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Routing Clustering Protocol for 3D Wireless Sensor Networks Based on Fragile Collection Ant Colony Algorithm

TIANYI ZHANG[1], GENG CHEN[1], QINGTIAN ZENG[1], GE SONG[1], CHAO LI[1], AND HUA DUAN[2]

[1]College of Electronic and Information Engineering, Shandong University of Science and Technology, Qingdao 266590, China
[2]College of Mathematics and System Science, Shandong University of Science and Technology, Qingdao 266590, China

Corresponding authors: Geng Chen (gengchen@sdust.edu.cn), Qingtian Zeng (qtzeng@163.com), and Hua Duan (huaduan59@163.com)

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ABSTRACT Compared with two-dimensional wireless sensor networks (2DWSNs), three-dimensional wireless sensor networks (3DWSNs) have higher node energy consumption and weaker load balancing. To alleviate these problems, we propose a new multi-hop routing clustering protocol for a wide range of 3DWSNs. In terms of clustering, nodes will run for cluster head (CH) by timing broadcast based on their remaining energy and their average distance from surrounding nodes. Two new identity nodes are added between the CH and the member nodes, the load transfer node responsible for transferring the energy consumption of the CH, and the secondary cluster head node (SCH) acting as the CH for the next round. In order to reduce energy consumption in key node areas, we also enable key nodes to communicate directly with the sink node. In the aspect of routing construction, SN generates the routing table corresponding to each CH through our proposed fragile ant colony algorithm. Because CH and SCH exist at the same time and have a certain replacement order, the SN only needs to obtain the location of each CH when the network is first clustered, and can continuously generate a new routing table corresponding to the CH, which reduces the energy consumption of the network in the routing path construction. We simulate this protocol, LEACH protocol, AZ-SEP protocol, and UCNPD protocol in a three-dimensional environment. The results show that this protocol is better than the other three protocols in terms of network lifetime and network load balance, respectively.

INDEX TERMS 3DWSNs, clustering algorithm, routing algorithm, network lifetime, network load balancing.

I. INTRODUCTION

WSNs are applied in many fields, such as agricultural environment monitoring, wartime data collection, industry, and manufacturing automation, etc., mainly for environmental data perception and transmission. As described in [19], WSN is always composed of hundreds of ordinary nodes (ODs), and one or more sink nodes (SNs), which play the role of data collection and upload. The OD is mainly responsible for the perception of environmental data and transmits the perceived data to SN through the set method to complete the communication. The cost of the OD is low, and the computing capacity is limited. OD is usually arranged in the detection space in the way of random distribution. In some cases, some or all nodes will be manually installed at the designated location. For example, in the case of wartime data collection, OD is usually distributed in the way of aircraft sprinkling, while in the case of underwater detection data collection, the nodes are usually

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arranged in the environment by artificial arrangement. OD is powered by its own batteries, and the energy of the batteries is limited and can not be supplemented. According to the similarities and differences of the initial energy of each node, the network can also be divided into homogeneous networks and heterogeneous networks. Obviously, extending the life cycle of WSNs, improving the energy utilization rate, and collecting more data under the fixed energy is an important problem faced by WSNs.

The method of data transmission and collection in the network is called routing protocols.

In recent years, many researchers have proposed various routing protocols of WSNs. According to the data transmission between OD and SN, these routing protocols can be divided into single-hop routing protocol and multi-hop routing protocol. In the multi-hop routing protocol, OD and SN can communicate in the way of single-hop or multi-hop, while in the single-hop routing protocol, OD only communicates with SN in the way of single-hop. In the development of sensor networks, the low-energy adaptive cluster hierarchical (LEACH) [1] protocol proposed the clustering method, and the hierarchical routing protocols were born. The OD distributed in WSNs is divided into member nodes (MN) and CH. MN is mainly responsible for collecting information and sending it to the corresponding CH by single hop. CH aggregates information and transmits the message to the SN in a single hop manner or multiple hop manner.

With the development of WSNs, some problems are found. First of all, the network load imbalance is a key problem that restricts the network life. The nodes with the same initial energy are distributed in the WSNs, and each node consumes different energy in each round of data collection. The nodes with high energy consumption die faster, which will shrink the network coverage or make SN fall into an island, and eventually lead to WSNs failure. Secondly, the problem of "hot point" derived from the phenomenon of network load imbalance refers to the problem that some nodes bear much more network load than other nodes in the network due to the problem of routing protocols or node distribution. In WSNs with randomly assigned nodes, no protocol can avoid these two problems. It can only be alleviated by various methods to balance the network load as much as possible.

On the research of WSNs, most researchers assume that the application environment of WSNs is a 2D environment. In real life, although there is a WSNs application scenario that can be regarded as a 2D environment with small fluctuation, most of the WSNs are still applied in the 3D application scenario. The routing protocol in the 2D environment can also be used in the 3D environment. In reference [2], the performance of LEACH protocol in 2D and 3D space is simulated under the same conditions. It is found that compared with the LEACH protocol in 2D space, the lifetime of LEACH protocol in 3D space is reduced by about 21%. It is proved that the 2D approximation of the environment in the traditional protocol is unreasonable. Due to the problem of the structure of the 3D environment itself, the energy consumption of nodes in a 3D environment is usually higher than that in the 2D environment [3]. It is not difficult to prove that, if there are an equal number of nodes uniformly distributed in the circular plane area and in the sphere with radius R, SN is in the center of the network. In both environments, it is not difficult to find through the formula of the circular area $S = 2\pi r^2$ and the formula of sphere volume $V = 4/3\pi r^3$. The proportion of the number of nodes with a distance less than r to the total number of nodes is reduced from $(r/R)^2$ in 2D space to $(r/R)^3$ in 3D space, that is to say, in 3D space nodes with a distance less than R have only r/R in 2D space. The number of nodes in the area closer to SN decreases more obviously. When the network coverage is broad, the total number of nodes close to the SN in 2D WSNs will be several times that in 3D WSNs. The decrease of the proportion of nodes close to the sink leads to the increase of the average distance between the node and the sink. In the LEACH protocol, the energy consumption of nodes is positively related to the distance between nodes. The increase of average distance will inevitably lead to an increase in energy consumption and a decrease in the lifetime of LEACH protocol. Not only that, but the decrease of the number of nodes close to the convergence node also reduces the load balance of the network when using the multi-hop routing protocol. In most multi-hop routing protocols, it is inevitable to call the nodes in the range of one hop from the SN to act as the relay nodes. The decrease in the number of relay nodes increases the load of existing relay nodes, which makes the network load imbalance more serious. In order to alleviate the problem of energy consumption and load imbalance in 3DWSNs, it is urgent to design an energy optimization protocol for load balancing.

This paper proposes a new clustering multi-hop routing protocol for large-scale 3DWSNs: Routing clustering protocol based on fragile collection ant colony algorithm protocol (ASRCP). In this protocol, the timed broadcast is adopted to cluster. According to the residual energy of nodes, and the average distance between nodes and surrounding nodes, the time for each node to broadcast CH claim information is calculated. The nodes with relatively high residual energy and the small average distance from the surrounding nodes are preferred to be CH. In order to reduce the energy consumption of the network and balance the load of the network, two new identity nodes are added between CH and MN. One is the load transfer node (LTN), which is responsible for sharing the communication load between CH nodes, and the other is the secondary SCH, which is used as the standby CH. In the initial clustering process, CH nodes and SCH nodes are generated in order. In the subsequent clustering process, the SCH nodes directly become the new CH, and only the new SCH nodes are generated. This protocol uses SN with strong computing power to replace OD to generate routing tables. In the initial clustering of the network, the CH node informs SN of its location and residual energy by directional flooding. The SN makes the routing table corresponding to each CH. CH node sends data information to the SN node according to the routing table and adds the location and residual energy of

SCH in the data information. So, the SN node can obtain the location and energy information of CH of the next round and directly generate the routing table corresponding to the new CH. Therefore, in the route construction method proposed in this paper, CH nodes only need to inform SN nodes of their own location when clustering for the first time. The newly generated CH in the subsequent process only needs to wait for the routing table made by SN nodes, which significantly reduces the energy consumption in the route construction process. SN generates the routing table corresponding to each CH through the fragile collection ant colony algorithm. The fragile collection ant colony algorithm is a load balancing routing algorithm proposed by us for WSNs. Based on the ant colony routing algorithm, we add the fragile coefficient of each edge, so that the ant not only considers the total length of the path but also considers the energy of the node in the path. Under the 3D sphere wireless sensor model and the network energy consumption model, we compare several routing protocols. Results show this protocol is superior to other protocols in terms of network lifetime and load balance.

