

## Research Article

# Energy Balance Routing Protocol for Wireless Sensor Networks Based on Fuzzy Control Strategy

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The existing routing protocols for wireless sensor networks were not reasonable in design, which limited their application. Most of the existing studies did not take into account the energy consumption of the network and the balanced use of the energy of sensor nodes, which led to the unsatisfactory application effect of wireless sensor networks in some fields. Therefore, from the perspective of energy balance in wireless sensor networks, this paper proposed a construction method of an energy balance routing protocol in wireless sensor networks based on a fuzzy control strategy. Firstly, based on the analysis of the basic composition of wireless sensor networks and the structure of sensor nodes, this paper expounded the basic process of wireless data transmission and summarized the classification and characteristics of routing protocols in wireless sensor networks from different angles. Secondly, according to the node data transmission characteristics of wireless sensor networks, the energy balance use model of sensor nodes was established, and the design method of the energy balance routing protocol based on fuzzy control strategy was proposed, and the data transmission link was optimized. Finally, through experimental comparative analysis, the results showed that the energy balanced routing protocol proposed in this paper can effectively realize the energy balanced use of the network data transmission process. Compared with other common routing protocols, the wireless sensor network routing protocol proposed in this paper can not only improve the data transmission efficiency and reduce the data redundancy but also save energy consumption and prolong the network running time. The design method of routing protocol proposed in this paper will be conducive to the optimization and application of routing protocol in wireless sensor networks and provide a theoretical basis for the related research of wireless sensor networks.

## 1. Introduction

In recent years, Internet of Things technology has been widely used in related fields, among which the wireless sensor network (WSN) plays a vital role. As a new generation of sensor networks, wireless sensor networks provide important support for effective data acquisition, monitoring, and remote control. The wireless sensor network is a comprehensive application of distributed computing, sensors, computer network, communication, embedded, and other methods and technologies [1]. WSN adopts multiple sensor nodes and collects data from various monitoring objects through adaptive network, which provides a bridge for the dialogue between human and the physical world. With the rapid development of wireless communication and elec-

tronic technology, sensor nodes are connected to the Internet by wireless communication and can be effectively applied to environmental monitoring, industrial control, and other fields. Compared with traditional networks such as mobile communication, WSN has obvious differences in node distribution, reliability, and storage performance, which brings new challenges to the wide application of WSN in various fields. Relevant scholars at home and abroad have carried out a lot of research work on the design and application of WSN and achieved some results.

WSN mainly enables users to obtain the required information by collecting and transmitting monitoring data. The information transmission process of WSN depends on the communication link, and the link performance depends not only on the network topology but also on several sensor

nodes distributed on the link. For example, with the energy consumption of sensor nodes in the process of data transmission, some nodes affect the forwarding of data due to insufficient energy, which can not ensure the normal communication quality [2]. At the same time, if the energy distribution of the wireless sensor network is uneven or the energy consumption is unbalanced, the energy consumption of some nodes may be too large, which will affect the communication process of the whole network. According to the existing research, the uneven energy consumption of wireless sensor networks is mainly due to the distribution of sensor nodes or the design of the routing protocol. Due to the uneven energy consumption, the data transmission in the communication process is not smooth enough, and the workload of some nodes varies greatly, which may make the energy consumption of nodes unbalanced. In addition, because sensors are generally limited by energy, they are usually unable to supply energy by themselves. Therefore, nodes cannot ensure the monitoring and transmission of data information due to insufficient energy.

Because the nodes in wireless sensor networks are limited by energy and the number of sensor nodes is large, in order to ensure the normal transmission of data, how to balance the energy consumption of network nodes through reasonable energy-saving methods, so as to effectively prolong the running time of wireless sensor networks, which is also a common concern of relevant scholars at home and abroad [3]. Researchers at home and abroad have made some progress in the energy consumption design of wireless sensor networks, but there are still many problems to be solved in the balanced utilization of network energy, the design of wireless routing protocol and network operation efficiency. Therefore, starting from the energy balance of wireless sensor networks, this paper used a fuzzy control strategy to study the design of the routing protocol. Based on the relevant theories of wireless sensor networks, the network energy balance processing model was established, and the energy balance routing protocol optimization algorithm based on the fuzzy control strategy was proposed, which provided a theoretical reference for the energy consumption design and routing protocol research of wireless sensor networks.

## 2. Related Works

According to the existing research, the energy consumption of WSN sensor nodes in the working state mainly includes the energy consumed by their own circuit operation and the energy consumed in the communication process. The energy required for data communication increases with the increase of transmission distance. Therefore, the energy consumption for data transmission is the largest. At present, most wireless sensor networks use wireless transmission free space model to realize data communication, but the energy consumption is relatively large. In order to reduce the energy required for data transmission, some scholars propose to adopt multihop transmission path in the WSN plane routing protocol or cluster routing protocol to reduce the direct data transmission between cluster head and sink node in the net-

work [4]. Some people have studied how to optimize the selection of sensor nodes in wireless sensor networks and effectively communicate with sink nodes. On this basis, the establishment of routing protocol can reduce the energy consumption of sensor nodes affected by transmission distance to a certain extent.

