ABSTRACT With the gradual expansion of the application field in wireless sensor networks, the problems of the energy consumption has received more and more attention. In wireless sensor networks, the location of sensor nodes and gateway nodes are usually fixed. To ensure that the energy consumption of the sensor network is minimized during data transmission, it is necessary to optimize the placement of relay nodes. This paper proposes the solution of relay nodes placement based on optimal transmission distance, which can minimize the energy consumption and extend the lifetime of the entire network during the transmission process. This scheme starts with a one-dimensional queue network and calculates the optimal distance for each hop transmission to minimize the energy consumption of the one-dimensional queue network. Due to the poor connectivity of the one-dimensional queue network, the concept of the optimal transmission distance is introduced into two-dimensional network, so that the placement scheme can be divided into the symmetrical relay node placement and the asymmetric relay node placement. Finally, the energy consumption of the network is minimized by properly selecting relay nodes. The simulation show that the proposed relay node placement scheme can reduce the energy consumption of the sensor network and extend the network life cycle.

INDEX TERMS Wireless sensor networks, energy consumption, the one-dimensional queue network, the two-dimensional network, network lifetime.

I. INTRODUCTION
With the rapid development of micro-motor technology, wireless communication and digital electronic technology, the wireless sensor networks have been applied to many fields that require reliable and real-time data transmission [1]. Wireless sensor network is composed of many compacts, low-cost and low-power nodes. The sensor node is responsible for data collection, processing, and wireless transmission. The relay node is responsible for data forwarding and the gateway node is responsible for data aggregation. The unique feature of wireless sensor networks is the cooperative operation of sensor nodes. Sensor nodes do not send raw data to nodes which is responsible for fusion. Instead, they use their processing power to perform simple calculations locally and transmit only the data that needs to be processed.

In wireless sensor networks, in addition to the importance of node location information for sensor networks, the energy consumption is also the focus of research. Because most sensor nodes are randomly deployed and powered by batteries, the energy consumption of node plays an important role in the effectiveness of sensor network applications. The first problem is that the layout of various nodes in real-life applications needs to be considered for the wireless sensor network [2]. From the perspective of the overall placement, the positions of sensor nodes and relay nodes are relatively fixed, due to the reliability of data transmission between sensor nodes and gateway node. Therefore, the positions of relay nodes are needed to be set reasonably in wireless sensor network [3].

II. THE RELATED WORK
At present, there are many types of research about relay node layout. The research of relay node layout that requires routing
structures can be divided into single-tiered and two-tiered networks [4]. In single-tiered networks, in addition to collecting data, the sensor node also has the function of forwarding data collected by other sensor nodes. In the two-tiered network, the sensor node can only transmit the data collected by itself to relay node or directly to gateway node and cannot transfer data from another sensor node. The second method is based on network coverage connectivity [5]. In the relay node placement model with network connectivity as the target, its only necessary to ensure the connectivity between each sensor node and gateway node. The network fault tolerance needs to ensure that there are at least two disjoint communication paths between sensor node and gateway node. In addition to the above two methods, there are many other methods such as obstacle restrictions, hop count effects, and the number of relay nodes.

From the perspective of the energy consumption of wireless sensor networks, Zhang et al. [6] proposed an adaptive relay node selection algorithm based on opportunity. The adaptive algorithm mainly selects potential relay nodes as candidate nodes through the BER(Bit Error Ratio), and the simulations show that the proposed method can extend the life cycle of the network. Considering the layout of irregular shapes, an effective relay placement algorithm based on the perspective transformation technology [3] is proposed in the paper. This algorithm can minimize the total energy consumption and the total delay of the entire network, which not only does help to reduce the complexity of relay search, but also can optimize any shapes of the network. In one-dimensional queue networks, the energy saving optimization is also the focus of research in the routing protocols. The literature [7] is dedicated to research on minimizing the energy consumption of data relay and maximizing the network life cycle in the one-dimensional queue network. Based on above purpose, an opportunistic routing energy-saving algorithm is proposed to ensure the lowest power consumption during the data transmission. The simulations and real experimental test show that the proposed algorithm can significantly improves the energy saving and connection performance of the wireless sensor network compared with existing routing protocols.

