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An Improved Approach for Wireless Sensor Networks with Mobile Sink Using Dynamic Minimum Spanning Tree

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Abstract*—In wireless sensor networks (WSNs), finding the best transmission route from each node to the mobile sink is not a simple task because of the dynamic characteristics of sink node and cluster transmission. In order to balance energy consumption and reduce collisions in wireless transmissions, this paper proposes a Dynamic Spanning Tree with Mobile Sink (DSTMS) routing algorithm. Firstly, based on the Low Energy Adaptive Clustering Hierarchy Protocol (LEACH), a multi-layer transmission framework with dynamic minimum spanning tree (MST) is constructed to optimize data transmission route. In this framework, the selected rendezvous points, according to the motion parameters of mobile sink, build the dynamic rendezvous layer to constraint the hierarchical transmission of DSTMS. In addition, considering some factors of transmission energy consumption and residual energy distributionthe weight factor based on energy efficient function is introduced to evaluate the cost of transmission path within the MST. Moreover, the proposed algorithm not only reduces network energy consumption caused by frequent location updates of mobile sink, but also reduces data transmission congestion by constructing dynamic hierarchical transmission strategy. The simulation results show that the DSTMS algorithm can effectively prolong the network life, balance the network load and reduce collisions in wireless transmissions.

***Index Terms*—mobile sink, local position updating, rendezvous point, minimum spanning tree, energy optimization**

I. INTRODUCTION

WIRELESS Sensor Networks (WSNs) are composed of thousands of sensor nodes, which can perceive data and collect information to users [1] - [3]. WSNs are widely used in smart medical technology, military reconnaissance, climate environment monitoring, smart agriculture, natural disaster warning and treatment and other fields [4] - [7]. However, these sensor nodes are usually deployed in areas with large deployment scale and complex and dangerous environment, so it is difficult to maintain them [8] - [11]. The nodes energy cannot be replenished in time, the topology structure of the whole network will be affected, reducing the network monitoring performance [11] - [13]. Therefore, some scholars have designed a series of network energy consumption optimization algorithms aiming at the question, how to efficiently utilize network resources and balance network energy consumption [14] - [16].

A. Related Work

In WSNs, Heinzelman W R et al [17] proposed the Low Energy Adaptive Clustering Hierarchy (LEACH) which is the most classic network energy consumption optimization algorithm. Based on the idea of node clustering and process turning, the algorithm constructs the threshold of cluster head selection to periodically replace the cluster head. Besides, it can effectively prolong the network life cycle for the nodes joined with the cluster which head is nearest to. In addition, Distance Based Cluster Head (DBCH) algorithm [18] and LEACH-Distance Based Thresholds (LEACH-DT) algorithm [19] have also achieved certain results in prolonging the network life cycle. However, in this kind of algorithms, remote cluster heads transmit data to the sink node in a single-hop way, which will lead to the problem of unbalanced network energy consumption. In addition, the sink node is in a static state, which cannot meet the needs of complex specific scenes such as battlefield monitoring, forest fire detection and habitat monitoring.

According to the mobile characteristics, some scholars have designed real-time energy consumption optimization algorithms for mobile sink, which can meet the needs of complex scenes. Gawade R D et al. proposed a centralized energy efficient routing protocol called Centralized Energy Efficient Distance (CEED) [20], which determined the optimal number of cluster heads by the energy consumption model, and selected the cluster heads by the distance to the sink node and its own remaining energy. When the selection of cluster heads was completed, the chain multi-hop paths were constructed from

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near to far according to the distance between cluster heads and sink nodes, so as to reduce network energy consumption and balance network energy consumption. Wang J et al. proposed a stable election protocol [21] based on improved SEP [22], which constructed the threshold function of cluster head selection according to the initial energy and current remaining energy of nodes. According to the distance of the path between the cluster heads and the mobile sink and the level of their own cluster heads, a multi-hop transmission path between the cluster heads and mobile sink was constructed, so as to balance the network load and alleviate the transmission hot spot problem. Arora V K et al. proposed a distributed, multi-hop, adaptive, tree-based energy-balanced routing approach called Distributed, Multi-hop, Adaptive, Tree-based Energy-Balanced (DMATEB) [23], which selected the relay node according to the distance between the node and the sink node and its own remaining energy. At the same time, according to the remaining energy and transmission energy consumption of the relay node, the associated parent node was selected for each sensor node, so as to form a tree structure for data transmission and reduce network energy consumption. However, due to the mobility characteristics of mobile sink nodes, the above algorithms need to broadcast their own location information frequently and receive monitoring data from all network nodes, which is prone to data transmission congestion. All sensor nodes need to acquire the location information of mobile sink in real time, which will cause rapid energy consumption.

Some scholars have proposed a series of routing algorithms to solve the problem of network energy consumption and data transmission congestion caused by frequent location updates of mobile sink. Kumar S et al proposed a load balancing algorithm for mobile sink and rendezvous points [24]. The algorithm selects some nodes as rendezvous points according to the current remaining energy of the node and the distance between the node and the mobile sink. Then, the rendezvous point sends data to mobile sink by using of the current location information of the mobile sink. Zhu C et al. proposed a data collection algorithm based on tree clusters technique [25], which selected a specific sensor node as the root node of the tree based on its remaining energy and the distance from the node to the sink node, that was, the rendezvous point. At the same time, some sensor nodes were selected the sub-rendezvous points according to the number of hops with the rendezvous point. Mobile sink collected data from each rendezvous point, which can effectively balance network load. Based on the LEACH algorithm, Kushal B Y et al. proposed an energy optimization algorithm to modify cluster head selection called Improved LEACH (ILEACH) [26]. In this algorithm, sensor nodes were divided into clusters for the node distribution region. And the cluster heads were selected based on the distance between nodes in each cluster. Cluster heads received the location information of mobile sink and sent data to the mobile sink through the shortest multi-hop transmission path between the cluster heads to reduce the network energy consumption. Donta P K et al proposed an data collection algorithm, named Hierarchical Agglomerative Clustering-based Data Collection (HACDC) [27]. This algorithm selected the optimal set of virtual rendezvous points for data collection according the distance to the MS path. The nodes transmitted their data to the nearest virtual rendezvous points, and mobile sink collected data from virtual rendezvous points. It can prolong the network lifetime and reduce data congestion. However, when selecting some nodes to receive the location information of the mobile sink, such algorithms do not fully consider the dynamic change of the position of the mobile sink, which cannot reduce collisions in wireless transmissions. Moreover, when constructing multi-hop transmission paths, the relationship among the energy consumption of the multi-hop transmission path, the remaining energy of the node, and the remaining energy of the next hop node is not fully considered, resulting in unbalanced network energy consumption.

B. Contributions

Summarizing, the current energy optimization algorithms focus less on the Excessive power consumption, unbalanced load, and data congestion transmission caused by frequent location updates of mobile sink moving in WSNs. In this paper, we propose a new network energy optimization algorithm called Dynamic Spanning Tree with Mobile Sink (DSTMS). The DSTMS algorithm constructs a multi-layer transmission framework with dynamic MST. In a multi-layer transmission framework, an adaptive location update threshold is constructed by considering the motion parameters (speed, distance) of mobile sink. On the basis of dynamic MST theory, the weight function of energy efficiency is introduced to get the weight of MST. Finally, this algorithm constructs a multi-hop routing protocol to reduce the energy consumption and balance the network load compared to the traditional multi-hop routing algorithm.

C. Paper Organization

The paper is organized as follows: The network model of the algorithm and motion model of mobile sink are given in Section II; In Section III provides an overview of the DSTMS algorithm; In Section IV the implementation process of the DSTMS algorithm is given; Some simulation experiments and analyses are presented in Section V; In Section VI a summary is given.

II. SYSTEM MODEL

Based on the idea of dynamic multi-layer transmission, the system model and the motion model of mobile sink in WSNs is constructed in this section. At the same time, the energy model of the sensor node is established.

A. Network Model

Typically, WSNs is composed of sensor nodes, mobile sink, Internet, Satellite, control center (see Figure 1) [28]. In the monitoring area, some sensor nodes are randomly distributed, and mobile sink moves according to the motion model.

A multi-hop transmission strategy based on dynamic spanning tree is proposed to collect sensors data. It can be clearly seen from Figure 1 that all sensor nodes are divided into three

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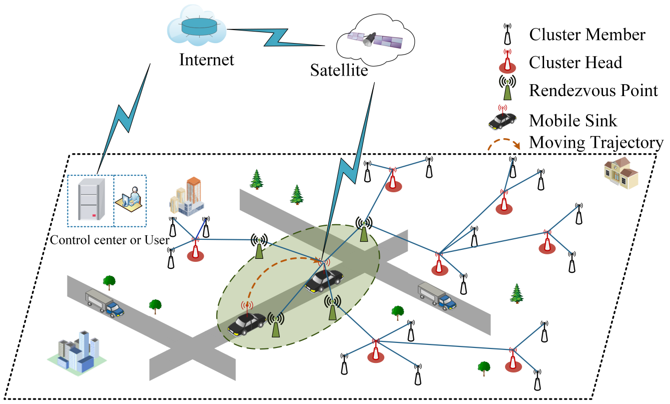


Fig. 1. WSNs architecture

categories: rendezvous point, cluster head and cluster member. For example, the rendezvous point (RP_1) is located in the local location update area, which is used to receive the location information of mobile sink (MS). The nodes outside the local location update region are divided into multiple clusters, and the sensor nodes in each cluster are divided into cluster heads (CH_1) and cluster members (CM_i). Cluster member (CM_i) sends monitoring data to its own cluster head (CH_1), which processes and fuses the data. Finally, the processed data is sent to mobile sink through rendezvous point (RP_1). And mobile sink (MS) sends the data to the control center or users via satellite and network.