In order to reduce the impact of transmission process on node energy consumption, some scholars optimize data communication links by constructing corresponding routing protocols. Some scholars adopt the multihop method to transmit the information collected by different nodes in WSN to the sink node, so that the nodes can send a large amount of data without consuming too much transmission energy [5]. At the same time, these nodes also play the role of data transmission as a part of routing. In addition, when designing the routing protocol of WSN, some scholars reduce the energy consumption of nodes by reducing the data forwarding tasks of some nodes, which can not only increase the survival time of sensor nodes in the network but also make the energy consumption of different nodes evenly distributed. WSN contains several sensor nodes. The data received by different nodes usually have a certain correlation. The information fusion method can be used to process the sensor node data before transmission, so as to reduce the redundant data in the process of network transmission, so as to reduce the workload of data transmission and save energy consumption to a certain extent.

Due to the different applications of wireless sensor networks, there are also some differences in the routing protocols or algorithms used. Therefore, some researchers start from the application requirements of wireless sensor networks and realize energy balance by designing or perfecting routing protocols. Some people combine ant colony algorithm with wireless mobile network and propose on-demand multipath routing algorithm. The data communication link mainly depends on the continuous movement of forward ants and backward ants [6]. Later, someone applied the gradient calculation method to the routing protocol, using the node energy and other information collected by the forward ant to update the communication link. When the intermediate node receives the information from the backward ant, it needs to update the path according to the gradient value in the information packet, so as to continuously optimize the data transmission path. Considering the network energy consumption in the process of data transmission, some researchers use the traditional energy-efficient ant-based routing (EEABR) algorithm to propose a routing optimization protocol for wireless sensor networks based on ant colony algorithm [7, 8]. The routing protocol stipulates that during network data transmission, any sensor node should send a link signal to the sink node and then select an optimal transmission path to complete the data transmission according to the information fed back to the ant.

In order to enable network nodes to make balanced use of energy, some scholars have proposed a low-energy adaptive clustering hierarchy (LEACH), which randomly selects the cluster head nodes in the network in a circular way and balances the energy load to the sensor nodes,

which can not only reduce the network energy consumption but also improve the running time of wireless sensor networks [9, 10]. At present, most researchers design routing protocols from the perspective of establishing multipath communication links, and most of them do not consider the energy consumption of wireless sensor networks and the energy efficiency of nodes. For example, although the traditional ant colony algorithm can find an optimal communication link, it will cause the data sent from different nodes to be transmitted through this path. Because the nodes of wireless sensor networks are not controlled, the path constructed by these methods will shorten the running time of sensor nodes. Therefore, the routing protocols constructed by these methods are usually difficult to apply to the application fields of wireless sensor networks with high energy consumption requirements. In addition, although some routing protocols consider the energy consumption on different paths, they lack the balance of the energy consumed by each node and different paths, resulting in the limited running time of the whole network.

### 3. Basic Theory and Routing Classification of Wireless Sensor Networks

*3.1. Wireless Sensor Network System Structure.* It is known from the existing research that although the definition of wireless sensor network (WSN) is not unified, the architecture and basic functions of WSN are similar. In terms of structure, it is mainly composed of one or several aggregation nodes, gateways, and sensor nodes, which generally include the functions of data perception and processing, data transmission, and information feedback. Generally, WSN is deployed around the node manually. Then, the nodes are organized into a wireless network in an adaptive way, and the information can be collected, analyzed, and processed at any time [11]. All nodes on the network transmit information to the sink node through routing, extract and process the node data, and then output it to the remote control center for processing through the transmission link. As shown in Figure 1, a wireless sensor network structure with one receiver node is described.

In wireless sensor networks, each node is usually distributed around the observation object. Each node routes the collected data to the gateway or sink node and finally to the user. The data contained in each node passes through the gateway and is output to the user in a multihop manner. The gateway can communicate with the management server and end users through wireless network or Internet.

WSN contains several sensor nodes, which are usually composed of sensor components, data processing center, wireless communication system, and power supply, as shown in Figure 2. Sensors are mainly used to realize object perception and information monitoring. The data processing center is used to allocate the work of each node and store and process the data from each node. It is the main component of the node [12]. A wireless communication system is mainly used to forward wireless signals and

ensure normal communication between nodes. The main power supply for each sensor node.

Different from the traditional computer network or wired network, the architecture of the wireless sensor network is mainly composed of several network layers and various network protocols, including each layered network communication protocol, network monitoring and management center, and network support system. Similar to the traditional Internet protocol architecture, the communication protocol structure of the wireless sensor network also includes different protocol layers such as the network layer, link layer, and application layer. The data stored in each source node of the sensor needs to be transmitted to the sink node through the network layer of WSN. Therefore, the network layer mainly provides routing for data transmission.

Generally, the data in the source node can be transmitted not only through the single hop wireless communication network but also through the multihop wireless communication network. Compared with the single-hop wireless communication, the distance of data transmission using multihop wireless communication is shorter. Therefore, it can not only reduce the energy consumption of sensor nodes but also reduce the intensity of signal propagation in the network. Generally speaking, wireless sensor network nodes are densely distributed and the distance between nodes is close. In order to effectively transmit data, the source node mainly uses multihop path to transmit data to the sink node.

In addition, the data transmitted from the monitoring object node to the sink node mainly adopts the many-to-one transmission mode. Since the data from different nodes enter the sink node, the use of multihop wireless communication will often increase the data transmission load of the intermediate node, which may lead to the data blocking and loss of each packet and the rapid consumption of node energy. Therefore, when designing the network layer routing protocol, we need to give priority to the energy use conditions of sensor nodes in order to ensure the stable transmission of data and efficient utilization of energy.