Most of the research focused on the absence of obstacles in the scene currently. Aiming at the situation of the limited location, the proposed method by Bagaa et al. [8] can ensure that the number of relay nodes which are used to be normally connected is small, and it has also greatly improved the network lifetime. What’s more, considering the impact of obstacles on radio propagation in the indoor environment, an effective relay node placement method is proposed [9] to deal with the situation with restrictions. Its algorithm uses the inherent properties of the problem to convert it into the problem of minimum connected-K, which can greatly reduce the number of relay nodes and is able to be applied to indoor monitoring systems.

Considering how to reduce the number of relay nodes in wireless sensor networks, many literatures have made related research. Ma et al. [10] proposed a novel relay connectivity approximation algorithm based on the two-tiered networks. The local search approximation algorithm and relay location selection algorithm were used to save the number of relay nodes. The literature [11] considers the situation of high attenuation and low attenuation of the channel, and the relay node deployment is regarded as a Markov decision process. The proposed method makes the relay nodes evenly distributed in the case of high attenuation, and makes the relay nodes mostly close to the source node in the case of low attenuation. The results show that this method can reduce the system cost. In addition, a one-step constrained relay node placement method is proposed [12] to connect the sensor nodes to the base station using a minimum number of relay nodes.

The number of hops is also an important factor affecting the end-to-end delay and reliability. The core of the literature [13] is the placement of relay nodes with limited hops for 1 connection and the placement of relay nodes with limited hops for 2 connections. The simulation results show that the complexity of the proposed 1-connected placement algorithm is lower than existing 1-connected placement algorithm, the proposed 2-connected relay node placement problem can provide clear performance guarantee. From the perspective of packet receiving rate, the literature [14] gives an optimal algorithm for the placement of relay nodes, which minimizes the total number of re-transmission of the data packets, and can ensure the lowest communication cost under simulation. Radio frequency energy transmission (RFET) has become an effective technology to extend the life of the energy-constrained wireless sensor networks. In order to improve the efficiency of RFETs, Mishra and De [15] proposed a novel and optimal model to determine the best relay node placement. The proposed algorithm can obtain global optimal solution in the process of iteration, and can save most of the network energy.

In summary, the existing literature mainly studies the energy consumption problem from number and connectivity of relay nodes, and targeted network space is relatively single. From the perspective of optimizing energy consumption in wireless sensor networks, this paper proposes a relay node layout scheme based on optimal transmission distance. Firstly, using the one-dimensional queue network as the starting point, the optimal transmission distance per hop of the transmitted data is calculated. One-dimensional queue network is easily affected by one of the nodes. When one of the nodes fails, the entire network will collapse, so the network connectivity and reliability is poor, the concept of the optimal transmission distance is introduced into the two-dimensional space network, and the placement model of the relay nodes is further optimized, which can minimize the energy consumption of the entire network. The simulation results show that the relay node placement scheme based on optimal transmission distance proposed in this paper can effectively reduce the average energy consumption and improve the network lifetime.
III. THE ONE-DIMENSIONAL QUEUE NETWORK MODEL
A. THE ONE-DIMENSIONAL QUEUE NETWORK

The one-dimensional queue network is a sensor node that transmits the collected data to the gateway node along a straight line of relay nodes. The one-dimensional queue network model is shown in Fig.1. Assume the collection of all nodes is \( N = \{0, 1, 2, \ldots, M - 1, M\} \), where the 0 represents the location of the source node, the M represents the location of the sink node, the 1, 2, 3, \ldots, M - 1 indicate the location of the relay nodes. These nodes are equally spaced and have the same transmission radius and its value is \( R \).

\[
\begin{align*}
\text{FIGURE 1. One-dimensional queue network model.}
\end{align*}
\]

B. THE ENERGY CONSUMPTION MODEL

By referring to the literatures [7], [16], the energy model used in this paper is the simplified power model based on radio transmission, and its the simplified power model is shown in Fig.2. Assume that a B-bit data packet needs to be transmitted in wireless sensor network. First, the data packet needs to pass through the transmitting circuit and an amplifying circuit at the transmitting end, and then the B-bit data packet is received via the receiving circuit.

\[
\begin{align*}
\text{FIGURE 2. Simplified energy power model.}
\end{align*}
\]

It can be known from Fig.2 that the energy consumption at the transmitting end includes the energy consumption of the transmitting circuit and the amplifying circuit, the energy consumption at the receiving end only includes the energy consumption of receiving circuit. The energy consumption at the transmitting end is shown in formula (1).

\[
E_T = (E_{\text{elec}} + \epsilon_{\text{amp}}d^\tau)B
\]

The energy consumption at the receiving end is shown in formula (2).

\[
E_R = E_{\text{elec}}B
\]

where \( E_{\text{elec}} \) indicates the basic energy consumption of sensor board to run transmitter or receiver circuitry. \( \epsilon_{\text{amp}} \) represents the energy dissipation of the transmitting amplifier. \( d \) indicates the distance between the transmitter and the receiver. \( \tau \) represents the channel path loss factor of the antenna, and its value is between 2 and 4.