II. RELATIVE WORK

When it comes to WSNs, one protocol you can't bypass is called LEACH protocol. LEACH protocol proposes the mechanism of clustering. LEACH protocol, as the first one to apply clustering to WSNs protocol, its method of selecting CH is relatively simple. However, the birth of the clustering concept still dramatically reduces the single-hop distance of nodes in the whole network. LEACH protocol selects CH by generating a random number and setting cluster probability. The nodes that have served as CHs can not run for the next round of CHs to avoid the node acting as CH continuously. LEACH protocol chooses CHs in a random way, and the distribution of CHs can not be interfered and guided. The total number of CHs can only be controlled by fuzzy control through adjusting the clustering probability, which is easy to lead to the situation that the number of MN of some CH is too large, which destroys the load balance of the network.

It is unreasonable for LEACH to select CHs in a completely random way, so a new clustering method is generated after LEACH. The clustering method to determine CHs through calculation represented by hybrid energy-efficient distributed (HEED) [4] protocol. HEED protocol considers the influence of the total network energy of the WSN and the residual energy of the nodes. It makes the nodes with larger residual energy have a higher probability of becoming CH, which makes the selection of CH nodes from completely equal probability random to unequal probability random. To some extent, the residual energy of nodes has an impact on the selection of CHs. However, the average energy of nodes in the whole network is considered in the calculation of clustering probability. Nodes need to obtain energy information from all other nodes. Therefore, the energy consumption of nodes is increased. In large-scale networks or networks with high node density, energy consumption is higher. However, it is meaningful to use the residual energy of nodes to determine the probability of nodes becoming CHs.

In addition, there are other clustering methods. For example, the energy-optimization clustering routing protocol based on dynamic hierarchical clustering in 3D WSNs(3DHCP) [5] protocol adopts the clustering method of first calculating the optimal number of clusters in the network. It is dividing the network according to the optimal number of clusters and then finding suitable nodes in each region to become CHs. In this way, the total energy consumption of the network is reduced, and the load balance of the network is enhanced. But this clustering method takes a long time and can not guarantee the scale of each cluster. It is easy to generate clusters with a large size gap in the network.

The routing protocol can be divided into single-hop routing and multi-hop routing. LEACH protocol, HEED protocol, and 3DHCP protocol mentioned above belong to the single hop routing protocol, and their application scenarios are often the case where the number of nodes is low, and the network coverage is small. If the network coverage is broad, the energy consumption of the single-hop routing protocol will be greatly increased. In a large network coverage, it is more suitable to use a multi-hop routing protocol. The energy-efficient uneven clustering (EEUC) protocol, the nodes communicate with the SN in a multi-hop way. After the clustering phase, CHs that can communicate with the SN directly transfer the data to the SN. On the premise of data forwarding to the SN, other CHs use a greedy algorithm to choose their next-hop by calculating the distance from other nodes and finally forward the data to the SN to complete the communication. EEUC protocol adopts multi-hop and non-uniform clustering to reduce the energy consumption of the network and balance the load of the network. However, it adopts a "use and throws" clustering method. After clustering, the CH collects the node data in the cluster and sends it to SN, the cluster will fail immediately, and the network will start a new round of CH selection. Although the frequency of CH replacement avoids the problem of "hot point" when the node acts as CH for a long time, too frequent clustering also leads to the rise of overall energy consumption and the decline of network life. Then we determine the optimal clustering period of this protocol through experiments.

In fact, some of the current multi-hop WSNs protocols are relatively simple to build multi-hop routing. For example, when the EEUC protocol constructs the routing path, the sending CH selects the relay node by judging the distance between the candidate CH and itself on the premise of ensuring the data transmission to the SN direction. Advanced zonal stable election protocol (AZ-SEP) [6] protocol uses CHs far away from the SN to communicate with the SN through flooding.

But in recent years, researchers have found that the construction of routing will affect the energy consumption and load balance of the network. Therefore, many new route construction methods are proposed. For example, unequal clustering routing protocol considering energy balancing based on network partition & distance (UCNPD) [7] protocol, which takes the method of expanding the sensing range of nodes and increasing the consideration factors of routing path when building communication between clusters. UCNPD takes a reasonable way to expand the sensing range of nodes and take the remaining energy of nodes as the judgment factor of next-hop selection in the stage of building inter-cluster routing. However, the expansion of the sensing range of nodes and the increase of the amount of data that nodes need to acquire also increase the energy consumption of the network.

And gradually, the mature path planning algorithm is applied to the route construction [8]. PEGASIS in WSN based on an improved ant colony algorithm (PEG-ant) protocol, which uses the ant colony algorithm to generate the routing chain connecting each node. PEGASIS in 3DWSN based on genetic algorithm (PEG-GA) [9] protocol improves the PEGASIS protocol in the 3D application environment, using a genetic algorithm instead of the greedy algorithm to link nodes into the chain to generate the node chain with the minimum length. Adaptive Periodic Threshold-sensitive energy-efficient sensor network (APTEEN) [10] protocol uses the ant colony algorithm to build multi-hop routing. These protocols have improved the performance of the network to some extent. But, using the routing algorithm to build routing requires that the OD have strong computing and storage capacity, and will increase the energy consumption in the process of building inter-cluster routing. As a widely distributed node in the network, the increase of OD cost will greatly increase the overall cost of the network. Therefore, we propose a method of using SN to generate routing paths without increasing the cost of common nodes.

As a mature path search algorithm, the ant colony algorithm [11] is often used to solve the traveling salesman problem (TSP) and point-to-point path planning, so it can be used to build routing paths. However, there are some differences between the application conditions of the ant colony algorithm and WSNs, which need to be improved to better adapt to the environment of WSNs.

In this paper we propose a new cluster routing protocol. In clustering, nodes will calculate the waiting time of sending cluster head claim information by their relative energy and distance from the surrounding nodes. We have added two new roles, SCH and LTN, in the cluster to balance the network load and reduce the energy consumption of the network routing path construction process. In terms of routing path construction, we propose a new method, which transfers the construction task of routing paths from OD to SN. Simulation results show that the proposed cluster routing protocol effectively reduces network energy consumption and enhances network load balance. This paper makes the following main contributions.

1) The reasons for the performance degradation of the two-dimensional wireless sensor network routing protocol in three-dimensional wireless sensor networks are analyzed.

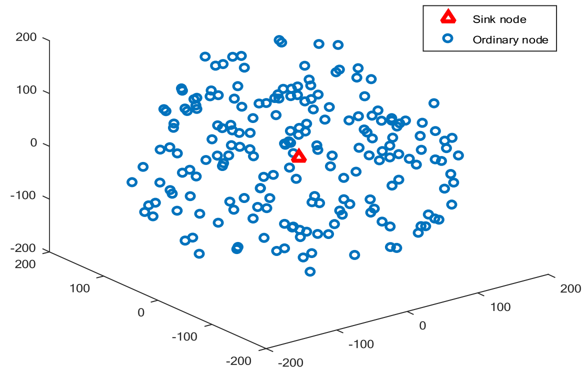

FIGURE 1. Sensor network model.

2) A new model for measuring the fitness value of the cluster head is proposed. Considering the relative distance between the nodes and the surrounding nodes, the nodes with a smaller average distance from the surrounding nodes have a higher probability to become cluster heads.
3) The SN replaces the OD and cooperates with the cluster head update mechanism to generate a routing table corresponding to each cluster head.
4) A new path finding algorithm based on ant colony algorithm is proposed, which is more suitable for wireless sensor network routing construction. The algorithm not only considers the total length of the generated path, but also the energy of the nodes that the path passes through.

The architecture of this paper is as follows. Section III introduces the system model and the energy consumption model. The overall process of the protocol is presented in Section IV. Simulation results are shown in Sections V.

III. SYSTEM MODEL

A. NETWORK MODEL

The sensor network model is shown in Fig.1.

1) The network consists of a SN and n ODs.
2) The position of the SN is located in the center of the sensor network.
3) Ordinary nodes are randomly distributed in three-dimensional space, and the energy is isomorphic and cannot be supplemented.
4) Each node has its own unique ID.
5) The communication power of OD can be adjusted according to the communication distance.
6) CH nodes use the data fusion method to process the data of nodes in the cluster.
7) Nodes periodically perform data acquisition and always send data to SN.

Because the protocol proposed in this paper does not involve the coverage and data processing of wireless sensor nodes, similar to the protocol [8]–[10], we do not consider issues such as sensor node coverage and noise.