Moreover, three assumptions related to system model of WSNs are as follows:

- Each sensor node has a fixed Position and unique ID after random deployed.
- Each sensor node has limited energy, and their initial energy is the same.
- The mobile sink has unlimited energy, powerful information processing and storage capacity ability.

B. Motion Model of Mobile Sink

Assume that mobile sink is located in a two-dimensional monitoring area and turns at an angular velocity ω. The random disturbance received in the movement process is expressed as $\mathbf{U}\left(t\right)$. The motion model is shown in Equation (1) [29].

$$\left\{\begin{array}{l} \dot{x}\left(t\right)=-r\omega\sin\left(\omega t+\varphi\right)+u_x\left(t\right)t \\ \dot{y}\left(t\right)=r\omega\cos\left(\omega t+\varphi\right)+u_x\left(t\right)t \\ \ddot{x}\left(t\right)=-r\omega^2\cos\left(\omega t+\varphi\right)+u_x\left(t\right) \\ \ddot{y}\left(t\right)=-r\omega^2\sin\left(\omega t+\varphi\right)+u_x\left(t\right) \end{array}\right. \tag{1}$$

where, $\dot{x}\left(t\right), \dot{y}\left(t\right)$ are the velocity in x and y direction; $\ddot{x}\left(t\right), \ddot{y}\left(t\right)$ are the accelerated velocity in x and y direction; x_c, y_c are the turning center in x and y direction; r is the turning radius; φ is the turning angle; t is the time of motion; u_x, u_y is the process noise in x and y direction.

C. Energy Model

It can be seen from Figure 2 the energy consumption of node is described by the first order radio model in this paper.

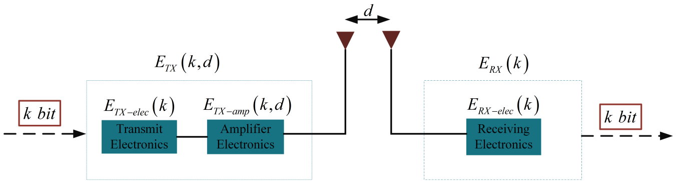


Fig. 2. First order radio model.

Assuming that each packet has k bit data, the energy consumption of transmitting k bit data E_{TX} and the energy consumption of receiving k bit data E_{RX} [17] can be expressed as follows:

$$\begin{aligned} E_{TX}\left(k,d\right) &= E_{TX-elec}\left(k\right)+E_{TX-amp}\left(k,d\right) \\ &= \left\{\begin{array}{ll} kE_{elec}+k\varepsilon_{fs}d^2 & d\leqslant d_0 \\ kE_{elec}+k\varepsilon_{mp}d^4 & otherwise \end{array}\right. \end{aligned} \tag{2}$$

$$E_{RX}\left(k\right)=E_{RX-elec}\left(k\right)=kE_{elec} \tag{3}$$

where, $E_{TX-elec}$, $E_{RX-elec}$ and E_{TX-amp} are the energy consumption of transmitter, the energy consumption receiver and energy consumption amplifier, respectively. ε_{fs} and ε_{mp} are coefficient amplify of free space and coefficient amplify of multi-path, respectively. E_{elec} is the energy consumption of 1 bit data processing related to node, k is bits of data, d is the distance between transmitter and receiver, d_0 is the critical communication distance.

$$d_0=\sqrt{\varepsilon_{fs}/\varepsilon_{mp}} \tag{4}$$

III. THE PROPOSED DSTMS ALGORITHM

This paper proposes DSTMS algorithm, which constructs a dynamic multi-layer transmission framework to optimize network energy consumption, balance network load and reduce data transmission congestion. In this framework, firstly, by considering the change of motion parameters of mobile sink, an adaptive location update threshold is constructed. Then, the dynamic rendezvous layer is obtained. Next, based on LEACH algorithm, a dynamic MST is constructed by considering the residual energy and transmission energy consumption of sensor nodes. The overall framework of the DSTMS algorithm is shown in Figure 3.

According to the overall framework of DSTMS algorithm, the details related to the multi-layer transmission framework, the construction of dynamic rendezvous layer, and construction of dynamic MST are discussed in this section.

A. The Dynamic Multi-Layer Transmission Framework

In WSNs, the position of mobile sink changes frequently in the monitoring area, which leads to excessive energy consumption of sensor nodes. Based on the idea of dynamic MST, a dynamic multi-hop transmission path tree of mobile sink is constructed to reduce network energy consumption.

Assume that N sensor nodes are randomly deployed in a monitoring area and mobile sink collects data from all sensor nodes in each round. Based on the idea of graph theory, this

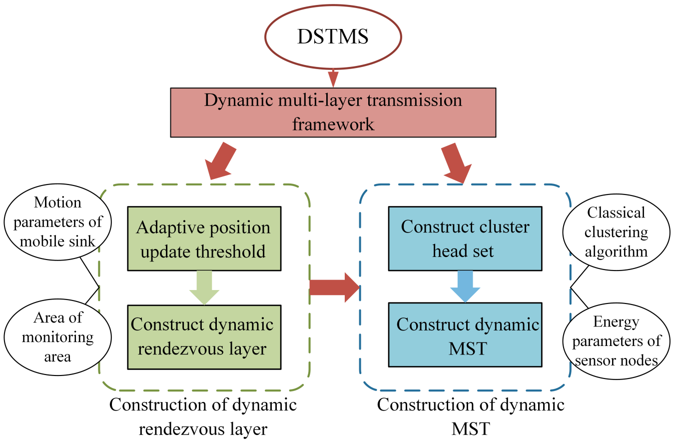


Fig. 3. Overall Framework of DSTMS Algorithm

paper constructs a network model including mobile sink and sensor nodes as follows:

$$\left\{ \begin{array}{l} G = (V, E) \\ V = \{ v_i \,| i = 0, 1, 2, \cdots, N \} \\ E = \{ (v_i, v_j) \,| (v_i, v_j) \in V \} \end{array} \right. \tag{5}$$

where, G is the undirected graph of the whole wireless sensor network; V is the set of mobile sink and N sensor nodes; E is the set of edges of the transmission path constructed by all nodes of the network communicating with each other.

On the basis of G, the purpose of this paper is to construct a MST including all network nodes starting from mobile sink, namely multi-hop transmission path tree , as shown in the Figure 4.

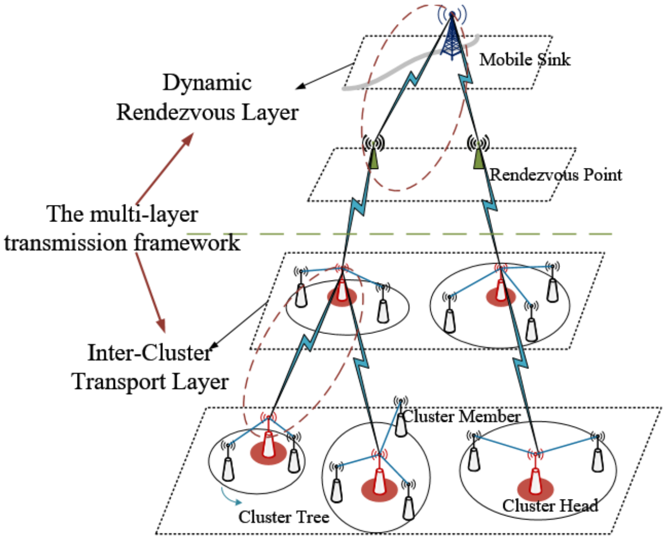


Fig. 4. The multi-layer transmission framework

As shown in the Figure 4, the MST $T\left(V_{opt}, E_{opt}\right)$ consists of dynamic rendezvous layer and inter-cluster transport layer. The dynamic rendezvous layer of the MST is composed of rendezvous point and mobile sink. Among them, the rendezvous point receives the location information of mobile sink and sends the received data to the mobile sink. Cluster head and cluster member together constitute the inter-cluster transport layer. Cluster member send data to its cluster head. Finally, the data is sent to mobile sink through rendezvous point.

In order to obtain the dynamic MST, the energy efficient weight function is introduced, as follows:

$$\text{minimum} f\left(\mathbf{A}, \mathbf{z}\right) \tag{6}$$

where, $\mathbf{A}$ is the energy efficient weight matrix of dynamic MST; $\mathbf{z}$ is the selection scheme matrix of dynamic MST.