*3.2. Key Technologies of Wireless Sensor Networks.* Starting from the working characteristics and different application requirements of wireless sensor networks, due to the limited conditions of sensor nodes in energy consumption, data processing, and storage space, the design of network protocol can not be too complex. The scale of wireless sensor networks generally changes with the distribution of sensor nodes deployed by the monitoring object. When a large number of network nodes need to be deployed in a monitoring area, large-scale networking should be adopted. Considering that the sensor nodes may be randomly distributed in the monitoring object, the wireless sensor network can be networked in an adaptive way, and the network configuration and management can be completed automatically. Due to different application backgrounds, wireless sensor networks usually have different functional and performance requirements. The software, hardware, and network protocol of sensor network

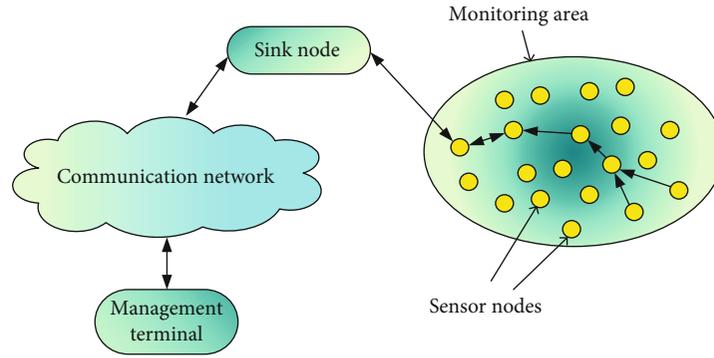


FIGURE 1: Schematic diagram of basic model of wireless sensor networks.

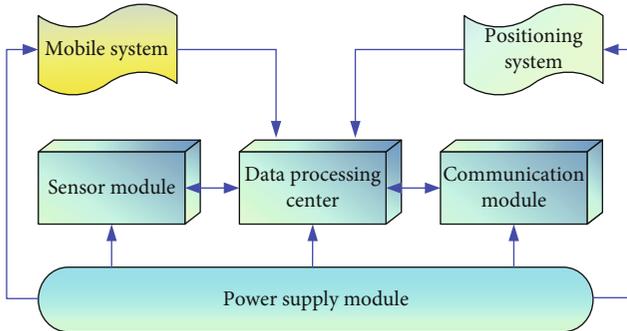


FIGURE 2: Schematic diagram of sensor node structure.

nodes should be designed according to the application requirements.

Due to the frequent data transmission between different network nodes, in order to ensure that the data transmission and reception of wireless sensor network can be completed normally, it is necessary to determine the wireless data transmission and reception model. From the practical application, the nodes of wireless sensor networks can generally carry out all-round communication [13]. As shown in Figure 3, it is advisable to represent the communication area of the node as a two-dimensional plane and set the communication frequency of all sensor nodes to be the same. At this time, there may be interference in the wireless communication channel, and only one node can be allowed to complete the transmission or reception of data at any time.

When the distance between node  $P$  and node  $Q$  is less than or equal to  $r$ , node  $Q$  can receive transmission data from node  $P$ . If node  $Q$  is receiving the data sent by  $P$  and node  $T$  overlaps with  $Q$  in the communication area, node  $T$  is not allowed to send the data to node  $Q$ . Otherwise, node  $Q$  will fail the data transmission due to the communication channel conflict. In order to meet the needs of practical applications, generally, when the communication areas overlap, any sensor node can only receive or send data at the same time. Meanwhile, any sensor node is only allowed to receive the data of one node at the same time.

The bandwidth of wireless sensor networks can be expressed as the number of bits transmitted per unit time, or as the time required to send a data packet. If the time is

divided into several time slots of equal size, the data transmission scheduling of network nodes can serialize the time slots. It can be seen from Figure 3 that node  $T$  is within the communication area of node  $P$ . When node  $P$  is sending data to node  $Q$  in a certain time slot, node  $T$  is not allowed to send data before node  $P$  sends data due to the interference of communication channel. At the same time, since the distance from node  $S$  to node  $Q$  is  $R$ , which is greater than  $r$  and there is no transmission communication overlap, node  $S$  can perform the data transmission task at this time.

### 3.3. Routing Classification in Wireless Sensor Networks.

Because the routing protocols of wireless sensor networks are related to the network environment and application background, the routing protocols can be classified according to the different network configuration and application requirements. From the aspects of network topology, transmission path, and routing composition, the routing protocols of wireless sensor networks are divided into plane routing and cluster routing. The nodes included in plane routing are the same in structure and function, and the routing protocol is relatively simple, which is suitable for small-scale network construction [14]. Different from plane routing, cluster routing is generally used for large-scale networking. As shown in Figure 4, it is the basic structure diagram of clustering network routing. In the cluster routing mode, the status of each network node is no longer equal, and the network is divided into several relatively concentrated clusters. In each cluster, one node is responsible for the communication control within the cluster. This node belongs to the central node, also known as the cluster head node. The data of all nodes in the cluster is sent to the cluster head, and then, the cluster head transmits the data to the sink node by multihop or single-hop communication.

