therefore, this algorithm can significantly reduce and trade off the energy consumption of sensor nodes, which is conducive to ensuring the stability of network data transmission.



(a) Alive node (100 nodes) (b) Dead node (100 nodes)



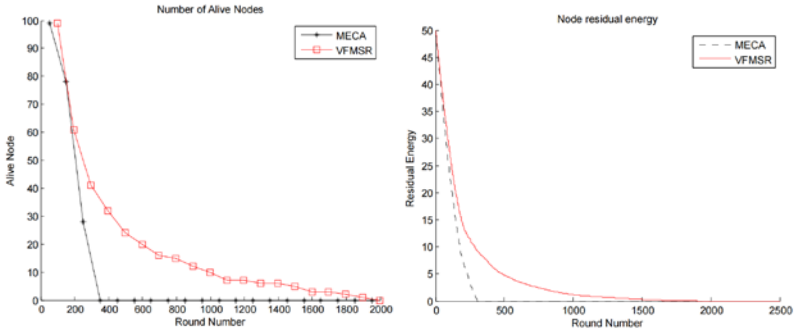
(c) Dead node (200 nodes) (d) Dead node (300 nodes)

**Fig. 10.** Analysis of dead nodes

The network life cycle is the key to measure the performance of routing protocol, and the first node death time is usually used as the reference index to evaluate the network lifetime. In the 100 sensor node environment, when the first dead node appears in the network, the number of rounds of LEACH, EIP-LEACH and ANT-LEACH is 65, 90, 95 and 248 respectively. Compared with the former three, the performance of this algorithm is improved by 3.8 times, 2.7 times and 2.6 times respectively, which can ensure the effective monitoring of the monitoring area for a long time.

As shown in **Fig. 10 (a)**, the proposed algorithm (VFMSR) still survives a large number of nodes when the first three algorithms run out of energy. It can be seen from the **Fig. 10 (b) (c) (d)** that compared with other three algorithms, when the number of dead nodes is the same, the VFMSR algorithm can run more rounds. And the network lifetime of the VFMSR algorithm is much higher than other algorithms. Therefore, in large-scale network, VFMSR algorithm has obvious performance advantages compared with LEACH, EIP-LEACH and ANT-LEACH protocols.

Compared with MECA algorithm, the simulation environment is changed to a circular area with radius of $R = 300m$, and the number of sensor nodes is $n = 100$, which is randomly distributed in this area.



(a) Alive node (b) Residual energy

**Fig. 11.** Network lifetime impact

Compared with the MECA protocol with mobile Sink node, as shown in **Fig. 11**, VFMSR protocol has better performance in the number of surviving nodes and residual energy than MECA protocol. If the network lifetime is defined as the time when the first node runs out of energy, VFMSR protocol has a longer lifetime than MECA protocol. Moreover, the residual energy of MECA decreases faster than VFMSR, which indicates that MECA consumes more energy than VFMSR in the routing process.

### 5.4 Algorithm Complexity Analysis

For the network with $N$ sensor nodes and $N_{CH}$ CHs ($N \geq N_{CH}$), The time complexity of selecting CH and initial clustering part is $O(N)$ and $O(N \times N_{CH})$ respectively, The time complexity of determining the location of the mobile Sink node is $O(N_{iter1} \times N_{CH})$, $N_{iter1}$ is the number of iterations to determine the location of the Sink node. Considering that the data transmission needs multi hop, the time complexity of selecting the optimal path is $O(N_{CH1} \times N_{iter2} \times N_T \times N_{pop} \times (N_{CH2}+N_{CH3}))$, Where, $N_{CH1}$, $N_{CH2}$ and $N_{CH3}$ represent the number of CHs in the region 1, region 2 and region 3 respectively, $N_{iter2}$ represents the number of iterations of ACA, $N_T$ represents the number of multi hops, and $N_{pop}$ represents the population number of ACA. Considering that the number of CHs is far less than the product of the population number of ACA and the number of CHs, the time complexity of this algorithm is $O(N_{CH1} \times N_{iter2} \times N_T \times N_{pop} \times (N_{CH2}+N_{CH3}))$. The time complexity of LEACH and EIP-LEACH algorithms in the comparison algorithm is low, because their algorithm process is simple. Therefore, their performance is far lower than that of the VFMSR algorithm. The time complexity of ANT-LEACH is $O(N_{CH} \times N_{iter2} \times N_{pop})$. Due to adding the regional multi hop in this paper, the time complexity is slightly higher, but the effect is better in terms of network lifetime.

## 6. Conclusion

This paper proposed a routing protocol for WSNs based on virtual force disturbing Sink node movement. Because the selection of CHs in traditional routing protocols is random, the selected CHs may be far away from Sink node, resulting in premature death of nodes. According to the above energy consumption problems, the fitness function of CH was constructed according to the centroid of cluster, the energy of sensor node, the position of Sink node and other factors. The multi hop strategy between clusters was analyzed and designed. The modified ACA was introduced to optimize the data transmission path, which shortened the distance between clusters and depressed the energy loss of data transmission. Aiming at minimizing the energy consumption and reducing frequent transmission of Sink node, a hexagon fixed-point moving trajectory model was proposed. The control of virtual force on the mobile Sink node was added, and the influence of the moving radius of Sink node on energy consumption was studied. Simulation results showed that, compared with LEACH, EIP-LEACH and ANT-LEACH, the proposed VFMSR protocol could effectively reduce the network energy consumption, prolong the network lifetime, and greatly improve the network lifetime of LEACH protocol. The VFMSR algorithm needs further optimization in heterogeneous networks. Because the impact of heterogeneous sensor nodes on network energy consumption is not considered, further research will be carried out around heterogeneous sensor nodes in the future.

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