Based on Equation (3), on the premise that the minimum energy consumption for receiving location information of mobile sink is satisfied, the problem of selecting minimum energy efficiency weights for each node can be described as:

$$\begin{array}{ll} \underset{\mathbf{z} \in [0,1]^j}{\text{minimum}} & f\left(\mathbf{A}, \mathbf{z}\right) \\ \text{subjectto} & \mathbf{1}^T \mathbf{z} = 1 \end{array} \tag{7}$$

here,

$$\mathbf{z} = \left[z_1, \cdots, z_j, \cdots, z_p\right]^T \tag{8}$$

where, z_j indicates whether the jth node is selected or not and $\mathbf{z} \in \{0,1\}^j$; if $z_j = 1$, the node is selected, vice versa. Finally, the edge with the lowest weight is found for each node to obtain the dynamic MST $T\left(V_{opt}, E_{opt}\right)$.

B. Construction of Dynamic Rendezvous Layer

In WSNs, frequent position updates of mobile sink will lead to rapid energy consumption of sensor nodes. Therefore, in order to minimize the energy consumption of receiving the location information of the mobile sink, an adaptive local location update strategy is designed to select optimal rendezvous points and construct the dynamic rendezvous layer of path tree according to the motion performance parameters of the mobile sink.

- *Adaptive Local Location Update Strategy for Mobile Sink*

Assume that the monitoring area of the network is S_M, and mobile sink is located in the monitoring area and moves according to the motion model in Section II. The local update region S_m is shown in the Figure 5.

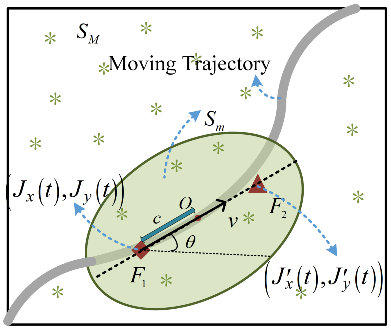


Fig. 5. The local update region

As shown in the Figure 5, the position coordinate of the mobile sink at time t is $F_1\left(J_x(t), J_y(t)\right)$, that is the back focus of the ellipse. And the semi-focal length c of the ellipse is positively correlated with the velocity v . The ideal elliptical position update area S_m is shown as follows.

$$S_m = \pi ab = n \cdot S_M / N \tag{9}$$

where, a, b are the long half axis and the short half axis of the ellipse region respectively.

The shape of the ideal region is determined according to the moving trajectory of mobile sink, that is, the elliptical region with the current position of mobile sink as the back focus and the direction of the tangent of the movement as the direction of the long axis. In order to determine the shape of the ellipse region at the current time, the velocity $v(t)$ at the time as follows:

$$v(t)=\sqrt{\left(J_x(t+\Delta t)-J_x(t)\right)^2-\left(J_y(t+\Delta t)-J_y(t)\right)}\Big/\Delta t \tag{10}$$

The semi-focal length of the ellipse is shown in Equation (9).

$$c=1/2\left|F_1F_2\right|=\lambda v \tag{11}$$

where, λ is the velocity weighting coefficient of the semi-focal length c. Combined with the mathematical definition of an ellipse, the long half axis a and the short half axis b as follows [30]:

$$a=\frac{\sqrt{2}S_m}{\pi\sqrt{\frac{\sqrt{(\lambda v)^4\pi^2+4{S_m}^2}}{\pi}-(\lambda v)^2}} \tag{12}$$

$$b=\frac{\sqrt{2}}{2}\sqrt{\frac{\sqrt{{(\lambda v)}^4\pi^2+4{S_m}^2}}{\pi}-(\lambda v)^2} \tag{13}$$

The area and shape of the ellipse region can be determined according to the related parameters of the ellipse. According to the motion state of mobile sink at the time , the elliptical region can be established to select the rendezvous point for local update of position information to save energy. As the motion states of mobile sink are constantly changing, a reasonable local update strategy is required, as shown in the Figure 6.

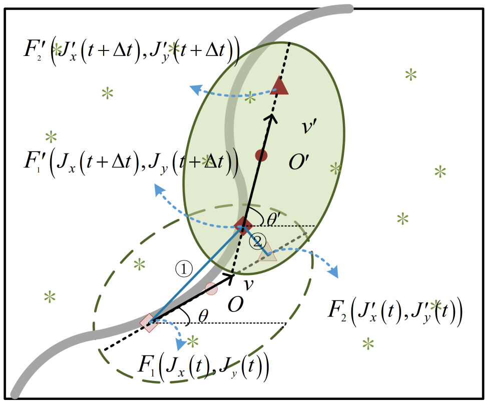


Fig. 6. The elliptic region of local location updates

It can be seen from the Figure 5, once the elliptic region is established, the rendezvous points in the elliptic region receive the position information of mobile sink. Only when the mobile sink is about to move out of the ellipse region at the time $t+\Delta t$, the global location information is broadcast to realize the reconstruction of the ellipse region to save energy. Therefore, according to the position information of the mobile sink, an adaptive position update threshold $T_{area}\left(t+\Delta t\right)$ is established, as shown in the Equation (14).

$$T_{area}\left(t+\Delta t\right)=\begin{cases}1 & d\left(t+\Delta t\right)\geq\mu\cdot a\\ 0 & d\left(t+\Delta t\right)<\mu\cdot a\end{cases} \tag{14}$$

here,

$$d\left(t+\Delta t\right)=\left|{F_1}'F_1\right|+\left|{F_1}'F_2\right| \tag{15}$$

where, μ is the update weight coefficient of the local update region. When $T_{area}\left(t+\Delta t\right)=1$, a new ellipse region is constructed according to the motion state of the moving sink at the time $t+\Delta t$,vice versa.

- *Construction of Dynamic Rendezvous Layer*

After the ellipse region at the current time is obtained, the rendezvous point can be determined. Therefore, in order to obtain the set of the rendezvous points, the rendezvous point selection threshold $T_{rp}(s_i)$ is introduced, as shown in the Equation (16).

$$T_{rp}\left(s_i\right)=\begin{cases}1 & d_i\leq 2a\\ 0 & d_i>2a\end{cases} \tag{16}$$

here

$$d_i=\left|PF_1\right|+\left|PF_2\right| \tag{17}$$

where, P is position of sensor node s_i. When $T_{rp}\left(s_i\right)=1$, the node s_i joins the rendezvous points set $\mathbf{R}$; Otherwise, the node s_i joins the non-rendezvous point set $\mathbf{R}'$.

When the rendezvous points set $\mathbf{R}$ is obtained, the dynamic rendezvous layer is constructed, as shown in Equation (18).

$$\begin{cases}T^r=\left(V^r,E^r\right)\\ V^r=\left\{v_i^r\left|i=0,1,2,\cdots,r\right.\right\}\\ E^r=\left\{\left(v_0^r,v_i^r\right)\left|v_i^r\in V^r\right.\right\}\end{cases} \tag{18}$$

where, v_0^r represents the mobile sink, E^r is the set of edges, V^r is the set of mobile sink and rendezvous points.

After the dynamic aggregation layer is obtained from Equation (18), the set of edges of the MST is introduced, and the set of points is shown in the following equation.

$$E_{opt}=E^r, V_{opt}=V^r \tag{19}$$

According to the above formula, E^r and V^r are merged into the edge set and the point set of the dynamic MSTrespectively.

C. Construction of Dynamic Minimum Spanning Tree Based on Energy Efficiency

The rendezvous points set can be determined according to the ellipse update region of mobile sink, which can determine the dynamic rendezvous layer of multi-hop transmission path tree, as shown in the Figure 7. Based on the clustering strategy of classical LEACH algorithm, the cluster head selection is carried out on nodes outside the ellipse update region to construct cluster head set in this section. Then, the energy efficient weight function is constructed to solve the inter-cluster transmission path tree in the inter-cluster transport layer, so as to reduce the network energy consumption.

- *Construction of Cluster Head Set*

Each node outside the update region of the ellipse generates a random number $T_{rand}\left(s_i\right)$ distributed between [0,1]. If

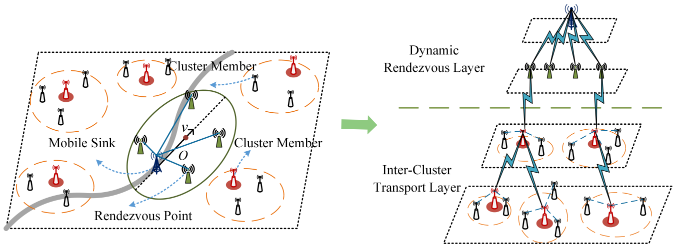


Fig. 7. The transmission path tree of dynamic rendezvous layer

$T_{rand}(s_i) < T(s_i)$, the node joins the cluster head set. Otherwise, the node joins the non-cluster head set. The cluster head selection threshold $T(s_i)$ is shown in Equation (18) [31].

$$T(s_i) = \begin{cases} \frac{p}{1-p[r \bmod (1/p)]} & s_i \in \mathbf{G} \\ 0 & \text{otherwise} \end{cases} \tag{20}$$

where, p is the desired percentage of cluster heads in the total number of nodes in the WSNs; r is number of current running round; $\mathbf{G}$ is the non-cluster head set in the round of $1/p$; is modulo operation. The node selected as the cluster head broadcasts the message that it is the cluster head, and the other nodes choose to join the cluster nearest to them according to the strength of the received signal. When all sensor nodes join the cluster, each sensor node informs its selection through the carrier sense multiple access (CSMA) MAC protocol. Moreover, each cluster head creates a time division multiple access (TDMA) schedules for its cluster members. In each cluster, each cluster number needs to send data to cluster head. Therefore, the path tree ${T_i}^c$ in each cluster is introduced in Equation (21).

$$\begin{cases} {T_i}^c = ({V_i}^c, {E_i}^c) \\ {V_i}^c = \{{v_i}^c \,|i = 0, 1, 2, \cdots, c_i\} \\ {E_i}^c = \{({v_0}^c, {v_i}^c) \,|{v_i}^c \in {V_i}^c\} \end{cases} \tag{21}$$

where, v_0^c is the cluster head CH_i; c_i is the number of the non-cluster head in the cluster.