From the perspective of transmission path, routing protocols can be divided into single-path routing and multipath routing. Although single-path routing consumes less resources, it is easy to lose data. Multipath routing can better adapt to data packet transmission and has good reliability, but it has high energy consumption and is more suitable for applications with high reliability requirements. Multipath routing is mainly to establish multiple transmission paths between data transmitting nodes and receiving nodes

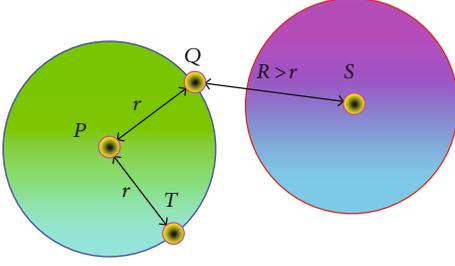


FIGURE 3: Schematic diagram of wireless data transmission model.

to realize data communication, which not only avoids the poor communication caused by the failure of public nodes but also enhances the fault tolerance and independence of wireless sensor networks.

In order to avoid the loss of data on the transmission path, some spare paths can be added to the constructed main path, so as to provide reliable path guarantee for data transmission [15]. As shown in Figure 5, the path between the data transmitting node and the sink node is the main path for realizing data transmission, and each local path distributed along the main path is the standby path for preventing data transmission failure.

In addition, routing protocols can be divided into active routing and on-demand routing according to different routing methods. Active routing needs to transmit data according to the established path, which has fast response ability, but the energy consumption is large. On-demand routing is to temporarily construct the transmission path when data is sent. Although the energy consumption is small, the corresponding capacity is poor.

Because the routing of wireless sensor networks is related to specific applications, routing protocols can also be classified according to different communication modes, state maintenance, delivery methods, and so on [16]. As shown in Figure 6, it describes the classification of routing protocols according to different strategies, in which the same routing protocol may be divided into different types according to the nature of classification.

#### 4. Design of Energy Balanced Routing Protocol for Wireless Sensor Networks Based on Fuzzy Control

**4.1. Energy Balance of Wireless Sensor Networks.** According to the distribution and application characteristics of wireless sensor networks, the network coverage can be equivalent to a circular area with  $R$  as the radius. It is assumed that  $N$  sensor nodes are evenly distributed in the network area and the sink node is located in the center. Each sensor node in the network has a unique ID, and the distribution position of each node remains unchanged. Except that the energy of the sink node is not limited, the energy of other ordinary nodes is limited.

According to the existing node data transmission energy consumption model [8, 9], the energy consumed by sensor nodes when sending data can be expressed by the following

model:

$$F_{\text{send}}(s, k) = \begin{cases} sM_e + s\lambda_1 k^2, & k < k_0, \\ sM_e + s\lambda_2 k^4, & k \geq k_0, \end{cases} \quad (1)$$

where  $s$  is the data size,  $M_e$  shows the power consumption value of the data transceiver circuit,  $k$  denotes the data transmission distance, and  $k_0$  represents the dividing point between the free transmission model and the multipath transmission model. When  $k < k_0$ , the free transmission model is adopted, and the power consumption coefficient of the data transceiver circuit is  $\lambda_1$ ; when  $k \geq k_0$ , the multipath transmission model is adopted, and the power consumption coefficient of the data transceiver circuit is  $\lambda_2$ .

The energy consumed by sensor nodes when receiving data can be represented by the following model:

$$F_{\text{receive}}(s, k) = sM_e. \quad (2)$$

The energy consumed by sensor nodes in data fusion processing can be expressed by the following model:

$$F_{\text{datafusion}} = sF_{df}, \quad (3)$$

where  $F_{df}$  represents the energy consumed by fusing unit bit data.

The fixed energy consumption of sensor nodes can be expressed by the following model:

$$F_{\text{nodeID}} = M_e. \quad (4)$$

Most nodes in wireless sensor networks adopt adaptive multihop communication when transmitting data. Limited by the energy resources of sensor nodes, energy control is very important to ensure the normal operation of wireless sensor networks. The key to effective control of energy is how to make balanced use of energy among nodes [12]. Energy consumption is usually related to the communication link. Therefore, a path with the lowest energy consumption of data transmission can be found between the data transmitting node and the receiving node, so as to complete more data transmission tasks under the same energy consumption conditions, and improve energy efficiency.

According to the existing research on energy control of wireless sensor networks, the topology of wireless sensor networks can be optimized by adjusting the energy of sensor nodes in the network layer. In the data link layer, the data transmission power and data reception power of each node can be determined according to the size of data packets and the distance between adjacent nodes. At the same time, the energy consumption of nodes can be controlled and optimized, which can not only prolong the running time of wireless sensor network but also improve the data processing capacity of the network.

The energy control method mainly adopts relevant algorithms and reduces the energy consumption of nodes under the condition of ensuring the normal transmission

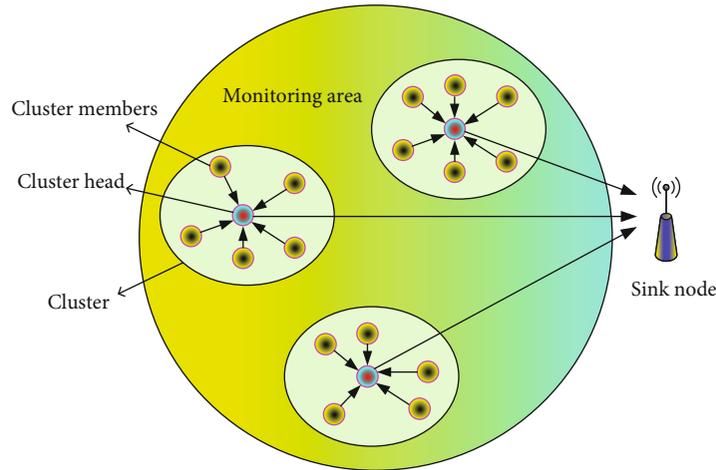


FIGURE 4: Basic structure diagram of clustering network.