C. THE OPTIMAL TRANSMISSION SCHEME

As shown in Fig.1, the coordinate of the \( h \)th relay node is set \( x_h \) in a one-dimensional queue network, the distance between the \( h \)th relay node and gateway node is \( d = M - x_h \). According to the energy consumption formulas (1) and (2), the total energy \( C_h \) consumed by the node \( h \) can be obtained by in formula (3).

\[
C_h = \sum_{i=1}^{n} E_T + \sum_{i=1}^{n-1} E_R
\]

\[
= (2n - 1)E_{\text{elec}}B + \sum_{i=1}^{n} \epsilon_{\text{amp}}(x_i - x_{i-1})^T B
\]

where \( n \) represents the count of hops that \( h \)th node relay data to sink. To make the energy consumption of node \( h \) have the minimum value, the mean inequality is further optimized for formula (3), and then inequality (6) can be obtained. Among them, the inequality optimization process is shown in inequality (4) and (5).

\[
\begin{align*}
\sqrt[n]{\sum_{i=1}^{n} (x_i - x_{i-1})^T} & \geq \frac{\sum_{i=1}^{n} (x_i - x_{i-1})}{n} \\
\sqrt[n]{\sum_{i=1}^{n} (x_i - x_{i-1})^T} & \geq \frac{\sum_{i=1}^{n} (x_i - x_{i-1})}{n^{\frac{\tau}{\tau - 1}}} \\
C_h & \geq (2n - 1)E_{\text{elec}}B + \frac{\epsilon_{\text{amp}} \sum_{i=1}^{n} (x_i - x_{i-1})^T B}{n^{\frac{\tau}{\tau - 1}}}
\end{align*}
\]

According to inequality (4), the minimum of energy consumption can be derived, and the formula of the minimum value is shown in (7).

\[
C_h^{\text{min}} = (2n - 1)E_{\text{elec}}B + \frac{\epsilon_{\text{amp}} \sum_{i=1}^{n} (x_i - x_{i-1})^T B}{n^{\frac{\tau}{\tau - 1}}}
\]

In mathematical problems, derivatives are used in solving minimum of an expression. To deal with minimum value of formula (7), the first derivative is calculated, and the first derivative is shown in formula (8).

\[
\frac{\partial C_h^{\text{min}}}{\partial n} = 2E_{\text{elec}}B - (\tau - 1)\frac{\epsilon_{\text{amp}} (M - x_h)^T B}{n^{\frac{\tau}{\tau - 1}}}
\]

Letting formula (8) equal to zero, the value of the hop count can be obtained, which is expressed as formula (9).

\[
n_{\text{op}} = \left(\frac{(\tau - 1)(2E_{\text{elec}})^{\frac{1}{\tau}}(M - x_h)}{\epsilon_{\text{amp}}^{\frac{1}{\tau}}(2E_{\text{elec}})^{\frac{1}{\tau}}}ight)^{\frac{1}{\tau - 1}}
\]

In order to determine whether the energy consumption obtained under the above hop count is the minimum value,
formula (9) is subjected to the second derivative, and the second derivative is shown in (10).

$$\frac{\partial^2 C_{\text{min}}}{\partial n^2} \bigg|_{n=n_{\text{op}}} = \tau (\tau - 1) \frac{e_{\text{amp}} (M - x_h)^2 B}{n+1} > 0 \quad (10)$$

In the second derivative, when the value of the second derivative is greater than zero, it can be determined that the function is convex and has a minimum value. Therefore, when the number of hops is as shown in formula (9), the energy consumption can be minimized. Therefore, the theoretically optimal transmission distance of per hop is shown in formula (11).

$$d_{\text{op}} = \frac{M - x_h}{n_{\text{op}}} = \left[(2E_{\text{elec}})/((\tau - 1)e_{\text{amp}})\right]^{1/\tau} \quad (11)$$

However, it is no guarantee that there are real nodes at the optimal transmission distance of per hop in actual situation, so it is necessary to reasonably select the real node according to the optimal transmission distance to ensure the minimum energy consumption of entire network. The actual situation and theoretical situation are shown in Fig.3. h, h+1, h+2, h+3 represent the location of the real node, but there is no real node at the optimal transmission distance, so selection mechanism is needed to select real node near the optimal transmission distance.