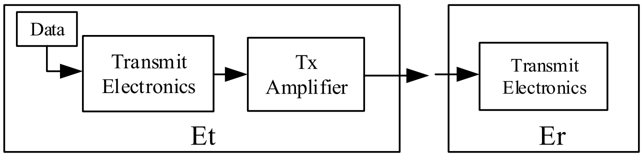

FIGURE 2. Energy consumption model of node receiving and transmission.

B. NODE ENERGY CONSUMPTION MODEL

We adopted a general energy consumption model as adopted in the literature [6], [7], [10]. Node energy consumption includes two parts: data receiving energy consumption and data sending energy consumption. Data receiving energy consumption includes receiving circuit energy consumption. Data sending energy consumption includes transmitting circuit energy consumption and power amplifier circuit energy consumption. The energy consumption of the node receiving and transmission model is shown in Fig. 2. The energy consumption of node receiving and transmission data is shown in Eq. (3) & (4).

$$E_r = data \times E_{elec} \tag{1}$$

$$E_t = \begin{cases} data \times (E_{elec} + \varepsilon_{fs} \times d^2), & d \le d_0 \\ data \times (E_{elec} + \varepsilon_{mp} \times d^4), & d > d_0 \end{cases} \tag{2}$$

$\varepsilon_{\mathrm{fs}}$ and $\varepsilon_{\mathrm{mp}}$ are the energy consumption coefficients of power amplifier circuits under different channel propagation models, and d_0 is the switching threshold of amplifier circuits determined by Eq. (3). In order to simplify the process, data is divided into Control Message (CM) and Data Message (DM). The DM packet is the data information generated by the OD. In addition, the other short packet data communication used for routing and ACK code are regarded as CM packets.

$$d_0 = \sqrt{\frac{E_{fs}}{E_{mp}}} \tag{3}$$

Moreover, CH nodes consume additional energy for data fusion. CH nodes compress and pack the collected information of cluster nodes, which reduces the total amount of data flowing into the network. The process of packaging and compression is called data fusion. In order to simplify the design, this paper assumes that the CH will compress all DM emitted by the collected intra-cluster nodes into the DM size, and the energy consumption of data fusion is set to E_{DA} =5nJ/bit. The energy consumption of data fusion E_{f} is shown in Eq. (4).

$$E_f = E_{DA} \times data \tag{4}$$

IV. PROTOCOL DESIGN

The overall process of the protocol is shown in Fig.3, which can be divided into three parts: node hop synchronization, node clustering, and inter-cluster routing. The synchronization of node hops occurs before the initial clustering of the network. The node obtains the minimum number of hops needed for communication with the SN by forwarding the control information sent by the SN. In the initial clustering of the network, the nodes run for CH node and SCH node at the same time. In the subsequent clustering process, the network only runs for SCH. When CH runs to the set number of rounds, SCH becomes a new CH directly. Before the inter-cluster routing data transmission, CH and SCH nodes exist at the same time. The communication route between clusters is generated by SN through the fragile collection ant colony algorithm. The detailed process of each part will be described in Section A, B, and C.

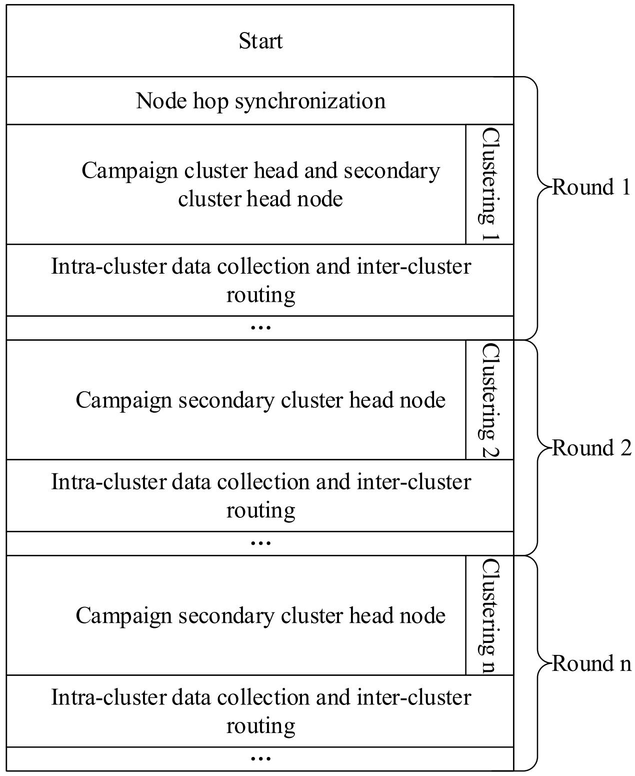

FIGURE 3. Routing protocol overall process.

A. NODE HOP SYNCHRONIZATION

When the network layout is completed, the SN sends the node hop synchronization packet, so that each node can obtain its own hop information. When the network layout is completed, the SN sends the node hop synchronization packet. The number of hops in the packets sent by the SN is one. The node receiving the packets marks its own hop information as one and increases the hop information in the packets by one before forwarding. After receiving the hop synchronization packets forwarded by other nodes, the nodes are compared with the hop number marked by themselves. If it is less than the number of hops recorded by itself, update its own hop number and forward the hop number information in the hop synchronization packet after adding one. If it is not less than the number of hops marked by itself, the node discards the packet. Finally, all nodes in the network will get the minimum number of hops to SN. When the subsequent CH sends data to SN, the data can only flow from the high-level nodes to the low-level nodes to realize the function of directional flooding. In this way, unnecessary flooding can be avoided, and the energy consumption of the network can be reduced.

B. CLUSTERING ALGORITHM

In this protocol, ODs are divided into MN and identity nodes. Identity nodes can be divided into CH, LTN, and SCH, which are respectively responsible for different tasks. The MN is only responsible for the perception of environment data and sends its perceived data to the corresponding CH. In the identity node, CH is responsible for the collection of information within the cluster and the transmission of data to SN in a single hop or multi-hop way according to the routing table. LTN is the node with the highest energy within the CH communication radius, specified by the CH node. LTN is responsible for sharing some inter-cluster communication tasks of CH. The task of the SCH node is the same as that of the MN, but when the current CH node reaches the set number of replacement rounds, the SCH node directly becomes a new CH, and its corresponding standby LTN becomes a new LTN. Each node can run for CH and SCH by calculating the waiting time T_c of sending CH claim information. T_c is calculated by Eq. (5):

$$T_{\mathrm{c}} = T_h \times (a\frac{\overline{E}_{ro}}{E_i} + b\frac{\overline{N}}{R}) \tag{5}$$

In Eq.(5), $a + b = 1$, a is the network load balancing coefficient, b is the network energy consumption coefficient, T_h is the time constant, $\overline{E}_{ro}$ is the average residual energy of the node within the cluster radius, E_i is the residual energy of the node itself, $\overline{N}$ is the average distance between the node and other nodes within the cluster radius, and R is the cluster radius of the node. The algorithm tends to select the nodes with relatively high energy and short average communication distance with the surrounding nodes as CH. As CH consumes more energy, choosing a node with higher energy as CH has less effect on the load balance of the network. In order to reduce the communication consumption in the cluster, the nodes with a smaller average distance from the surrounding nodes are selected as CHs, which can reduce the total communication energy consumption in the cluster. The clustering process of nodes is as follows:

Step 1: Environmental awareness stage. Each node broadcasts control information containing its own residual energy and position to its cluster radius. After receiving the control information from other nodes, the nodes within their cluster radius are sorted according to the residual energy to generate the candidate LTN list and calculate their corresponding T_c through Eq. (5).

Step 2: CH campaign stage. Only when the network is clustered for the first time can the network run for CH. if the node receives the CH claim information from other nodes before T_c arrives, the node exits the CH campaign stage and moves to step 3 to run for Sch. If the node does not receive the claim information from other nodes, the node broadcasts its own CH claim information to the cluster radius. The claim information contains the ID of the node itself and the ID of the node with the highest energy in the candidate LTN list of the node. In this way, the node claims itself as the CH node and specifies its own corresponding LTN node. For the first time, the node receiving the CH claim information marks the claimed node as its corresponding CH. The LTN node exits the identity node campaign after receiving the information.

Step 3: SCH campaign stage. The node is retimed according to the time calculated in step 1, waiting for the claim to be SCH. If the node receives the information that other nodes claim SCH before the time arrives and is not designated as the LTN of the SCH, then the node becomes MN. If the node does not receive the SCH claim information from other nodes, the node claims itself as SCH in the same way as CH and claims its corresponding standby LTN.