When the construction of all cluster trees $T_i^c(V_i^c, E_i^c)$ is completed, which is merged into the set of cluster group trees $T^c = \{{T_i}^c \,|i = 1, \cdots, c\}$. c is the number of cluster head.

- *Construction of Dynamic Minimum Spanning Tree Based on Maximum Path Energy Efficiency*

In this section, based on the idea of MST, the energy efficient weight function is solved, so as to construct the path tree of inter-cluster transport layer. The construction process of dynamic MST is shown in Figure 8.

Step 1: The edges of the dynamic rendezvous layer containing rendezvous points and moving sink nodes are ①,②,③ and ④, that is, the set of edges of the MST is E_{opt}, and the set of the nodes is V_{opt}, as shown in Figure 8(a). Since the cluster head can only send data to the rendezvous point, an optimized set of spanning tree nodes $\mathbf{P} = \{v_i^r \,|i = 1, 2, \cdots, r\}$ is introduced.

Step 2: As shown in Figure 8(b), an edge $\text{Min}\left\{\left(CH_i^j, CH_i\right)\right\}$ with the lowest weight is merged into the set E_{opt} among all edges $\left(CH_i^j, CH_i\right) \in E$ in $CH_i^j \in \mathbf{P}$, $CH_i \in \mathbf{C}$. For example, the minimum weight of the edge of the node that CH_1 can connect is obtained according to the energy efficiency weight function. The energy efficiency weight function is relaxed as follows:

$$\begin{aligned} \underset{\mathbf{z}\in[0,1]^j}{\text{minimum}} \quad & \mathbf{A} \cdot \mathbf{z} \\ \text{subject to} \quad & \mathbf{1}^T \mathbf{z} = 1 \\ & 1 \leqslant j \leqslant M, 0 < \alpha, \beta, \delta < 1 \\ & E_{cur}(j) \leqslant E_0 \\ & d_{i,j} \leqslant d_{j\max} \\ & d_{j,p} \leqslant d_{jp\max} \end{aligned} \tag{22}$$

where, E_0 is the initial energy of sensor node; M is the number of the rendezvous points and the cluster heads in current round. The energy efficiency matrix of optimized spanning tree $\mathbf{A}$ is composed of energy efficiency a_j of the node set $\mathbf{P}$ of the optimized spanning tree $T_{opt}(V, E)$, as shown in the Equation (23).

$$\mathbf{A} = [a_1, \cdots, a_j, \cdots, a_p] \tag{23}$$

where, a_j is composed of the energy factor $E_r(j)$, the path energy consumption factor $E_p(j)$ and the next hop path energy consumption factor $E_{PP}(j)$ of the MST that can be joined, as shown in the Equation (24).

$$a_j = \alpha E_r(j) + \beta E_p(j) + \delta E_{pp}(j) \tag{24}$$

where, α, β, δ the weighting coefficient of energy efficiency a_j.

In the Equation (24), in order to increase the probability that a node with large remaining energy becomes a spanning tree node to be joined for cluster head CH_1 under the premise of maximum energy efficiency, a normalized energy factor $E_r(j)$ is constructed as follows:

$$E_r(j) = 1 - \frac{E_{cur}(j) - E_{avg}}{E_{avg}} \tag{25}$$

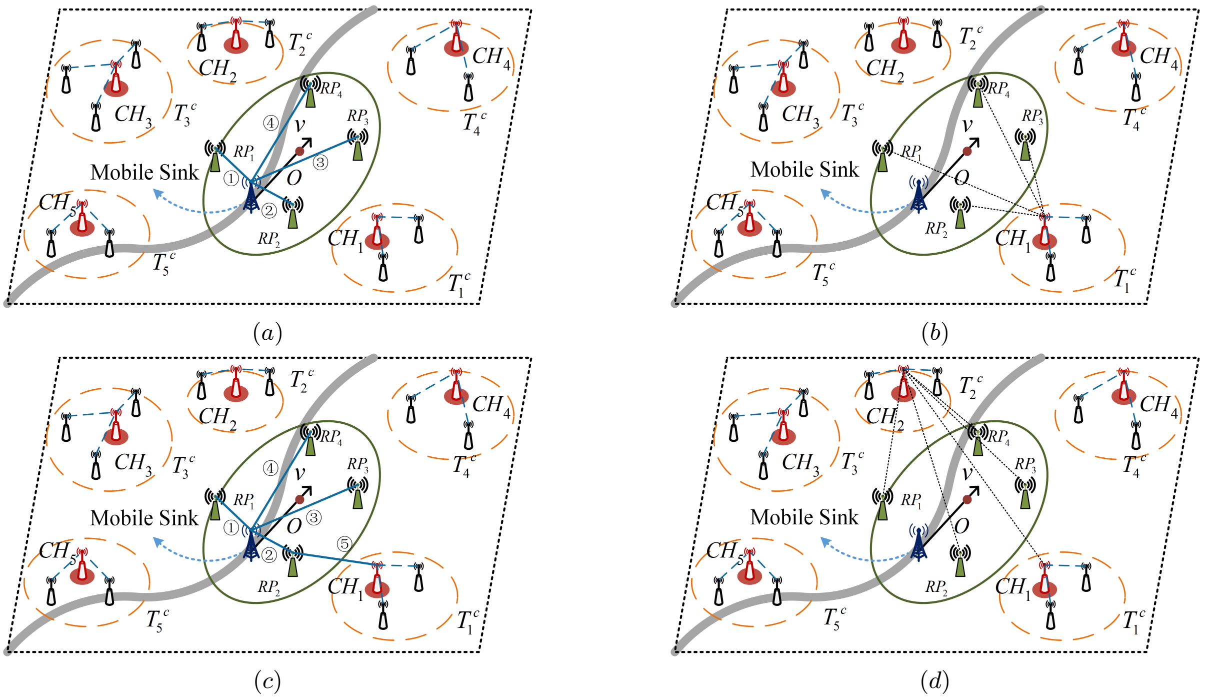
where, $E_{cur}(j)$ is the current remaining energy of the jth node of the spanning tree that can be joined; E_{avg} is the average remaining energy of all the spanning tree nodes that can be joined.

Data transmission energy consumption is a key factor affecting the network lifecycle. Therefore, the path energy consumption factor $E_p(j)$ is introduced in the Equation (26).

$$E_p(j) = \frac{E(d_{i,j})}{E(d_{j\max})} \tag{26}$$

where, $E(d_{i,j})$ is the transmission path energy consumption between cluster head CH_i and the node ${CH_i}^j$ of the spanning tree that can be joined; $E(d_{j\max})$ is the maximum transmission path energy consumption between cluster head CH_i and the node ${CH_i}^j$ of the spanning tree that can be joined; The calculation model of energy consumption is referred to reference [32].

In order to balance the energy of the entire network, not only the remaining energy and the energy consumption of the transmission path must be considered, but also the transmission energy consumption of the next hop path of the



(a) (b)

(c) (d)

Fig. 8. The construction process of dynamic MST

spanning tree node that can be added. Therefore, the next hop path energy consumption factor $E_{pp}(j)$ is introduced, as shown in Equation (27).

$$E_{pp}(j) = \frac{E(d_{j,p})}{E(d_{jp\max})} \tag{27}$$

where, $E(d_{j,p})$ is the transmission energy consumption between the node of the spanning tree that can be joined and the next hop node.

According to the Equation (22), the edge between RP_2 and cluster head CH_1 has the lowest energy efficiency weight. By calculating the energy efficiency weight function, the edges and nodes of the minimum energy efficiency weights of CH_i can be obtained. Then, the path tree constructed by finding the edge $\left(CH_i^j, CH_i\right)$ with the lowest weight is ①,②,③, ④ and ⑤, as shown in Figure 8(c)

Step 3: The edges (RP_2, CH_1) and edges $T_1{}^c(V_1{}^c, E_1{}^c)$ in the cluster tree are merged into the optimized edges set E_{opt} of MST. Meanwhile, the node CH_1 is merged into the set $\mathbf{P}$ of optimized spanning tree nodes and the set $V_1{}^c$ of nodes in the cluster tree $T_1{}^c(V_1{}^c, E_1{}^c)$ are added to the set V_{opt} of nodes in the MST. The cluster head CH_1 is removed from the cluster head set $\mathbf{C}$.

Step 4: The node CH_i^j with the lowest energy efficiency weight is obtained for the cluster head CH_i according to Equation (20), as shown in Figure 8(d). Repeat the above operation until the cluster head set is an empty set. Finally, the dynamic MST $T(V_{opt}, E_{opt})$ is completed.

The symbolic instructions in the dynamic MST building steps above are shown in Table I.