**FIGURE 3.** Difference between the real nodes and the optimal transmission distance.

**IV. THE TWO-DIMENSIONAL NETWORK**

**A. THE DESCRIPTION OF RELAY NODE PLACEMENT MODEL**

The model of one-dimensional queue network and the concept of optimal transmission distance are described in the third part. The theoretically optimal transmission distance per hop in the one-dimensional queue network means that the minimum network energy consumption can be obtained according to optimal transmission distance. On this basis, the concept of optimal transmission distance is introduced into a two-dimensional network, and its relay node layout model is shown in Fig.4. Among them, the red dots denote the location of the gateway node, the blue points represent the location of the relay node under ideal conditions, and the black dots represent the location of the evenly distributed sensor nodes.

**FIGURE 4.** Basic relay node placement model.

**FIGURE 4(a).** Basic relay node placement model. The model will be discussed in detail as shown in Fig.5. h, h+1, h+2, h+3 represent the location of the real node, but there is no real node at the optimal transmission distance, so selection mechanism is needed to select real node near the optimal transmission distance. As shown in Fig.4(a), the black nodes represent sensor nodes, the blue nodes indicate relay nodes, and the red nodes represent gateway nodes. Therefore, from the overall distribution of nodes, the symmetrical relay node placement model can be approximated as an isosceles triangle, where the distance between each node is set to the optimal transmission distance. The energy consumption of the entire sensor network can be minimized under this placement model.

**FIGURE 4(b).** Asymmetric relay node layout model. Compared with the symmetric relay node layout model shown in Fig.4(a), the difference is that the position of the gateway node has changed. As the position of the gateway node changes, the angle between the sensor node and the gateway node also changes. And each hop between nodes transmits data with the optimal transmission distance, the coordinates of the relay nodes have changed, but the energy consumption of the entire network can also reach the minimum under this layout model. Next, the symmetric relay node layout model and the asymmetric relay node layout model will be discussed in detail as shown in Fig.5.

As shown in Fig.5(a), $A_1, A_2, \ldots, A_h, A_n$ represent the relay nodes. $A, B$ indicate the sensor nodes, and $C$ indicates the gateway node. Set the coordinates of $A$ and $B$ to $(x_A, y_A)(x_B, y_B)$ respectively, and set the coordinate of $C$ to $(x_C, y_C)$, where $x_c = 1/2(x_A+x_B), y_c = 1/2(y_A+y_B)$. Of course, this model is similar to the one-dimensional queue network because there is no real node at the optimal transmission distance. Therefore, how to effectively select the relay node is a key issue in studying energy consumption.

As shown in Fig.5(b), when the position of gateway node $C$ moves to $C'$, the angle from the sensor node $A$ to the gateway
node $C$ increases from $\theta$ to $\theta + \Delta \theta$, and the angle from the sensor node $B$ to the gateway node $C$ decreases from $\theta$ to $\theta - \Delta \theta$. Therefore, $A_1(x_1, y_1)$ will move to $A'_1(x'_1, y'_1)$, and its coordinates satisfy the relationship of expression (12) and (13). The situation is similar for sensor node $B$ to gateway node $C$. In this case, it is also necessary to effectively select the relay node to minimize energy consumption.

\[
\begin{align*}
\sqrt{x_1^2 + y_1^2} &= d_{op} \\
\sqrt{x'_1^2 + y'_1^2} &= d_{op} \\
x'_1 &= x_1 - \Delta x \\
y'_1 &= y_1 + \Delta y
\end{align*}
\]

In summary, how to carefully select the relay nodes is the key to study the energy consumption problem in the above two cases and considering the actual situation.

**B. THE SELECTION OF RELAY NODES**

According to the research on the above relay node layout model, the selection of relay nodes is divided into three parts as shown in Fig.6.