Step 4: When the CH runs to the set number of rounds, the CH node turns to MN, SCH becomes the new CH, and the standby LTN becomes the new LTN. The remaining nodes go to step 1 and skip step 2 to execute step 3 campaign to generate new SCH and standby LTN.

The overall process of clustering in the protocol is shown in Fig. 4, where r is the number of rounds of the network.

In addition, in order to prolong the life of the key nodes, we also make the key node area adopt different communication methods. In the multi-hop routing, all nodes in the range of one-hop of SN are called key nodes, because they are inevitably needed to act as relay nodes when the data is

$$\begin{aligned} E_a &= data \times (n \times E_{elec} + \varepsilon_{fs} \times \sum_{i=1}^{n} d_i^2) \\ &= n \times data \times E_{elec} + n \times data \times \varepsilon_{fs} \times \overline{d_i^2} \end{aligned} \tag{6}$$

$$\begin{aligned} E_{a1} &= n \times data \times E_{elec} + n \times data \times \varepsilon_{fs} \times \overline{r_i^2} + n \times data \times E_{elec} + s \times data \times E_{elec} + s \times data \times \varepsilon_{fs} \times \overline{d_i^2} \\ &= (2 \times n + s) \times data \times E_{elec} + (n \times \overline{r_i^2} + s \times \overline{d_i^2}) \times data \times \varepsilon_{fs} \end{aligned} \tag{7}$$

$$\mathrm{s} = \frac{-(-data \times \varepsilon_{fs} \times n \times \overline{d_i^2} + data \times \varepsilon_{fs} \times n \times \overline{r_i^2} + data \times E_{elec} \times n)}{(data \times \varepsilon_{fs} \times \overline{d_i^2} + data \times E_{elec})} \tag{8}$$

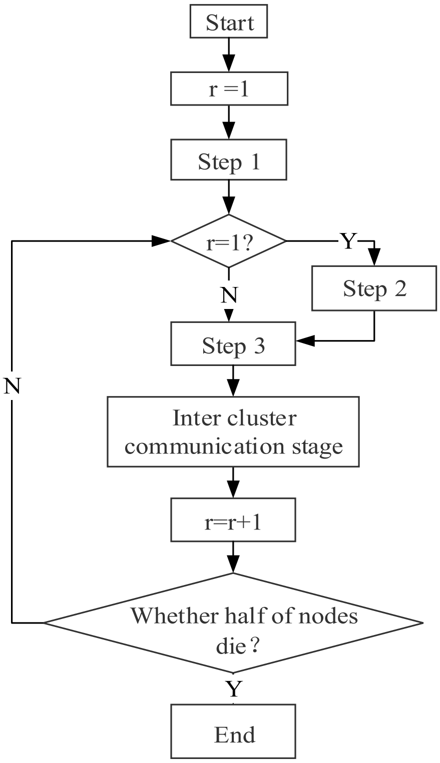

FIGURE 4. The main process of clustering in this protocol.

transmitted to the SN in other locations. In the first section, we prove that in the 3DWSNs, the node with the distance of r from the SN is only r/R in the 2D network, so the reduction of the number of key nodes is very obvious. In multi-hop 3DWSNs, the load of key nodes is higher, and the phenomenon of load imbalance is more serious than the 2D network. If there are a large number of deaths in the key nodes, it is inevitable that only other nodes close to the SN can act as the relay nodes between the SN and the key nodes. The increase in communication distance leads to an increase in energy consumption. Finally, the nodes in the network gradually die towards the sphere with SN as the center. Therefore, extending the life of key nodes can effectively extend the life of the whole network.

The energy consumption of CH node is divided into communication energy consumption within-cluster and communication energy consumption between clusters. The purpose of adding LTN is to share the heavy communication between clusters of CH nodes. The energy consumption originally borne by a single CH node is transferred to that shared by CH nodes and LTN nodes, which reduces the loading gap between CH and OD. However, from the perspective of regional energy consumption, the adoption of LTN can not reduce regional energy consumption, only make the regional node load more balanced. Therefore, in the key node area, we adopt the method that the key node abandons part of the communication within the cluster to reduce the energy consumption of the key node area. As the node within the SN communication radius, the key node can communicate with SN directly. So, it can only retain the CH and the LTN that act as the relay node, so that other nodes can communicate with SN directly, reducing the overall energy consumption of the key node area. When all the key nodes communicate with the SN directly, the total energy consumed by the network in (6), as shown at the bottom of the previous page, because all d_i is less than d_0 in the range of one hop of the SN, the free space energy consumption model is adopted. If all the key nodes send data to the corresponding s CHs, which are forwarded to SN by CH, the total energy consumption in (7), as shown at the bottom of the previous page.

When $E_a = E_{a1}$, the total number of clusters to be distributed in the key node area s can be solved in (8), as shown at the bottom of the previous page, Because E_{elec} is about 4000 times more than ε_{fs}, so that $data \times \varepsilon_{fs} \times n \times r_i^2 + data \times \varepsilon_{fs} \times 4000 \times n > data \times \varepsilon_{fs} \times n \times \overline{d_i^2}$ so s<0, Therefore, the total energy consumption of the network when the nodes in the key node area communicate with the SN directly is less than the total energy consumption of the network when the nodes transfer to the SN through the CH. Therefore, the energy consumption of the key node area can be effectively reduced by giving up the communication within the cluster.

C. INTER-CLUSTER ROUTING ALGORITHM

After the clustering stage is completed, CH transfers ID and residual energy of itself and LTN to SN through directional flooding. Through the synchronized hops in A, the information of the high hop nodes can only be forwarded by the low hop nodes so that the data can be sent to SN. According to the location and residual energy of each CH, SN generates a routing table through the fragile ant colony algorithm and transfers it to all CH by way of routing table flashback, so that all CH can get their own routing table. After receiving the routing table sent by the SN, CH will include the SCH and standby LTN information in the packet and send them to the SN according to the routing table, so that the SN can obtain the location of the next round of CHs and their transfer nodes.

In view of the fragile node environment in WSNs, an improved ant colony algorithm is proposed, which we call "fragile collection ant colony algorithm.". The original ant colony algorithm is often used for path navigation, and the path is constructed by simulating the way ants search for food. Ants will randomly move in the network and finally arrive at the destination. The generated path length will mark different concentrations of pheromones on the path passing through the network. The shorter the path length is, the higher the concentration of pheromones generated will be. The pheromone concentration of the path will affect the subsequent path selection of ants. The path with high pheromone concentration has a higher probability of being selected. In this way, the pheromone concentration of the short path is gradually increased, so that more ants choose this path, and further improve its pheromone concentration. By this way of positive feedback, an optimal path is selected.

The application model of the original ant colony algorithm can be understood as a model with infinite path life, that is, the connection path between nodes does not change with other factors, and is in a stable state. But the construction of routing in WSNs is more like ants searching for food in a fragile environment that is likely to be destroyed at any time. The environment will change with the collection of ants, so it is necessary to search for an optimal path under the premise of avoiding danger as much as possible. This assumption is based on the fact that node energy is limited in WSNs. When a routing table calls a node to act as a relay node, the energy of the node will inevitably decrease. If a single node is called frequently or the energy of the node itself is low, but it is still designated as a relay node of multiple nodes, the node will die, and the path between the node and other nodes will be destroyed. This is what we don't want to see in terms of network load balancing. An ant walking on the path composed of two low-energy nodes is a dangerous behavior for load balancing of WSNs. In order to avoid this situation, we added the path fragile coefficient to the original ant colony algorithm. The fragile coefficient is an indicator to measure the degree of communication fragile between nodes. It is generated by the calculation of the residual energy of the nodes at both ends of the edge. The higher the energy of the nodes at both ends, the lower the fragile degree of the edge. On the contrary, the lower the energy of the nodes at both ends, the higher the fragile degree of the edge. The fragile degree is calculated by Eq. (9), P_{ij} is the fragile coefficient of communication between node i and node j, E_i, E_j is the residual energy of node i and node j, E_o is the initial energy of node. The steps of fragile ant colony algorithm are as follows:

Step1. At the beginning of the ant colony algorithm, the distance between nodes is calculated first, and the heuristic factor η_{ij} is calculated by Eq. (10), where L_{ij} is the distance between node i and node j. And the pheromone concentration between nodes τ_{ij} initialization is set to 1.

Step2. Set M ants to start from the starting node and calculate the transfer probability of each node according to Eq. (11) According to the probability of node transfer, ants select nodes to arrive at the destination node step by step. Among them, $\alpha\beta$ is the information heuristic factor and the expectation heuristic factor, and $J(i)$ is the set of optional nodes in i.