TABLE I
SYMBOLIC REPRESENTATION

Symbol	Name
$\mathbf{A}$	Energy efficient weight matrix
$\mathbf{z}$	Selection scheme matrix
p	Number of nodes in MST
S_m	The ideal elliptical position update area
a, b, c	the long half axis, the short half axis and the semi-focal length of the ellipse
$F_1(J_x(t), J_y(t))$	Back focus of the ellipse
$F_2(J_x(t), J_y(t))$	Back focus of the ellipse
$T_{area}(t{+}\Delta t)$	Adaptive position update threshold
μ	Update weight coefficient
$T_{rp}(s_i)$	Rendezvous point selection threshold
$\mathbf{R}$	Rendezvous points set
$\mathbf{R}'$	Non-rendezvous point set
$\mathbf{G}$	Non-cluster head set
$T(s_i)$	Cluster head selection threshold
$G(V, E)$	Undirected graph of the whole WSNs
$T^r(V^r, E^r)$	Path tree in dynamic rendezvous layer
$T(V_{opt}, E_{opt})$	MST
$T_i^c(V_i^c, E_i^c)$	cluster trees
a_j	Energy efficiency of the node set
$E_r(j)$	Energy factor
$E_p(j)$	Path energy consumption factor
$E_{PP}(j)$	Next hop path energy consumption factor
α, β, δ	Weighting coefficient of energy efficiency a_j
$E_{cur}(j)$	Current remaining energy
E_{avg}	Average remaining energy

IV. DSTMS ALGORITHM IMPLEMENTATION

The flow chart of the DSTMS algorithm in this paper is shown in Figure 9.

In the Figure 9, it can be seen that the ellipse update region is determined by calculating the adaptive function threshold in the DSTMS algorithm. Meanwhile, some nodes located in the ellipse region are selected as rendezvous points to construct the

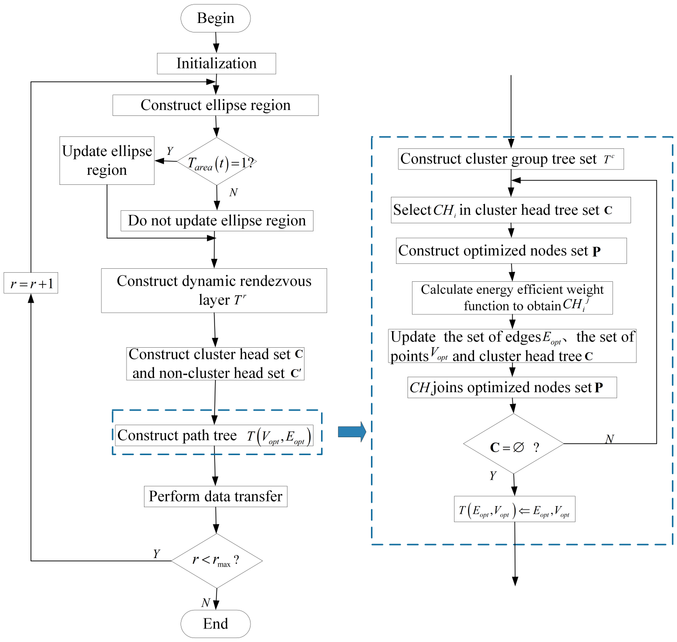


Fig. 9. Dynamic Spanning Tree with Mobile Sink (DSTMS) algorithm flow chart

dynamic rendezvous layer. Then, based on the idea of dynamic MST, the energy efficiency weight function is introduced to construct dynamic path tree.

V. SIMULATION RESULTS AND ANALYSIS

In order to verify the effectiveness of the proposed DSTMS algorithm, two types of experiments were conducted, one under a single scenario and the other under variable conditions in this section.

A. Simulation Parameters in A Single Scenario

It is assumed that N sensor nodes are randomly and uniformly deployed in the WSNs in the monitoring area of S_M. And the sensor nodes continuously generate data and send packets in every time interval [33]. In Figure 10, mobile sink moves from the lower left corner of the monitoring area, and the initial position coordinates of mobile sink are $(0m, 0m)$.

Simulation parameters related to the experiment are shown in Table II.

In order to verify the feasibility and effectiveness of the proposed DSTMS algorithm, this section mainly compares and analyzes the proposed DSTMS algorithm with CEED algorithm [20], DMATEB algorithm [23] and ILEACH algorithm [26]. The simulation experiment environment of this paper was carried out in MATLAB2019a.

B. Simulation Results and Analysis in A Single Scenario

This section mainly verifies the effectiveness of the proposed DSTMS algorithm from the aspects of network node survival time, total remaining energy, energy consumption of transmission path, energy variance of cluster head and stability analysis.

- *Survival Round Analysis of Network Nodes*

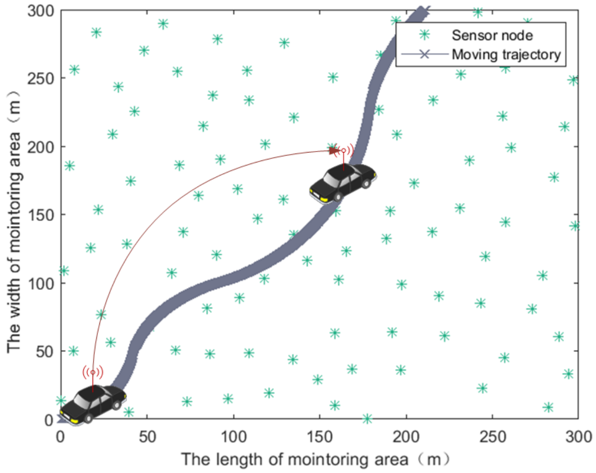


Fig. 10. Moving trajectory of mobile sink

TABLE II
EXPERIMENTAL PARAMETERS

Name	Symbol	Value
Area of Monitor	S_M	$300m \times 300m$
Number of Sensor Nodes	N	100
Initial Position of Mobile sink	(x_{MS}, y_{MS})	$(0m, 0m)$
Initial Energy of Node	E_0	1J
Communication Energy Consumption	E_{TX}/E_{RX}	$50nJ/bit$
Energy Consumption of Signal Amplification in Free Space	ε_{fs}	$10\text{pJ}/bit/m^2$
Energy Consumption of Signal Amplification in Multipath	ε_{mp}	$0.0013\text{pJ}/bit/m^2$
Energy Consumption of Data Fusion	E_{DA}	$5nJ/bit/packet$
Length of Control Signal	l_1	100 bit
Length of Monitor Data	l_2	4000 bit
Optimal Probability of Cluster Heads	P_{opt}	0.1
Maximum Number of Running Rounds	r_{max}	1800
Time Slot	T_{slot}	$1\mu s$
Packet Generation Rate	P_{rate}	50 packet $\cdot\text{s}^{-1}$

The variation trend of the number of survival nodes of the four algorithms are shown in Figure 11.

In this figure, there were 100 survival nodes at the beginning of the network. With the increase of the network running rounds, the corresponding curves of the four algorithms showed a downward trend. At the same time, the number of nodes surviving decreased, and dead nodes began to appear. The round of first death node with respect to CEED, DMATEB, ILEACH and DSTMS algorithm were $207th$, $86th$, $269th$, $337th$, respectively. Compared with the other three algorithms, first death node round of DSTMS algorithm was extended by 62.8%, $291\%$and 25.27%, respectively. The round of all death nodes with respect to CEED, DMATEB, ILEACH and DSTMS algorithm were $906th$, $958th$, $1133th$, $1724th$, respectively. Compared with the other three algorithms, the life cycle of the DSTMS algorithm extended by 90.28%, 76.96% and 52.16%, respectively. The relationship between the number of node deaths and the number of running rounds of the four algorithms is shown in Figure 12.

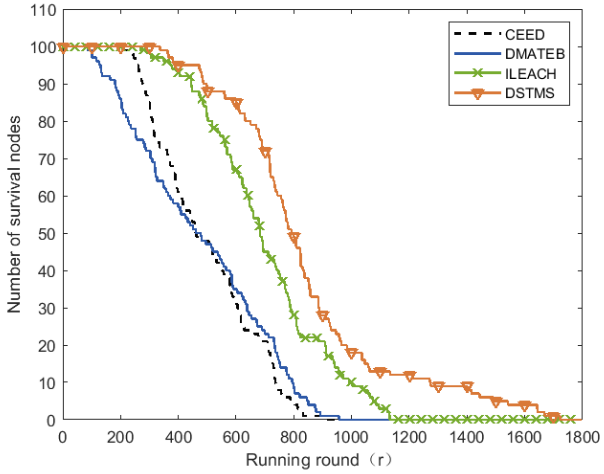


Fig. 11. The number of surviving nodes

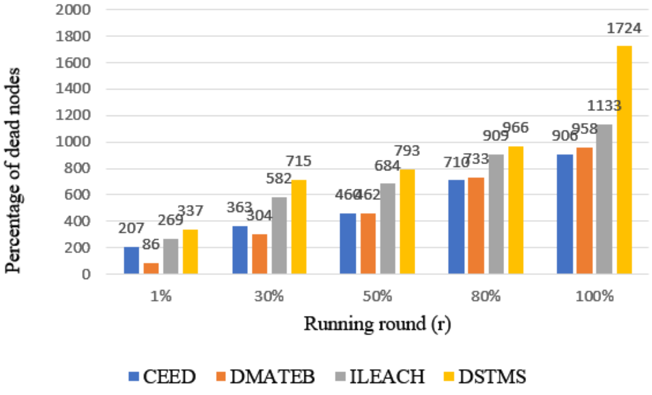


Fig. 12. The relationship between the percentage of dead nodes and running rounds

It can be seen from the above Figure 12, compared with the other three algorithms, DSTMS algorithm had the longest running round and could effectively extend the network life cycle.