As shown in Fig.6(a), the theoretically optimal transmission scheme is $A_1 \rightarrow A_2 \rightarrow A_3$, where the distance from $A_1$ to $A_2$ and $A_2$ to $A_3$ is $d_{op}$. However, there may not exit the real node at $A_2$ in actual situation, the suitable relay node should be selected reasonably near $A_2$. First, the point closest to $A_2$ is selected. When there are multiple points with the same distance from $A_2$, the point with higher residual energy among the candidate nodes is selected.

As shown in Fig.6(b), the theoretically optimal transmission scheme is $A_5 \rightarrow A_6 \rightarrow A_7$ and $B_5 \rightarrow B_6 \rightarrow B_7$, where the distance from $A_5$ to $A_6$, from $A_6$ to $A_7$, from $B_5$ to $B_6$ and from $B_6$ to $B_7$ is $d_{op}$. It can be known from the energy consumption model that only the energy consumption when transmitting data is related to distance. Therefore, when there is a point $D$ that can make two paths pass at the same time, and the paths for selecting relay nodes are $A_5 \rightarrow D \rightarrow A_7$ and $B_5 \rightarrow D \rightarrow B_7$. This solution not only does ensure the minimum energy consumption in the data transmission process, but also reduces the number of nodes in the entire network.

As shown in Fig.6(c), the theoretically optimal transmission scheme is $A_8 \rightarrow A_9 \rightarrow A_{10}$ and $B_8 \rightarrow B_9 \rightarrow B_{10}$, where the distance from $A_9$ to $A_{10}$, from $A_{10}$ to $A_{10}$, from $B_9$ to $B_{10}$ and from $B_9$ to $B_{10}$ is $d_{op}$. When there is a point $E$ that can make two paths pass at the same time, the paths for selecting relay nodes are $A_8 \rightarrow E \rightarrow A_{10}$ and $B_8 \rightarrow E \rightarrow B_{10}$. However, the biggest difference is that the number of candidate relay nodes in the range will be relatively reduced compared with Fig. 6(b), because there is an overlapping area.

In Fig.6(b) and Fig.6(c), if there are such relay nodes in the node placement, the first choice is to use the common node for data transmission, and the energy consumption by the two paths is equal to the energy consumption of the two paths passing through the common node are guaranteed. The expression is shown in (14). When the energy of such nodes is exhausted, the nodes are also selected at the theoretically optimal transmission distance. When there are multiple relay nodes with the same distance, the relay nodes with more residual energy will be selected for data transmission.

\[
E_{A_5 \rightarrow 6 \rightarrow 7} + E_{B_5 \rightarrow 6 \rightarrow 7} \equiv E_{A_5 \rightarrow D \rightarrow 7} + E_{B_5 \rightarrow 6 \rightarrow 7} \\
E_{A_8 \rightarrow 9 \rightarrow 10} + E_{B_8 \rightarrow 9 \rightarrow 10} \equiv E_{A_8 \rightarrow E \rightarrow 10} + E_{B_8 \rightarrow E \rightarrow 10}
\]

(14)
C. THE CONSTRAINTS ON COMMUNICATION PATH

As shown in Fig.7, the relay node selection scheme described above may cause the return path in path of data transmission when selecting the relay node, it is necessary to add the constraint condition of the path direction.

There are four types of path directions in model as shown in Fig.7, from SN to GN, from SN to RN, from RN to RN, from RN to GN. The formula (15) can be known by the number product in the vector.

\[ \vec{A} \cdot \vec{B} = |A| |B| \cos \theta \]  

(15)

where \( A \) is the reference vector, \( B \) is the vector which needs to be judged, and \( \theta \) is the angle between the vectors \( A \) and \( B \). With the direction from \( SN \) to \( GN \) as the reference vector, \( \cos \theta \) can be judged as positive or negative. When \( \cos \theta \) is less than zero, it means that the path does not satisfy the data communication path starting from \( SN \) and finally reaching \( GN \) through one or more \( RN \). Taking Fig.7 as an example, \( \cos \theta \) in the first path is greater than zero, and \( \cos \theta \) exists in the second path from \( RN \) to \( GN \). Therefore, the second path in Fig.7 does not satisfy the constraint condition of the path.

\[ \cos \theta_1 = \frac{\vec{V}_7 \cdot \vec{V}_{ref}}{|\vec{V}_7| |\vec{V}_{ref}|} < 0 \]  

(16)