Step3. After m ants reach the destination node, $\Delta\tau_{rs}$ is calculated according to Eq. (12) from the total path length L_{rs}, the average fragile coefficient $\overline{P_{rs}}$ of the path, the average fragile coefficient $\overline{P}$ for all paths, and the constant Q. All nodes in the path calculate the pheromone increment of each side according to the fragile degree P_{ij} of each side and the average fragile degree $\overline{P_{rs}}$ of the total path according to Eq. (13). The updated pheromone matrix is calculated by Eq. (14) according to the pheromone volatilization coefficient ρ. After that, step 2 is used to iterate until the set number of rounds is reached, and the global optimal solution is output.

$$P_{ij} = \frac{E_i}{E_o} \times \frac{E_j}{E_o} \tag{9}$$

$$\eta_{ij} = 1/L_{ij} \tag{10}$$

TABLE 1. Network environment simulation prerequisites.

Parameter	value	Parameter	Value
Network coverage	$\frac{4}{3}\pi \times 200^3$	d_0	90
Node number	500	CM size	200bit
Initial energy	0.25J	ε_{fs}	10pJ/bit/ m^2
DM size	4000bit	ε_{mp}	0.0013pJ/bit/ m^4
E_{elec}	50nJ/bit	E_{DA}	5nJ/bit

$$C_{ij} = \begin{cases} \dfrac{\tau_{ij}^{\alpha} \times \eta_{ij}^{\beta}}{\sum\limits_{r \in J_k(i)} \tau_{ir}^{\alpha} \times \eta_{ir}^{\beta}}, & j \in J(i) \\ 0, & otherwise \end{cases} \tag{11}$$

$$\Delta\tau_{rs} = \frac{Q \times \overline{P_{rs}}}{L_{rs} \times \overline{P}} \tag{12}$$

$$\Delta\tau_{rs}^{ij} = \Delta\tau_{rs} \times \frac{P_{ij}}{P_{rs}} \tag{13}$$

$$\tau_{ij} = (1-\rho) \times \tau_{ij} + \rho \times \Delta\tau_{ij} \tag{14}$$

The pheromone increment in the original AOC algorithm is calculated by $\Delta\tau_{rs} = Q/L_{rs}$, which is only related to the length of the construction path. We also take into account the average fragility coefficient of the constructed path when calculating the pheromone increment by Eq.12. The path pheromone with a larger average path fragility coefficient has a larger increment, and the side with a large fragility coefficient can obtain a larger pheromone concentration increase by Eq.13. Because the average energy of the nodes is declining, the fragility coefficient of each side will inevitably decrease. In order to avoid the decrease of pheromone concentration increment caused by the decrease of vulnerability coefficient of each side, we normalize the overall vulnerability of each path, so that it can not only reflect the relative vulnerability of each path, but also keep the same level of pheromone concentration increment as the original AOC algorithm. Because the energy consumption of nodes in WSNs is related to the single hop data transfer distance, a long transmission distance will consume a lot of energy of nodes. When using ants search solution, ants can only select the next hop node from the nodes less than the hop number of the node, avoiding the generation of solutions with high energy consumption and unnecessary solutions. Moreover, the ant colony algorithm generates routes from far to near, and nodes selected as relay nodes do not generate routes starting from them. Parameters of ant colony algorithm we refer to [13], $m = 10$, $\alpha = 1$, $\beta = 6$, $Q = 100$, $\rho = 0.1$.

V. SIMULATION RESULTS AND ANALYSIS

In order to verify the performance of this protocol, the simulation is carried out using MATLAB 2017a. The simulation conditions are shown in Table 1. The simulation contents include network life cycle comparison and network load balance comparison

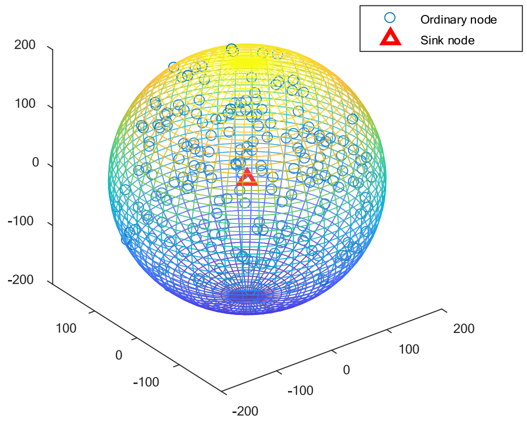

FIGURE 5. Network sensor node distribution in a 3D spherical network.

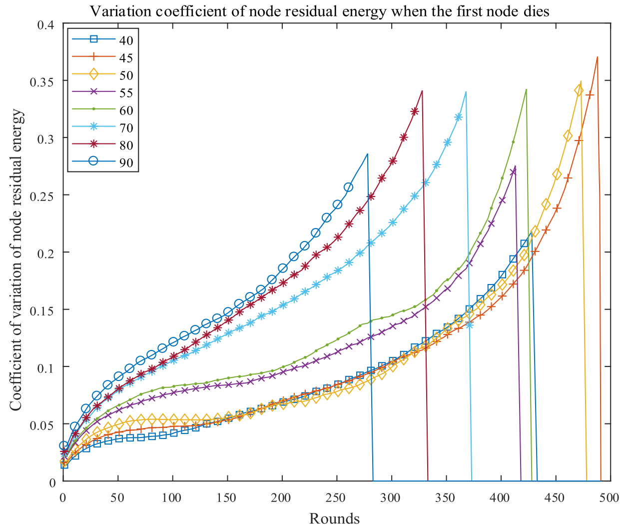

FIGURE 6. Change of energy variance when the first node dies under different cluster sizes.

Firstly, we show the distribution of sensor nodes in the 3D spherical network structure in Fig.5. 500 sensor nodes are evenly distributed in space. The blue dot represents the OD, and the red triangle represents the SN. The SN is at the center of the network.

In this simulation, the first node's dead time and coefficient of variation of node residual energy are used to measure the load balance and average communication energy consumption of the protocol. The lifetime of the network is measured by half of the node's dead time. The coefficient of variation can be used to compare the dispersion degree of two groups of data with different measurement scales. The lower the discrete degree of node residual energy, the stronger the load balance of the network, and the smaller the corresponding coefficient of variation. Therefore, the use of the coefficient of variation can reflect the load balance of the network. There is no unit of coefficient of variation. And the default energy unit of the simulation experiment is Joule (J).

A. PROTOCOL PARAMETER DETERMINATION

The size of the clustering radius will affect the balance of network load, and the total energy consumption of the network. Too small clustering radius will produce more clusters and more inter-cluster communication routes, and the total data reduction brought by data fusion is not significant, which makes the overall energy consumption of the network increase. A too-large clustering radius will reduce the ratio of CH to MN. A single CH needs to collect multiple MN data, which increases the energy consumption of CH and reduces the load balance of the network. Therefore, the load balance coefficient a is set to 0.5, and the CH replacement cycle is set to 10. In the process of cluster radius increased from 40 to 90, the dead time of the first node and the load balance of the network are simulated. The results are shown in Fig.6. When the cluster radius $R = 45$, the number of death rounds of the first node is 2% to 71% longer than that of other cases. The curve of $R = 40$ and $R = 50$ is close to that of $R = 45$. When $R = 40$, although the coefficient of variation of residual energy between 50 and 100 rounds is only 84% to 90% of that of $R = 45$, in other cases, the coefficient of variation is greater than $R = 45$, and the rounds of the first dead node is only 89.58% of that of $R = 45$. When $R = 50$, the coefficient of variation of the remaining energy of the corresponding node between 200 and 300 rounds is only 92% to 96% when $R = 45$, but in other cases, the coefficient of variation is greater than $R = 45$, and the rounds of the first death node is 98% when $R = 45$. So we set the cluster radius R to 45.

In the same way, the CH replacement cycle will also affect the network life and load balance. If the CH is replaced frequently, the energy consumption of the clustering process will be as large as that of the EEUC protocol. If the CH replacement cycle is too long, the node will be the CH for a long time, reducing the load balance of the network. Therefore, we simulate this protocol under different CH replacement rounds, and the results are shown in Fig.7. It can be found from Fig.7 that the smaller the number of CH replacement rounds T is, the lower the coefficient of variation of the corresponding remaining energy before 350 rounds is. However, the problem of high energy consumption caused by the small number of CH replacement rounds after 350 rounds gradually appears, which leads to the surge of coefficient of variation and the emergence of the first dead node. When the number of CH replacement rounds T is 7, the rounds of the first death node is delayed by 1% to 24% compared with other cases. Compared with the curve when $T = 4$, although the coefficient of variation is higher before 400 rounds, the coefficient of variation is gradually lower than $T = 4$ after 400 rounds, and the rounds of the first death node is delayed by 1% compared with $T = 4$. Therefore, we set the number of replacement rounds of cluster head to 7. After seven times of CH node sending, CH is replaced.