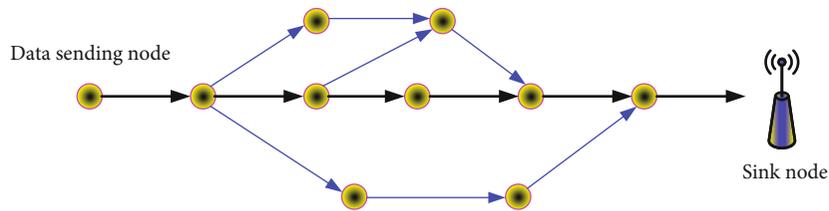


FIGURE 5: Schematic diagram of data transmission process based on multipath routing.

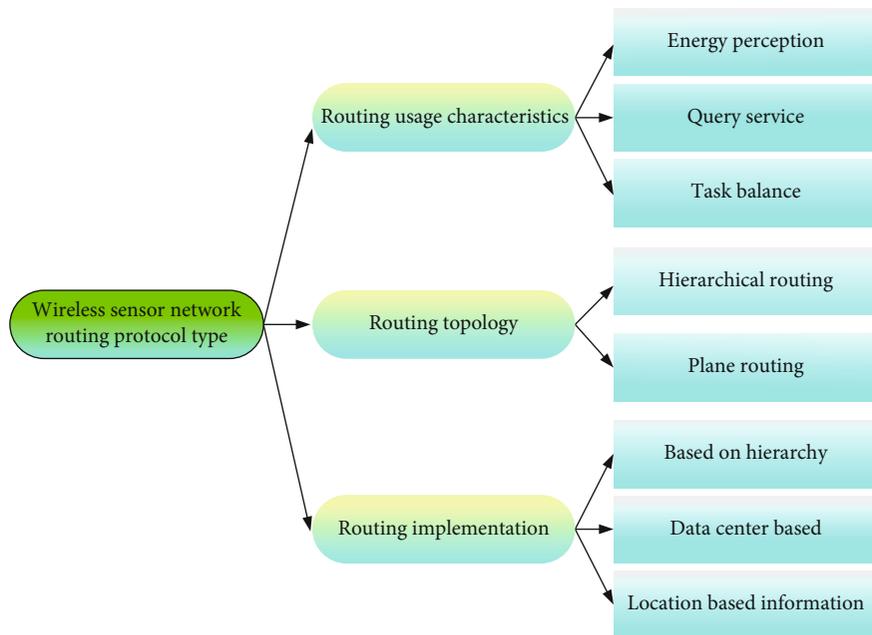


FIGURE 6: Common types of routing protocols for wireless sensor networks.

of data and then increases the running time of the network through the energy balance consumption of wireless sensor network. The method based on node energy consumption reduction does not consider the energy balance consumption of the whole network, resulting in data transmission being too concentrated on the path with the lowest energy consumption. However, when the node on

the path has a large task of data processing and transmission, the data transmission link may be blocked or interrupted due to the excessive energy consumption of the node.

In recent years, some scholars have proposed to use the energy on-demand routing method based on load balancing in wireless sensor networks. The algorithm

optimizes the data transmission route according to the energy and load status of sensor nodes and gives priority to providing transmission links for nodes with small workload and more energy. Through the routing control, the data transmission process will not be concentrated on a communication link, so that the energy of network nodes can be balanced and the overall operation performance of the network can be effectively improved. However, because the data transmission of different nodes in the network may have a certain delay, this method is generally not suitable for the situation with high real-time requirements.

At present, most of the energy balancing methods choose different routing transmission modes according to the information of adjacent nodes in the network. Although it can realize the balanced utilization of local energy, the communication path from the data sending node to the sink node may not be the best. Therefore, the energy balanced routing of wireless sensor networks can be realized by taking into account the energy balanced utilization of adjacent nodes and the optimal path selection [17]. When the node needs to send data, the node energy balance processing method can be used to make a data transmission request to the network system, and select the node with higher energy to send data. When the node energy consumption may cause the communication link to fail to work normally, you can select the standby node and adjust its transmission energy and then use the formed weak ring network topology to ensure the normal communication of data, as shown in Figure 7. This method can not only balance the energy consumption of the whole network but also increase the operation cycle and reliability of the whole network.

**4.2. Fuzzy Control Strategy Based on Energy Balance.** As a nonlinear control method, fuzzy control does not need to provide the actual model of the observation object but transforms human knowledge or experience into certain control rules, which are expressed in computer language and realize the control of the target by imitating human thinking. Fuzzy control is mainly based on knowledge expression and fuzzy reasoning and uses certain fuzzy logic rules to implement specific decisions [18, 19]. Common fuzzy control systems generally include data input and output modules, fuzzy control center, execution unit and measurement mechanism. The fuzzy control center is the main component of the control system, as shown in Figure 8.