- *Analysis of Total Remaining Energy of Nodes*

With the increase of the number of the network running rounds, the energy consumption of nodes gradually increases due to continuous data transmission, so the total remaining energy in the network gradually decreases. The variation trend of total remaining energy of the four algorithms are plotted in Figure 13.

It can be seen from Figure 13 that the number of nodes was set to be 100 and initial energy of each node was set to be $1J$. The curve corresponding to DSTMS algorithm was higher than other three algorithms, which indicated that the total remaining energy of WSNs corresponding to DSTMS algorithm was greater than that of other three algorithms. When the total remaining energy of the WSNs was $0J$, the round of running of CEED, DMATEB, ILEACH and DSTMS algorithm was $906th$, $958th$, $1133th$, $1724th$, respectively, which indicated the entire network running time of DSTMS algorithm was the longest. So, the DSTMS algorithm could effectively save the network energy and prolong network lifetime.

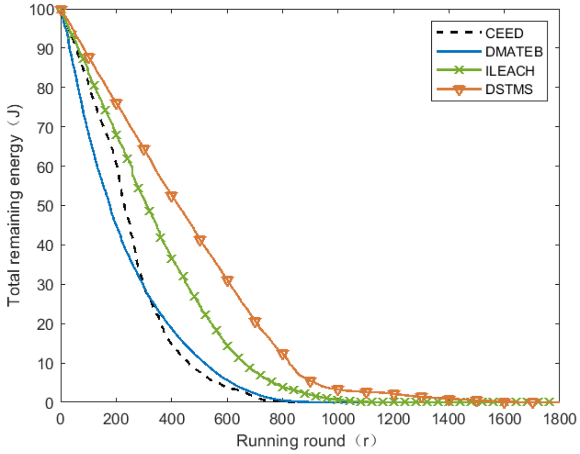


Fig. 13. The trend of total remaining energy

- *Energy Consumption Analysis of Cluster Head Transmission Path*

As the position of the mobile sink is different in each round, the data transmission path constructed by the cluster head to the mobile sink is different, resulting in different energy consumption. In $800th$ round , the cluster head transmission paths of the four algorithms are shown in Figure 14.

As can be seen from Figure 14, under the condition that cluster heads were located at the same position, the cluster head transmission path of the CEED algorithm adopted chain structure, so that the data transmission appeared to be oriented away from mobile sink. The cluster head transmission path of DMATEB, ILEACH and DSTMS adopted the tree structure, which can avoid the phenomenon of data transmission deviating from the mobile sink. However, the three algorithms have different strategies in constructing path trees, and there are certain differences in constructing path trees. When constructing path tree, DSTMS algorithm took the remaining energy of cluster heads and the weight of energy consumption of transmission path into full consideration. In addition, the location information of the whole network needs to be updated In CEED and DMATEB algorithms. In ILEACH algorithm, mobile sink needs to update its location information to cluster head node. Compared with the other three algorithms, DSTMS algorithm designs the position update strategy of the ellipse according to the motion parameters of the mobile sink. When mobile sink moves, it only needs to update its position in the elliptic region. Therefore, DSTMS algorithm can significantly reduce data transmission energy consumption and reduce data congestion caused by frequent location updates. In order to further illustrate the influence of DSTMS algorithm on reducing the energy consumption of the transmission path, Figure 15 shows the trend of energy consumption of cluster head transmission path among the four algorithms with the increase of the number of running rounds.

As can be seen from Figure 15, with the increase in the number of running rounds, CEED, DMATEB, ILEACH and DSTMS algorithm had different trends, but the rise rates of the four algorithms were different. The corresponding curve

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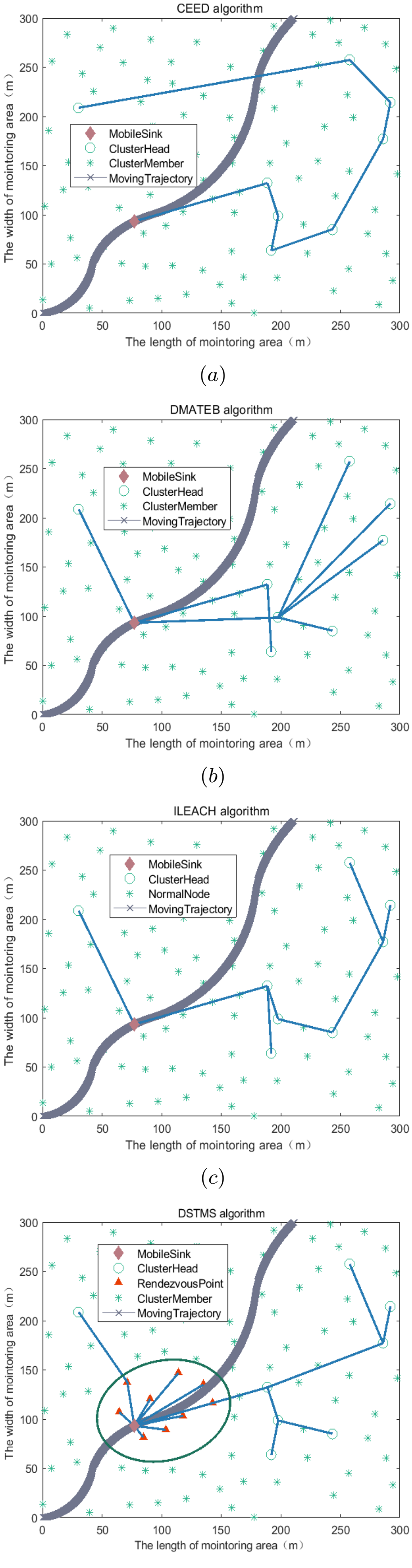

Fig. 14. Cluster head transmission paths of the four algorithms

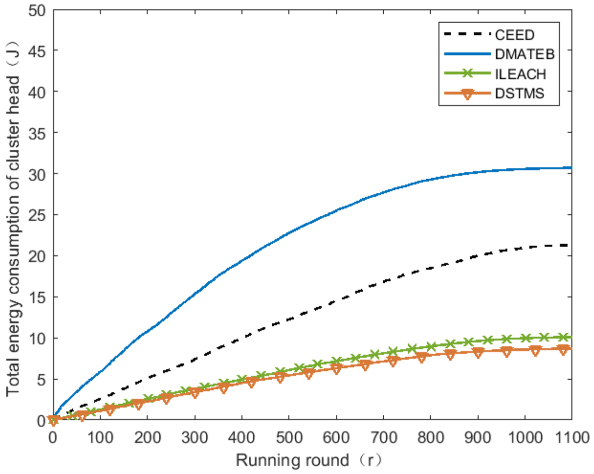

Fig. 15. The energy consumption of cluster head transmission path

corresponding to the DSTMS algorithm was above the other three curves. After the network is running to $800th$ rounds, the curve increase rate corresponding to the four algorithms is reduced. The reason is that with the operation of the network, a large number of nodes die, causing the cluster head to decrease, thereby decreasing the cluster head energy consumption. As shown in Figure 16, the cluster head node energy consumption is shown in $800th$ round, respectively.

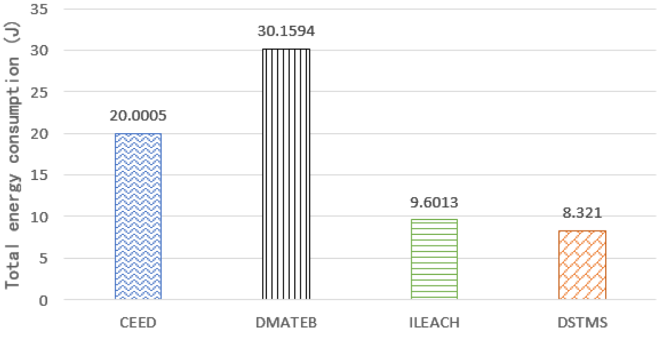

Fig. 16. Total energy consumption of cluster head of four algorithms

As shown in Figure 16, when the network operation to $800th$ round, CEED, DMATEB, ILEACH, DSTMS algorithm of total energy consumption of cluster transmission were $20.0005J$, $30.1594J$, $9.6013J$, $8.3210J$. Compared with the other three algorithms, the DSTMS algorithm saved 58.41%, 72.41% and 13.35%, respectively. The reason is that the DSTMS algorithm fully considers the energy consumption of data transmission and remaining energy of cluster head, which could reduce the energy consumption of cluster head data transmission and prolong the network life cycle.