Under the above conditions, in order to determine the value of the network load balance coefficient "a" and network energy consumption coefficient "b" in Eq. (5), we increase

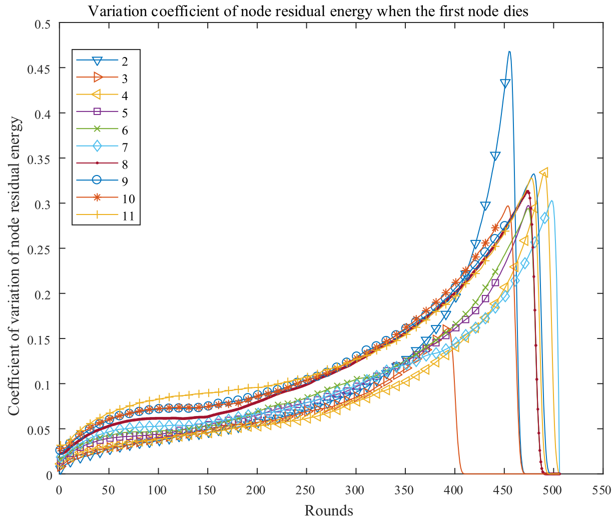

FIGURE 7. Change of energy variance when the first node dies under different cluster periods.

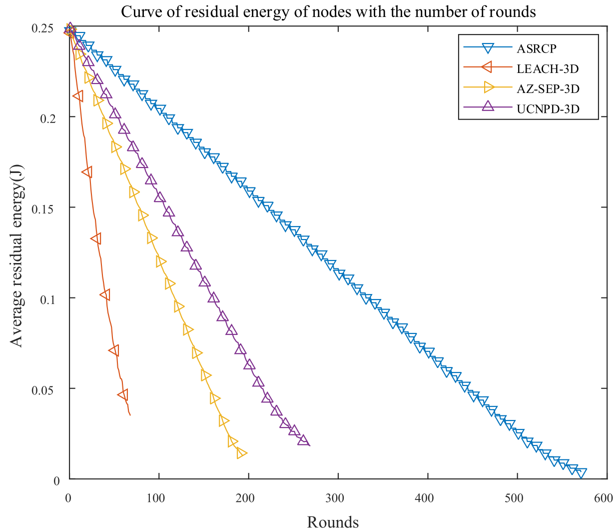

FIGURE 8. The average residual energy of each protocol changes until half of the nodes die.

TABLE 2. Network performance under different "*a*".

a	b	R_f	R_h
0.1	0.9	435	569
0.2	0.8	441	578
0.3	0.7	476	586
0.4	0.6	490	588
0.5	0.5	492	586
0.6	0.4	499	584
0.7	0.3	486	581
0.8	0.2	482	573
0.9	0.1	480	572
1	0	466	570

the value of a from 0.1 to 1 with 0.1 as the index value. The simulation results are shown in Table 2.

We determine the performance of the protocol by the size of the sum of the number of first node death rounds R_f and half node death time R_h. When $a = 0.6$, the performance of the protocol is the best.

B. PROTOCOL PERFORMANCE COMPARISON

Under the above conditions, we simulate this protocol, LEACH protocol, UCNPD protocol, and AZ-SEP protocol in a three-dimensional environment. In order to simplify the description, the LEACH protocol, UCNPD protocol, and AZ-SEP protocol in the three-dimensional space will be simplified as LEACH-3D, UCNPD-3D, and AZ-SEP-3D in the following process. LEACH-3D protocol is the representative of the single-hop routing protocol, which represents the performance of the single-hop routing protocol in this simulation environment. AZ-SEP-3D and UCNPD-3D protocols represent the multi-hop routing protocol. Among them, AZ-SEP-3D is similar to this protocol, which adopts the way that the node close to SN directly abandons the intra-cluster communication and directly sends the data to SN. The CH election method of UCNPD-3D protocol is similar to that of this protocol, but ODs are used to generate routing paths in the subsequent routing construction. The simulation results are as follows:

Fig.8 is the average residual energy curve of each protocol node when half of the nodes die. It can be seen from Fig.8, half of the nodes of LEACH-3D protocol, AZ-SEP-3D protocol, UCNPD-3D protocol and this protocol died in 70 rounds, 200 rounds, 280 rounds and 560 rounds, respectively. When half of the nodes of the UCNPD-3D protocol whose performance is second to this protocol die, the average residual energy of the nodes of this protocol is still higher than 50%, so the performance of this protocol is stronger than the other three protocols. UCNPD-3D protocol adopts a similar CH election method with this protocol. Although the standards for selecting CHs are different, the communication process of the clustering process is similar, but the UCNPD-3D protocol consumes a lot of energy in the subsequent construction of the routing path, so its overall energy consumption is high. Compared with the other three protocols, LEACH-3D protocol has the highest energy consumption, because LEACH-3D protocol adopts the single-hop communication mode to communicate with Sn. In large-scale networks, single-hop communication with SN will produce large energy consumption, so its overall energy consumption is high. However, AZ-SEP-3D protocol, because of giving up the construction of multi-hop routing, uses flooding to transfer data, which also consumes a lot of energy, but it is still better than LEACH-3D protocol. This protocol adopts the method of generating the route path by SN and cooperates with the rotation mechanism of CH and SCH and the fragile collection ant colony algorithm. The energy consumption of this protocol is lower in the process of clustering and route path construction, so the overall energy consumption of this protocol is better than the other three protocols.

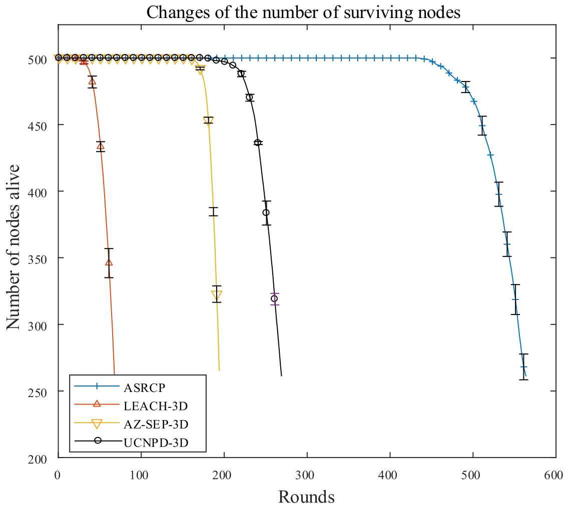

FIGURE 9. Changes in the number of surviving nodes of each protocol.

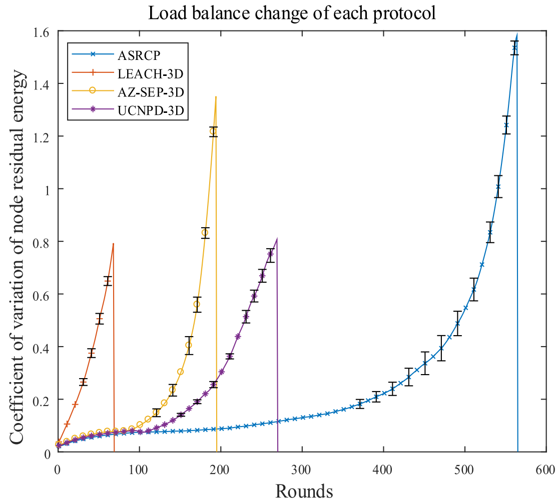

FIGURE 10. Load balance changes of each protocol until half of the nodes die.

Fig.9 shows the change curve of each protocol's surviving nodes in different rounds. The size of the error bars in the figure is the standard deviation corresponding to the number of surviving nodes in each round of ten repeated experiments for each protocol. It can be seen from Fig. 9 that LEACH-3D protocol, AZ-SEP-3D protocol, UCNPD-3D protocol and this protocol have the first death node in 20, 170, 180, 480 rounds, and half of the nodes have died in 70, 200, 280, 560 rounds. The UCNPD-3D protocol with the second highest performance has a lifetime of only 50% of this protocol. Similar to the energy consumption curve, because the energy consumption of this protocol is small in the process of CH election and inter-cluster communication, and load balancing is considered, the first dead node of this protocol appears the latest and the network life cycle of this protocol is the longest. The LEACH-3D protocol has less than 100 cycles of network life when half of the nodes die in this setting environment. The performance of the UCNPD-3D protocol is better than the AZ-SEP-3D protocol in this simulation environment because it adopts a better method of inter-cluster communication. However, because it fails to solve the high energy consumption in the process of inter-cluster routing construction, its life is only about 50% of this protocol.