V. THE EXPERIMENTAL RESULTS AND SIMULATION ANALYSIS

A. SIMULATION PARAMETERS

In this paper, MATLAB simulation software is used to simulate the proposed relay node placement scheme, the simulation parameters are shown in Table 1. It can be known from formula (9) that when the parameters \( E_0 \), \( \epsilon \) and \( \tau \) are fixed, the value of the optimal transmission distance can be calculated. According to the parameter in Table 1, the optimal transmission distance is 31.6m. The interference between the signals generated between each node is ignored in this paper. To analyze the performance of the proposed relay node placement scheme based on the optimal transmission distance, this algorithm is compared with the minimum distance transmission algorithm and the greedy optimization algorithm.

TABLE 1. Simulation parameters.

| Parameter       | Parameter’s value | Parameter       | Parameter’s value |
|-----------------|-------------------|-----------------|-------------------|
| \( E_{elec} \)  | 50×10⁻⁶/J/bit     | Gateway Node    | 1                 |
| \( \tau_{opt} \) | 100×10⁻¹²/J/m³    | Deployment Area | 500m×500m         |
| \( \tau \)      | 2                 | Sending Rate    | 1 bit/s           |
| Sensor Nodes    | 2                 | Packet Size     | 1024 bit          |
| Relay Nodes     | 30 - 150          | Testing Time    | 900 seconds       |

B. THE SIMULATION RESULTS AND ANALYSIS

From the perspective of average residual energy and network life cycle in the paper, the relay node placement algorithm based on optimal transmission distance is proposed. Greedy optimization algorithm [17], the optimal transmission algorithm, and minimum distance transmission algorithm are compared, and the simulation results are shown in Fig.8 and Fig.9. Minimum distance transmission algorithm is based on calculating the distance between relay nodes to select the next hop relay node. The greedy optimization algorithm is to use the greedy algorithm to reasonably select the appropriate relay node to transmit data and combine the path constraints to achieve the purpose of minimizing energy.
consumption. But the difference between the above two algorithms and the relay node layout algorithm based on optimal transmission distance is that the latter extend the concept of the optimal transmission distance in the one-dimensional queue network to the two-dimensional network, so as to select the optimal relay nodes.

As shown in Fig. 8, the process in which the average residual energy changes continuously over time is described. According to the curve, it can know that the average residual energy decreases continuously with the increase of time, and the average residual energy among the three algorithms also varies differently. The average residual energy of minimum distance transmission algorithm decreases greatly with time. When the algorithm’s running time is more than 200 seconds, the energy consumption value of entire network tends to zero. Compared with greedy optimization algorithm, the proposed relay node layout scheme has slower average residual energy.

In summary, the proposed relay node placement scheme based on optimal transmission distance can minimize the average energy consumption.

As shown in Fig. 9, the process that the life cycle of the network changes with the number of relay nodes is described. According to the curve shown in the figure, as the number of relay nodes increases, the network life cycle of the three algorithms also increases. Because the increase of relay nodes will increase the selectivity of relay nodes, which will increase the network maintenance time. The network lifetime maintained by the minimum distance transmission algorithm is more than 200 seconds, and the proposed optimal distance transmission algorithm can be maintained for more than 800 seconds, which has increased about three times compared with the minimum distance transmission algorithm. In addition, compared with the greedy optimization algorithms, the proposed relay node placement scheme based on optimal transmission distance also has the higher network life cycle under different numbers of relay nodes, and is also related to the average residual energy involved in Fig. 8.

VI. CONCLUSION

Wireless sensor networks are widely application in various fields due to their low cost and low power consumption. However, most nodes are powered by batteries, the problem of energy consumption is one of the key issues in the research of wireless sensor networks, and the placement of relay nodes is also one of the methods to reduce the energy consumption.

In this paper, the two-dimensional topology based on the optimal transmission distance is proposed to improve the lifetime of network and reduce the energy consumption in process of transmitting data. Firstly, the situation of least transmission energy consumption is analyzed in one-dimensional queue network. Due to the poor connectivity of the one-dimensional queue network, the concept of optimal transmission distance is introduced into the two-dimensional network space. The network energy is reduced by selecting appropriate relay nodes at different stages, thereby extending the network lifetime. In the future research process, we will further analyze how to further reduce energy consumption and extend the life cycle of the sensor network when there is signal interference between various nodes [18].

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