The fuzzy control center is mainly composed of fuzzy module, data rule base, fuzzy reasoning module, and fuzzy decision module. Firstly, we collect the relevant information of the monitoring object, compare it with the system reference value, and input the difference between the monitoring value and the reference value into the fuzzy module as the fuzzy quantity. Secondly, the fuzzy control center uses the data rule base to reason and make decisions on the fuzzy input, and generates the corresponding fuzzy output. Finally, a value that can accurately reflect the result of fuzzy reasoning is selected from the fuzzy output, and it is used as the parameter of driving the actuator to

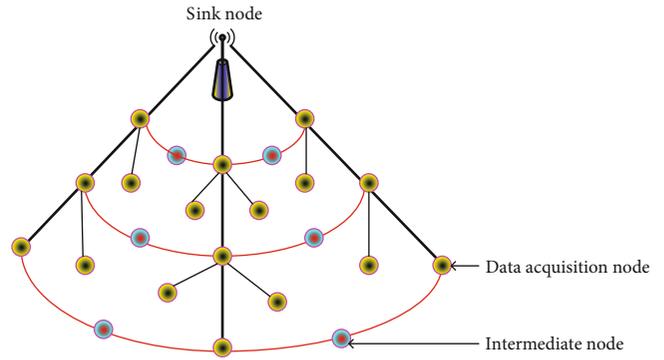


FIGURE 7: Topology diagram of ring wireless sensor networks.

realize the fuzzy control of the controlled object through the actuator.

From the perspective of fuzzy control strategy, the routing process of wireless sensor networks can be abstracted as a problem of continuous optimization of several parameters, and a multiparameter energy balance model can be established. According to the routing mechanism based on energy balance, the remaining energy and current load of network nodes can be used as the standard to measure the performance of sensor nodes.

In addition, during the process of data transmission in wireless sensor networks, it is necessary to select a node as the cluster head and forward the data to the sink node through it. Due to the randomness of choosing cluster heads in the traditional rotation mode, the cluster heads may not be evenly distributed in the communication area, so it is easy to form hot spots or holes in wireless sensor networks [20, 21]. In order to avoid the randomness of cluster head selection in wireless sensor networks, this paper uses fuzzy control strategy to select all cluster heads used for communication in wireless sensor networks. As shown in Figure 9, the working process of selecting cluster heads using fuzzy control center is described. We select any node in the wireless sensor network and take its position information and residual energy as the input value of the fuzzy control center. After the fuzzy processing of the data and relevant fuzzy reasoning, the probability of the node as the cluster head can be obtained.

**4.3. Design of Energy Balanced Routing Protocol for Wireless Sensor Networks Based on Fuzzy Control.** In order to maintain the energy balance of each node of wireless sensor network, according to the different structural characteristics and application requirements of WSN, the routing protocol of WSN usually needs to meet the following conditions: high energy utilization efficiency, balanced use of energy consumption, high reliability of data transmission, low delay of data transmission, minimizing redundant information, and improving the security of the system. How to solve the energy limitation of nodes is the prerequisite for designing WSN routing protocol. Therefore, we should try to reduce the complexity of routing algorithm and optimize the network energy utilization efficiency by improving the data transmission efficiency.

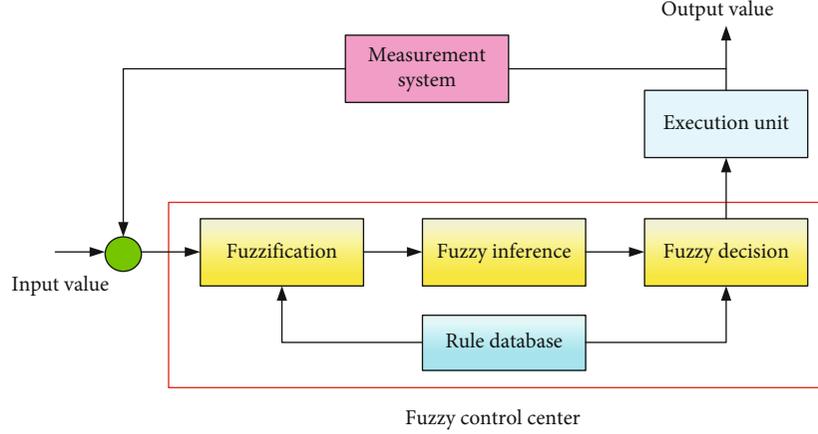


FIGURE 8: Basic structure diagram of fuzzy control system.

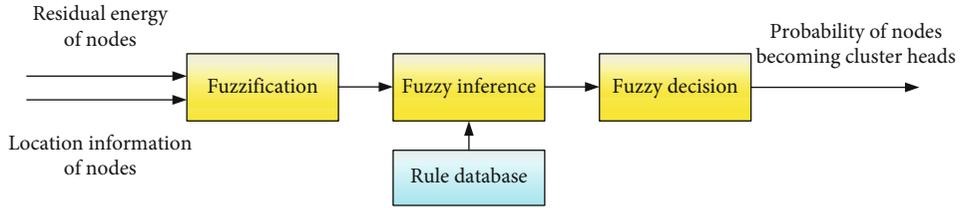


FIGURE 9: Basic structure diagram of fuzzy control center.