Figure.10 shows the variation curve of the node residual energy variation coefficient under different rounds of each protocol. The size of the error bar in the figure is the standard deviation corresponding to the coefficient of variation of each round in ten repeated experiments of each protocol. It can be seen that when the network runs to 200 rounds, the variation coefficient of node residual energy of AZ-SEP-3D protocol, UCNPD-3D protocol and this protocol is 1.2, 0.3 and 0.1, respectively. The smaller the variation coefficient is, the smaller the relative dispersion degree of node residual energy is, so it can be seen that this protocol is better than the other three protocols in terms of load balance. Because the LEACH-3D protocol uses the single-hop method to communicate with the sink node, there is a big difference in the residual energy between the inner and outer nodes under the premise of this simulation, so its load balance is reduced. Although the AZ-SEP-3D protocol enhances the network load balance by making the nodes close to the SN communicate with the SN directly, it adopts the method that the outer nodes communicate with the SN through flooding, so the CH load is large, so its load balance is also weak. UCNPD-3D protocol adopts the method of non-uniform clustering and considers the residual energy of nodes to enhance the load balance of the network when building the routing path. However, in the process of building the routing path, it expands the sensing range of CH, increases the energy consumption of CH, and fails to solve the key node problem, so it also fails to balance the load of the network. In order to enhance the load balance of the network, this protocol adopts the following three methods at the same time: in the clustering process, LTN is added in the cluster; the nodes in the key node area communicate with SN directly; the fragile collection ant colony algorithm is used to build the routing path. So, the network load balance of this protocol is strong.

In order to show the performance of this routing protocol in many aspects, we choose the second-best UCNPD-3D protocol to compare with this protocol.

First of all, we compare the number of packets received by convergence nodes with the number of rounds in the two protocols. Because all the surviving nodes in this protocol send data to the sink node periodically, the total amount of data packets received by the sink node can be obtained by the accumulation of the surviving nodes in each round. According to the change curve of the number of surviving nodes of this protocol and UCNPD-3D protocol with the number of rounds, the data packets received by the sink node when half of the nodes of this protocol and UCNPD-3D protocol are dead are in the order of 10^5. The amount of data packets received by the sink node in this protocol is about twice that

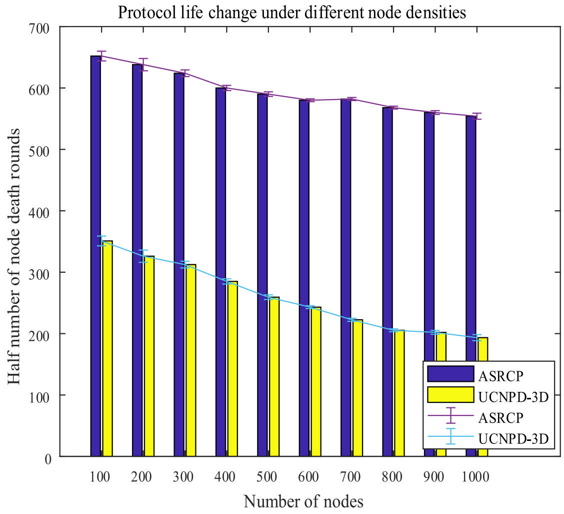

FIGURE 11. The change of network lifetime under different node density.

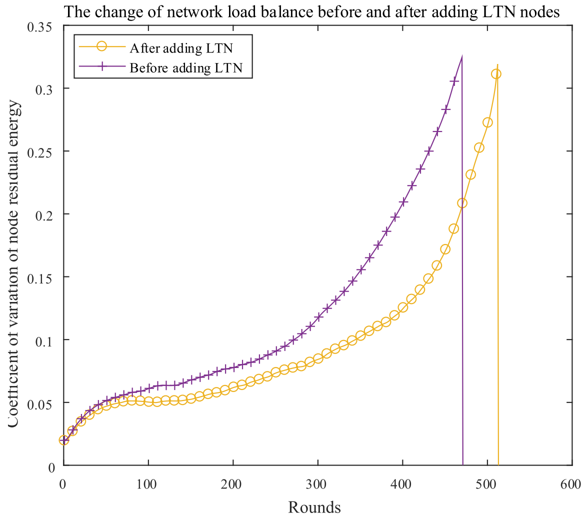

FIGURE 12. The change of network load balance before and after adding LTN.

of the UCNPD-3D protocol. Therefore, it can be proved that this protocol has a higher energy utilization rate for nodes.

Secondly, in order to study the performance changes of this protocol under different node densities, we have simulated this protocol and UCNPD-3D protocol under different node densities in the same layout area. Fig.11 shows the number of death cycles of half of the two protocols under different node numbers. The size of the error bar in the figure is the standard deviation corresponding to the number of rounds of death of half of the nodes in ten repeated experiments of the two protocols with different numbers of nodes. In addition to the number of nodes, other conditions of this simulation are the same as the above simulation.

It can be seen from Fig.11 that in the process of increasing the number of nodes from 100 to 1000, the network life of UCNPD-3D protocol is reduced by about 35%, while the network life of this protocol is only reduced by 10%. This means that compared with UCNPD-3D protocol, although the network life of this protocol decreases with the increase of node density, the performance is still relatively stable.

Compared with the UCNPD-3D protocol, the communication complexity of this protocol in the clustering stage is similar. The reason why this protocol has a longer life is that the communication complexity of this protocol in building the routing path is much smaller than the UCNPD-3D protocol. When the UCNPD-3D protocol constructs a routing path, the CH selects its next hop through multiple long-distance communication with each other and repeats this process until the data is transmitted to the sink node. Therefore, the UCNPD-3D protocol not only consumes a lot of energy but also takes a long time in the process of the building routing path. This protocol adopts the method of routing generated by SN. After the CH informs the SN of its location through directional flooding in the first round, the new CH node in the subsequent process only needs to forward the necessary routing table and transmit the sensor data. Therefore, the energy consumption and communication complexity of this protocol are low in the routing construction stage. Because the routing table calculation takes place at the sink node, and the sink node can obtain the location of the next cluster head after receiving the first round of information of the new cluster head, and the sink node can calculate in advance, so the time required to build the cluster head in this protocol can be ignored.

C. EFFECT OF PROTOCOL OPTIMIZATION

In order to enhance the load balance of the network, in the clustering phase, the protocol adds LTN and makes the key nodes communicate with SN directly. Although we use mathematical methods and theoretical analysis methods to prove the effectiveness of these methods. However, in order to make the optimization effect more intuitive, we compared the network load balance changes before and after the LTN node was added and before and after the optimization of the communication mode of key nodes under the same conditions. The results are shown in Fig.12 and Fig.13:

As can be seen from Fig.12, after adding LTN, the number of rounds of the first dead node appears 8.51% later than before. The coefficient of variation between 100 and 450 rounds with LTN was only 65.6% to 82.4% of that before optimization. From Fig.13, it can be seen that after the optimization of communication mode of key nodes, the number of rounds of the first dead node appears 6.82% later than before. Among 100 to 440 rounds, the coefficient of variation after optimization is only 68.03% to 88.23% of that before optimization. It is proved that our optimization in the clustering stage is effective. Moreover, the increase of LTN improves the network performance more than the optimization of key node communication mode.

In the aspect of inter-cluster routing construction, in order to prove that the improvement of the ant colony algorithm

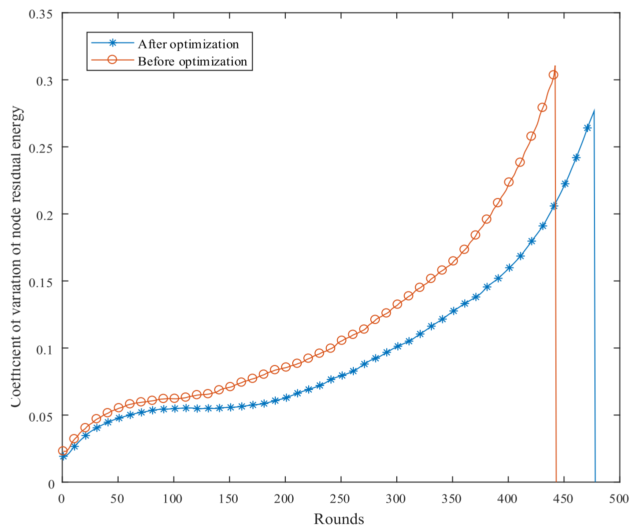

FIGURE 13. The change of network load balance before and after optimization of key node communication mode.