- *Analysis of Variance of Cluster Head Energy Consumption*

In order to better verify the equilibrium of DSTMS algorithm, the covariance V_{ch}^2 of cluster head energy consumption was introduced as one of the performance metrics.

$$V_{ch}^2 = \sum\nolimits_{i=1}^{n} \left(E_i - \bar{E}\right)^2 \Big/ (n-1) \tag{28}$$

where, E_i is the energy consumption of ith cluster head in the current round; $\bar{E}$ is the avergy energy consumption of all cluster heads in current round; n is the number of the cluster heads in current round.

Now, variance of cluster head energy consumption(Figure 17) was introduced here to describe the balance of four algorithms.

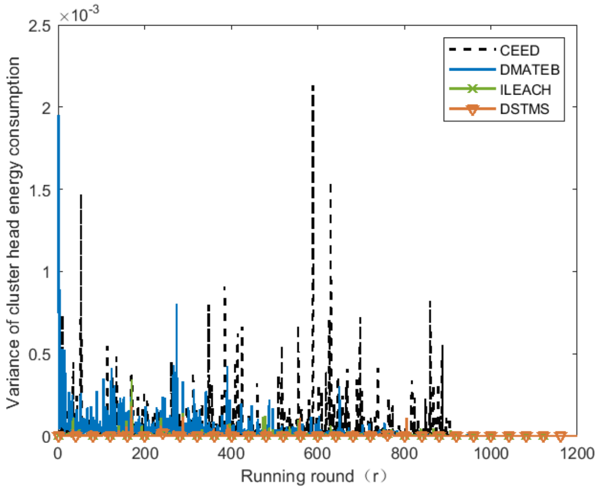

Fig. 17. The variance of cluster head energy consumption

Figure 17 shows that, with the operation of the network and the change of the location of mobile sink, the variance of cluster head energy consumption was different greatly in each round of four algorithms. The curve corresponding to DSTMS algorithm was under the other four algorithms, indicating that the variance of cluster head energy consumption corresponding to DSTMS algorithm was less than the remaining energy variance of the other three algorithms. So, DSTMS algorithm can effectively balance the network energy consumption.

- *Time Complexity Analysis*

The time complexity of the DSTMS algorithm is mainly determined by the number of cycles and iterations. The time complexity of four algorithms were shown in Table III.

TABLE III
TIME COMPLEXITY

Algorithm Name	Time Complexity
CEED	$\mathcal{O}\left(N_{\max} \cdot \log\left(n_{CH}\right)^2\right)$
DMATEB	$\mathcal{O}\left(N_{\max} \cdot n^2\right)$
ILEACH	$\mathcal{O}\left(N_{\max} \cdot \left(n_{area}\right)^2\right)$
DSTMS	$\mathcal{O}\left(N_{\max} \cdot n^2\right)$

In Table III, $N_{\max}$ is the number of running rounds, n is the number of sensor nodes, n is the number of cluster heads, n_{area} is the number of the part area in ILEACH. It can be seen that DSTMS algorithm has high time complexity, but it saves more energy.

C. Simulation Results and Analysis in Variable Conditions

In this section, the paper mainly verifies the effectiveness of the algorithm from two aspects. One is changing the moving trajectory of mobile sink and the other is changing the position of sensor nodes.

- *The Condition of Variable Moving Tracjectory of Mobile sink*

The moving trajectory of the mobile sink is an important indicator affecting the monitoring performance of the whole network. Therefore, the performance of the proposed algorithm can be verified by changing the moving trajectory of the moving sink in Figure 18.

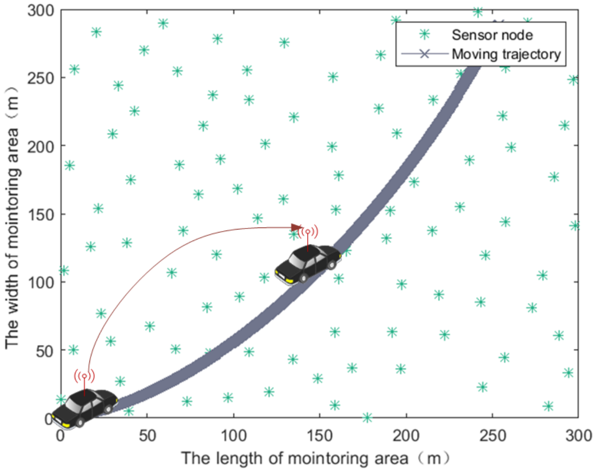

Fig. 18. Moving trajectory of mobile sink

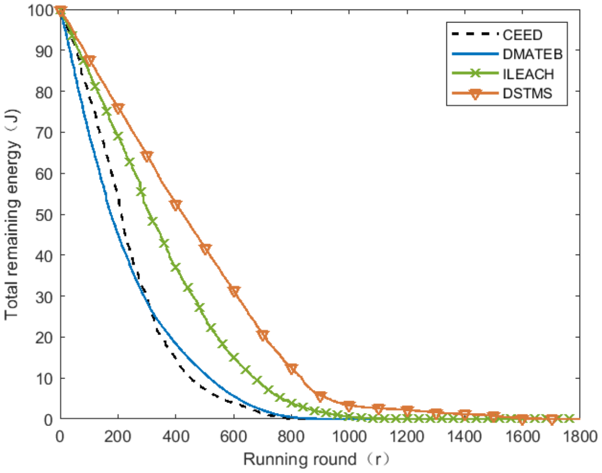

Fig. 19. Moving trajectory of mobile sink

When the moving trajectory of the mobile sink node changes, the total remaining energy of the entire network is shown in the Figure 19.

It also can be seen that the curve of the CEED algorithm has changed slightly. But the overall change trend of the four algorithms remains unchanged. The curve corresponding to

DSTMS algorithm was still higher than other three algorithms. So, the DSTMS algorithm could effectively save the network energy and prolong network lifetime.

- *The Condition of Variable Sensor Node Position*

In order to further verify the applicability of the proposed DSTMS algorithm to prolong the life cycle of the network, the location of the network nodes was randomly generated for many experiments. When the node position was randomly generated, the network life cycle of the CEED, DMATEB, ILEACH and DSTMS algorithm were shown in Figure 20.

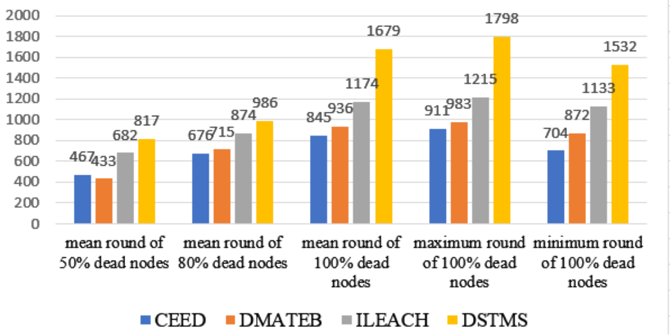

Fig. 20. The result of 50 experiments

In this paper, 50 experiments were carried out by randomly changing node positions. According to the experimental results given in Figure 20, the mean round of 100% dead node networks corresponding to CEED, DMATEB, ILEACH and DSTMS algorithm were $845th$, $936th$, $1174th$ and $1679th$ rounds, respectively. Compared with other algorithms, the mean network life cycle of DSTMS algorithm is extended by 98.70%, 79.38% and 43.02%, respectively. In 50 experiments, the minimum round of DSTMS algorithm was all higher than that of the other three algorithms and the maximum round was much higher than that of the other three algorithms in some cases, which indicated that DSTMS algorithm has high stability and can prolong the network life cycle effectively.

VI. CONCLUSION

In this paper, some factors including the mobility performance parameters of the mobile sink, the remaining energy of the node and the energy consumption of the transmission path are comprehensively considered. Based on the idea of MST, this paper proposed a routing algorithm in WSNs with mobile sink-DSTMS (Dynamic Spanning Tree with Mobile Sink). In this algorithm, a multi-level transmission framework for dynamic MST was constructed. In this framework, some nodes were selected as rendezvous points, according to the motion parameters of mobile sink, built the dynamic rendezvous layer to constraint the hierarchical transmission of DSTMS. At the same time, based on the idea of MST, the energy efficiency weight function was introduced to construct dynamic multi-hop transmission path tree of mobie sink. Thus, the DSTMS algorithm proposed in this paper can effectively prolong the network life, balance the network load and reduce data congestion in wireless transmission.

In addition, the algorithm proposed in this paper only considers a mobile sink and barrier-free in the path. When the monitoring area is large enough, a single mobile sink node cannot meet the real-time requirements. And the DSTMS algorithm has high time complexity. Hence, in the future work, it is necessary to research and design the dynamic path planning strategy of multiple mobile sinks to avoid obstacles in WSNs.

REFERENCES

[1] G. S. Dhunna and I.Al-Anbagi, “A Low Power WSNs Attack Detection and Isolation Mechanism for Critical Smart Grid Applications,” *IEEE Sensors Journal,* vol. 19, no. 13, pp. 5315–5324, Feb. 2019, 10.1109/JSEN.2019.2902357.

[2] S. Yadav, V. Kumar, S. B. Dhok and D. N. K. Jayakody, “Energy-Efficient Design of MI Communication-Based 3-D Non-Conventional WSNs,” *IEEE Systems Journal,* vol. 14, no. 2, pp. 2585–2588, Jun. 2020, 10.1109/JSYST.2019.2918184.