In order to prevent the excessive workload of network nodes from affecting the network performance, when designing the routing protocol, we should not only consider the principle of balanced utilization of energy consumption but also consider the problem of network operation efficiency. The routing optimization algorithm based on energy balance needs to reasonably allocate data transmission tasks according to the data processing capacity of sensor nodes, so as to prevent some nodes from affecting data communication due to energy consumption exhaustion, so as to effectively prolong the operation cycle of WSN.

In order to avoid the data transmission error or loss caused by the communication path failure of WSN, the designed routing protocol should increase the adaptive processing ability and fault-tolerant mechanism, so as to ensure that WSN can adopt the corresponding automatic processing method according to the changes of network environment in the communication process, so as to make the data transmission not only have certain adaptability but also improve the reliability of network operation.

In order to use WSN nodes to monitor and process relevant information in time, and then feedback the data processing results to users in time, the time limit in the process of data transmission should be fully considered in the design of routing protocol, and the delay should be minimized. In addition, in order to improve the efficiency of data transmission, the redundancy of data should be minimized when designing the routing protocol, which can not only reduce the error rate of data transmission but also reduce the energy consumption of the network. In order to meet the application requirements of WSN in different

fields, the designed routing protocol should also ensure certain security.

This paper adopts the routing optimization algorithm based on energy balance mechanism and uses the broadcast routing request module to select the appropriate sensor node to send data through the routing request. Using the routing reply module, a suitable communication link is selected through the link selection function to transmit data. Using the routing maintenance module, when the data transmission link fails, it depends on the intermediate node to establish a new network communication topology, and the data can continue to be transmitted forward through the new communication link, which also ensures the data transmission reliability of the wireless sensor network. As shown in Figure 10, the flow chart of routing optimization algorithm based on energy balance mechanism is described.

After selecting the data transmission node through energy balance, due to the limited energy of the sensor node, the remaining energy, hops, and load of each node on the communication link can be taken as the main parameters for selecting the data transmission path, and then, a network performance function can be determined as the basis for selecting the route [9].

If the number of hops from the data transmitting node to the receiving node is  $n$ , the remaining energy of node  $i$  on the data transmission link is  $F_i$  and the workload is  $U_i$ ; the performance  $Y_i$  of the node can be expressed as follows:

$$Y_i = \frac{F_i}{U_i}. \quad (5)$$

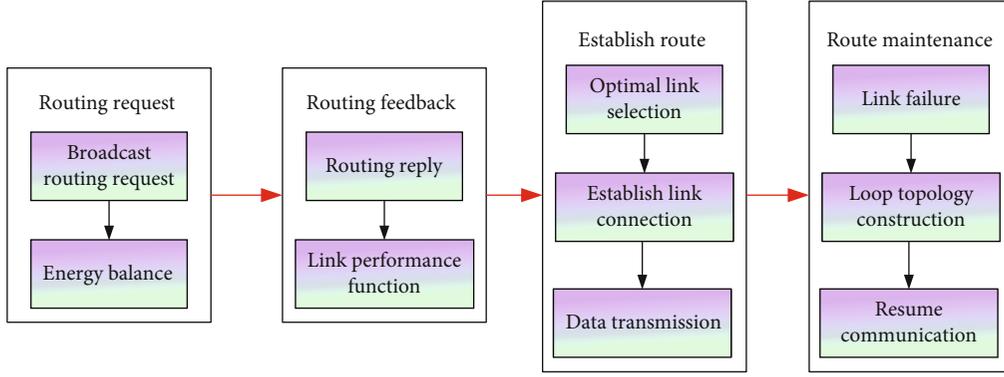


FIGURE 10: Flow chart of routing algorithm based on energy balance.

The calculation of residual energy variance can be expressed as

$$\sigma = \sqrt{\frac{1}{m} \sum_{i=1}^m (F_i - \bar{F}_i)^2}. \quad (6)$$

The performance of the data transmission link can be expressed as

$$H(Y) = \frac{\sum_{i=20}^n F_i / F_{MAX}}{n \times \sigma}, \quad (7)$$

where  $F_{MAX}$  is the maximum value of node performance on the data transmission link. The network performance of the node is directly proportional to the residual energy  $F_i$  and inversely proportional to the workload  $U_i$  of the node.

Simultaneous interpreting data from different transmission links is performed by data receiving nodes, and the best transmission link is selected on the basis of comparing different link performance. Data transmission nodes transmit the transmission link as routing data.

## 5. Experiment and Analysis

When verifying the performance of the energy balance routing protocol for wireless sensor networks based on fuzzy control strategy, this paper compares it with the common EEABR protocol and LEACH protocol. In order to facilitate the analysis of the results, the number of paths using multipath routing in the experiment is 3. In the routing protocol proposed in this paper, the cluster head of wireless sensor network divides the data packets to be sent into 6 subpackets, in which each packet has the same size. Then, all data packets are recoded to generate four coded packets and sent to the transmission chain in turn, regardless of the energy consumption during coding. During the experiment, it is necessary to record the running time of the network, that is, all the data from the first round until the first node in the network cannot work, and analyze the data transmission success rate, data redundancy, energy consumption, and running time of the network. In order to observe the performance of the

wireless sensor network in normal working state, the experiment mainly extracts relevant information from various data generated during network operation for processing and analysis.

During the experiment, the success rate of data transmitted by each data transmitting node in each round is calculated, and the average value is taken as the data success rate of the whole network. When the same network parameters are adopted, the change of network transmission data success rate with bit error rate after running different routing protocols in turn, as shown in Figure 11.