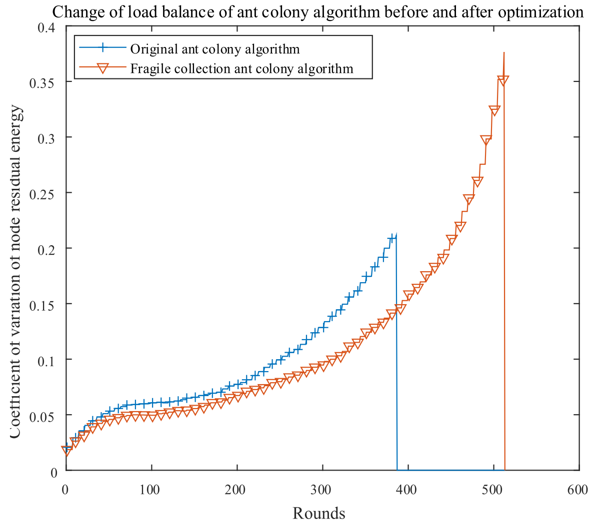

FIGURE 14. Algorithm optimization comparison.

TABLE 3. Algorithm performance changes under different parameters.

		Average Value	Optimal value	Worst value	Difference
α	2	153.653	128.655	224.148	95.493
	4	162.324	128.655	229.433	100.77
	6	154.967	128.655	191.961	63.306
	8	149.251	128.655	191.961	63.306
β	1	146.036	128.655	204.976	76.321
	3	142.053	128.655	147.794	19.139
	4	137.356	128.655	147.794	19.139
	6	142.053	128.655	147.794	19.139
	9	145.880	128.655	147.794	19.139
ρ	0.3	151.910	128.655	175.044	46.389
	0.5	151.367	128.655	175.044	46.389
	0.8	158.067	128.655	191.861	63.206

proposed by us for WSNs is effective, we simulate the protocol using the fragile collection ant colony algorithm and the original ant colony algorithm under the same other parameters. We hope to improve the ant colony algorithm to improve the load balance of the network under the premise of saving energy consumption. We use the coefficient of variation of each round of node residual energy before the first death node to measure the load balance of the network. The simulation results are shown in Fig.14.

As can be seen from Fig.14, the number of rounds of the first dead node of the route constructed by the fragile collection ant colony algorithm is 30.77% later than that of the original ant colony algorithm. And the coefficient of variation corresponding to the fragile collection ant colony algorithm between 100 and 350 rounds is only 69.14% to 87.47% of the original ant colony algorithm. This proves that the proposed fragile collection ant colony algorithm can effectively enhance the load balance of the network compared with the original ant colony algorithm.

The fragile ant colony algorithm with different parameters will change the computing efficiency of the ant colony algorithm. In order to find the optimal parameters of the fragile ant colony algorithm, we refer to the experimental method in [13] and test the performance of the fragile ant colony algorithm under different parameters. The default parameters are set to $m = 10$, $\alpha = 1$, $\beta = 1$, $\rho = 0.1$, $Q = 100$. That is, when setting $\alpha = 2$, other parameters $m = 10$, $\beta = 1$, $\rho = 0.1$, $Q = 100$. The number of running rounds of the algorithm is 20. The experimental results are shown in Table 3. In order to better show the influence of parameters on the path construction performance of fragile ant colony algorithm, we choose a long path and weight the path length through $V = L \times E_0/E$. Where L is the path length, E_0 is the initial energy constant of the node, and E is the average energy of the path passing through the node. The shorter the path length after weighting, the higher the fitness value of the corresponding solution.

As can be seen from Table 3, when $\alpha = 1, \beta = 4, \rho = 0.1$, the algorithm has the strongest performance, but because the output of the algorithm has not changed within a fixed number of rounds, new simulation parameters have not been used to repeat the completed simulation experiments.

VI. CONCLUSION

This paper considers the clustering routing protocol application of WSN in a 3D spherical network, and we propose a new energy optimized routing protocol based on a fragile ant colony algorithm in 3D WSN. Through theoretical analysis and simulation experiments, we get the following conclusions: Firstly, the overall energy consumption of 3DWSNs is higher than that of 2DWSNs, and the network load balance is weaker than that of 2DWSNs. Secondly, in terms of clustering, we propose to add LTN and make the key nodes give up the communication between clusters and directly communicate with the sink nodes, which improve the load balance of the network. Finally, in terms of inter cluster routing construction, we propose the method of using the fragile ant colony algorithm to generate inter cluster routing by combining SN and SCH, which greatly reduces the energy consumption of the whole network and enhances the load balance of the network. Through simulation, it can be proved that compared with LEACH-3D protocol, UCNPD-3D protocol, AZ-SEP-3D protocol, this protocol effectively reduces the energy consumption of the network, enhances the load balance of the network, and extends the life cycle of the network.

VII. LIST OF ABBREVIATIONS

Abbreviation	Full name
WSNs	Wireless sensor networks
3DWSNs	Three-dimensional WSNs
2DWSNs	Two-dimensional WSNs
CH	Cluster head
MN	Member node
LTN	Load transfer node
SCH	Secondary cluster head
OD	Ordinary node
SN	Sink node
LEACH	Low-energy adaptive cluster hierarchical
ASRCP	Routing clustering protocol based on fragile collection ant colony algorithm protocol.
EECS	Energy efficient clustering scheme
3DHCP	Energy-optimization clustering routing protocol based on dynamic hierarchical clustering in 3D WSNs
AZ-SEP	Advanced zonal stable election protocol
UCNPD	Unequal clustering routing protocol considering energy balancing based on network partition & distance
EEUC	The energy-efficient uneven clustering
PEGSIS	Power efficient gathering in sensor information systems
PEG-ant	PEGASIS in WSN based on an improved ant colony algorithm
PEG-GA	PEGASIS in 3DWSN based on genetic algorithm
APTEEN	Adaptive Periodic Threshold-sensitive energy-efficient sensor network
TSP	Traveling salesman problem
CM	Control massage
DM	Data massage

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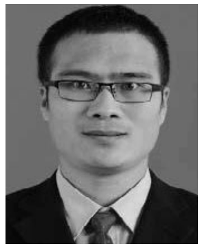
TIANYI ZHANG received the B.S. degree in measurement and control technology and instruments from Shijiazhuang Tiedao University, Shijiazhuang, China, in 2017. His current research interests include wireless sensor networks and deep learning.

GENG CHEN received the B.S. degree in electronic information engineering and the M.S. degree in communication and information system from the Shandong University of Science and Technology, Qingdao, China, in 2007 and 2010, respectively, and the Ph.D. degree in information and communications engineering from Southeast University, Nanjing, China, in 2015. He is currently an Associate Professor with the College of Electronic and Information Engineering, Shandong University of Science and Technology. His current research interests include heterogeneous networks, ubiquitous networks and software defined mobile networks, with emphasis on wireless resource management and optimization algorithms, and precoding algorithms in large scale MIMO.

QINGTIAN ZENG received the B.S. and M.S. degrees in computer science from the Shandong University of Science and Technology, Tai'an, China, in 1998 and 2001 respectively, and the Ph.D. degree in computer software and theory from the Institute of Computing Technology, Chinese Academy of Sciences, Beijing, China, in 2005. He is currently a Professor with the Shandong University of Science and Technology, Qingdao, China. His research interests include Petri nets, process mining, and knowledge management.

GE SONG received the master's degree in computer science and technology from the Shandong University of Science and Technology, Shandong, China, in 2004. He is currently a Teacher with the College of Electronic Information Engineering. His current research interests include the Internet of Things, wireless sensor networks, robot path planning, and deep learning.



CHAO LI received the B.S. and M.S. degrees from the Shandong University of Science and Technology and the Ph.D. degree from the Chinese Academy of Sciences, in 2014. He was a Visiting Scholar with The Hong Kong University of Science and Technology, from 2014 to 2015. He is currently a Lecturer with the Shandong University of Science and Technology. His research interests include social media, natural language processing, data mining, and network embedding learning. He is a member of CCF.

HUA DUAN received the B.S. and M.S. degrees in applied mathematics from the Shandong University of Science and Technology, Tai'an, China, in 1999 and 2002, and the Ph.D. degree in applied mathematics from Shanghai Jiao Tong University, in 2008. She is currently a Professor with the Shandong University of Science and Technology. Her research interests include process mining and machine learning.