[3] D. Lin, W. Min, J. Xu, J. Yang and J. Zhang, “An Energy-Efficient Routing Method in WSNs Based on Compressive Sensing: From the Perspective of Social Welfare,” *IEEE Embedded Systems Letters,* vol. 13, no. 3, pp. 126–129, Sep. 2021, 10.1109/LES.2020.3022848.

[4] A. S. Toor and A. K. Jain, “Energy aware cluster based multi-hop energy efficient routing protocol using multiple mobile nodes (MEACBM) in wireless sensor networks,” *AEU-International Journal of Electronics and Communications,* vol. 102, pp. 41–53, Feb. 2019, 10.1016/j.aeue.2019.02.006.

[5] Y. C. Wang and K. C. Chen, “Efficient path planning for a mobile sink to reliably gather data from sensors with diverse sensing rates and limited buffers,” *IEEE Transactions on Mobile Computing,* vol. 18, no. 7, pp. 1527–1540, Aug. 2018, 10.1109/TMC.2018.2863293.

[6] X. X. Yuan, and R. H. Zhang, “An energy-efficient mobile sink routing algorithm for wireless sensor networks,” 2011 7th International Conference on Wireless Communications, 2011, pp. 1-4, 10.1109/wicom.2011.6040374.

[7] R. Sharma, N. Mishra and S. Srivastava, “A proposed energy efficient distance based cluster head (DBCH) algorithm: An improvement over LEACH,” *Procedia Computer Science,* vol. 57, no. 7, pp. 1527–1540, Aug. 2015, 10.1016/j.procs.2015.07.481.

[8] H. Byun and S. Yang, “Energy-balancing node scheduling inspired by gene regulatory networks for wireless sensor networks,” *IET Communications,* vol. 11, no. 17, pp. 2650–2659, Nov. 2017, 10.1049/iet-com.2017.0082.

[9] B. Jiang, B. Ravindran and H. Cho, “Probability-Based Prediction and Sleep Scheduling for Energy-Efficient Target Tracking in Sensor Networks,“ *IEEE Transactions on Mobile Computing,* vol. 12, no. 4, pp. 735–747, Apr. 2013, 10.1109/TMC.2012.44.

[10] K. Murugan and A. S. K. Pathan, “Prolonging the lifetime of wireless sensor networks using secondary sink nodes,“ *Telecommunication Systems,* vol. 62, no. 2, pp. 347–361, Jun. 2016, 10.1007/s11235-015-0079-5.

[11] Z. Han, J. Wu, J. Zhang, L. Liu and K. Tian, “A General Self-Organized Tree-Based Energy-Balance Routing Protocol for Wireless Sensor Network,“ *IEEE Transactions on Nuclear Science,* vol. 61, no. 2, pp. 732–740, Apr. 2014, 10.1109/TNS.2014.2309351.

[12] F, Engmann, F. Katsriku, J. Abdulai, et al, “Prolonging the lifetime of wireless sensor networks: A review of current techniques,“ *Wireless Communications and Mobile Computing,* vol. 8, no. 1, pp. 1–23, Aug. 2018, 10.1155/2018/8035065.

[13] K. Haseeb, K. A. Bakar, A. H. Abdullah, et al, “Adaptive energy aware cluster-based routing protocol for wireless sensor networks,“ *Wireless Networks,* vol. 23, no. 6, pp. 1953–1966, Apr. 2017, 10.1007/s11276-016-1269-0

[14] J. Vazifehdan, R. V. Prasad and I. Niemegeers, “Energy-Efficient Reliable Routing Considering Residual Energy in Wireless Ad Hoc Networks,“ *IEEE Transactions on Mobile Computing,* vol. 13, no. 2, pp. 434–447, Jan. 2014, 10.1109/TMC.2013.7.

[15] C. Tunca, S. Isik, M. Y. Donmez and C. Ersoy, “Distributed Mobile Sink Routing for Wireless Sensor Networks: A Survey,“ *IEEE Communications Surveys & Tutorials,* vol. 16, no. 2, pp. 877–897, Oct. 2014, 10.1109/SURV.2013.100113.00293.

[16] S. Dhiviya, A. Sariga and P. Sujatha, “Survey on WSN Using Clustering,” 2017 Second International Conference on Recent Trends and Challenges in Computational Models (ICRTCCM), 2017, pp. 121–125, 10.1109/ICRTCCM.2017.87.

[17] W. R. Heinzelman, A. Chandrakasan and H. Balakrishnan, “Energy-efficient communication protocol for wireless microsensor networks,” Proceedings of the 33rd Annual Hawaii International Conference on System Sciences, 2000, pp. 1–10, 10.1109/HICSS.2000.926982.

[18] R. Sharma, N. Mishra and S. Srivastava, “A proposed energy efficient distance based cluster head (DBCH) algorithm: An improvement over LEACH,“ *Procedia Computer Science,* vol. 57, no. 7, pp. 807–814, Aug. 2015, 10.1016/j.procs.2015.07.481.

[19] K. A. Darabkh, J. N. Zomot, “An improved cluster head selection algorithm for wireless sensor networks,” 2018 14th International Wireless Communications & Mobile Computing Conference (IWCMC), 2018, pp. 65–70, 10.1109/IWCMC.2018.8450446.

[20] R. D.Gawade and S. L. Nalbalwar, “A Centralized Energy Efficient Distance Based Routing Protocol for Wireless Sensor Networks,“ *Journal of Sensors,* vol. 2016, pp. 1–8, Apr. 2016, 10.1155/2016/8313986.

[21] J. Wang, Z. Zhang, F. Xia, et al, “An energy efficient stable election-based routing algorithm for wireless sensor networks,“ *Sensors,* vol. 13, no. 11, pp. 14301–14320, Oct. 2013, 10.3390/s131114301.

[22] G. Smaragdakis, I. Matta, A. Bestavros, “SEP: A stable election protocol for clustered heterogeneous wireless sensor networks,” *Boston University Computer Science Department,* 2014.

[23] V. K. Arora, V. Sharma and M. Sachdeva, “A distributed, multi-hop, adaptive, tree-based energy-balanced routing approach,“ *International journal of communication systems,* vol. 32, no. 9, pp. 1–13, Apr. 2019, 10.1002/dac.3949.

[24] S. Kumar, A. Verma, P. R. Gautam, et al, “The load balancing of optimizing leach clustering algorithm with mobile sink and rendezvous nodes,” 2018 5th IEEE Uttar Pradesh Section International Conference on Electrical, Electronics and Computer Engineering (UPCON), 2018, pp. 1–6, 10.1109/UPCON.2018.8596989.

[25] C. Zhu, S. Wu, G. Han, et al, “A tree-cluster-based data-gathering algorithm for industrial WSNs with a mobile sink,“ *IEEE Access,* vol. 3, pp. 381–396, Apr. 2015, 10.1109/ACCESS.2015.2424452.

[26] B. Y. Kushal and M. Chitra, “Cluster based routing protocol to prolong network lifetime through mobile sink in WSN,” IEEE International Conference on Recent Trends in Electronics, 2016, pp. 1287–1291, 10.1109/RTEICT.2016.7808039.

[27] P. K. Donta, B. Rao, T. Amgoth , et al. “Data Collection and Path Determination Strategies for Mobile Sink in 3D WSNs,“ *IEEE Sensors Journal,* vol. 20, no. 4, pp.2224–2233, Feb. 2020, 10.1109/JSEN.2019.2949146.

[28] S. R. Barath, K. R. Abhiram, B. Nithin, et al, “A Survey of path reconstruction approaches by using optimization protocols in WSN,” 2019 International Conference on Smart Systems and Inventive Technology (ICSSIT), 2019, pp. 1258–1261, 10.1109/ICSSIT46314.2019.8987917.

[29] Q. Wei, K. Bai, L. Zhou, et al, “A Cluster-Based Energy Optimization Algorithm in Wireless Sensor Networks with Mobile Sink,“ *Sensors,* vol. 21, no. 7, pp. 1258–1261, Apr. 2021, 10.3390/s21072523.2018.5216.

[30] Y. Jin, L. Zhou, Y Fang, et al, “LEACH-TLC: A Strategy of Reducing and Uniforming Energy Consumption based on Target Location Constraint,“*IET Wireless Sensor Systems,* vol 9, no. 6, pp. 347–357, Oct. 2019, 10.1049/iet-wss.

[31] M. Tarhani, Y. S. Kavian, S. Siavoshi, “SEECH: Scalable energy efficient clustering hierarchy protocol in wireless sensor networks,“ *IEEE Sensors Journal,* vol. 14, no. 11, pp. 2523, Sep. 2014, 10.1109/JSEN.2014.2358567.

[32] S. Mottaghi, M. R. Zahabi, “Optimizing LEACH clustering algorithm with mobile sink and rendezvous nodes,“ *AEUE - International Journal of Electronics and Communications,* vol. 69, no. 2, pp. 507–514, Oct. 2015, 10.1016/j.aeue.2014.10.021.

[33] D. K. Sah, P. K. Donta, T. Amgoth, et al, “EDGF: Empirical dataset generation framework for wireless network networks,“ *Computer Communications,* vol. 180, pp. 48–56, Dec. 2021, 10.1016/j.comcom.2021.08.017.

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