According to the change results of each group's data success rate with bit error rate under different routing protocols, the data success rate gradually decreases with the increase of bit error rate. When the bit error rate is small, compared with other methods, the data success rate of the routing protocol proposed in this paper decreases the slowest, which shows that the routing protocol in this paper has good reliability and is not easy to be affected by the bit error rate. It can still transmit data effectively even in the case of poor channel conditions.

In order to observe the influence of different routing protocols on data redundancy in wireless sensor networks, the data redundancy of sensor nodes in each round of data transmission is counted until there are stopped nodes in the network. Then, the data redundancy obtained during each round of network operation is averaged and taken as the data redundancy of the whole network. As shown in Figure 12, it reflects the result that the data redundancy obtained by using different routing protocols varies with the bit error rate under the same conditions.

According to the experimental comparison results in Figure 12, although the data redundancy increases with the increase of bit error rate under different routing protocols, the data redundancy generated by using the routing protocol proposed in this paper is the lowest, and the increase is small with the increase of bit error rate, which has obvious advantages. It can be seen that the routing protocol proposed in this paper increases the fuzzy control process, but it is significantly higher than the other two protocols in the effectiveness of data transmission.

In order to explore the impact of different routing protocols on the energy consumption in wireless sensor networks, the energy consumption of sensor nodes in each

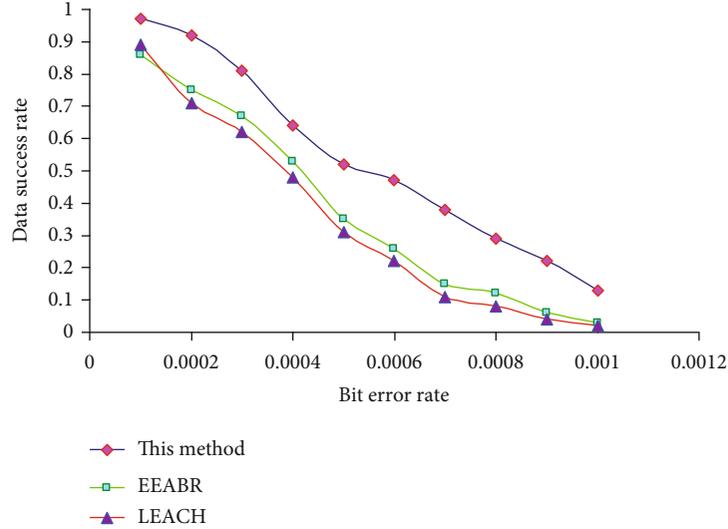


FIGURE 11: Variation of transmission data success rate with bit error rate under different routing protocols.

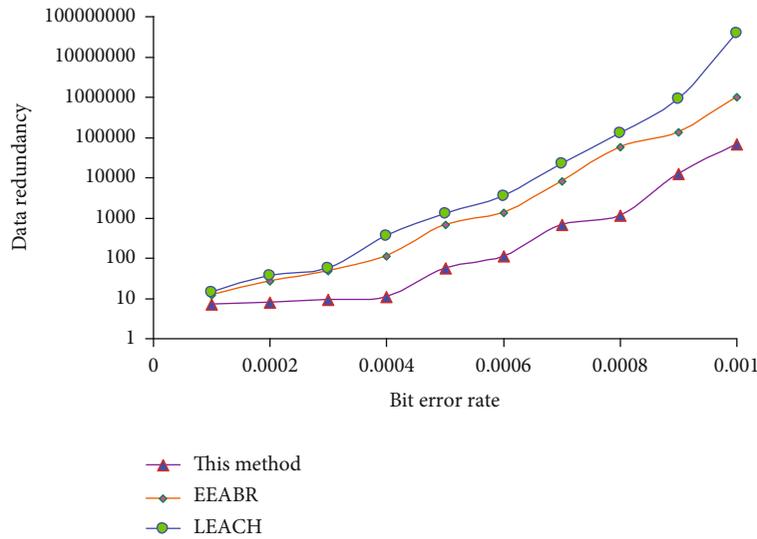


FIGURE 12: Variation of data redundancy with bit error rate under different routing protocols.

round of data transmission is counted until a node in the network stops running. Then, the energy consumption of each round during the operation of the network is averaged as the energy consumption of the whole network. As shown in Figure 13, according to the experimental results obtained by using different routing protocols under the same conditions, the energy consumption varies with the bit error rate.

According to the experimental comparison results reflected in Figure 13, with the increase of bit error rate, the energy consumption of different routing protocols increases to a certain extent, but the energy consumption generated by using the routing protocol proposed in this paper is the lowest, which has significant advantages. Although the routing protocol proposed in this paper increases some energy consumption due to the use of fuzzy control strategy, because the data transmission success rate

and effectiveness are better than other protocols, the corresponding energy consumption is lower, indicating that the energy efficiency is higher.

In order to test the impact of the routing protocol proposed in this paper on the network running time, data statistics are made on the relationship between the number of effective nodes and the number of running rounds under different routing protocols, as shown in Figure 14.

From the comparison results, compared with other methods, using the routing protocol proposed in this paper can ensure that more surviving nodes can complete the data transmission task during the operation of the network. At the same time, it also shows that although the routing protocol proposed in this paper is better in energy efficiency, the increased fuzzy control processing needs to consume more energy, which pays a certain price for improving the effectiveness of data transmission and network reliability.

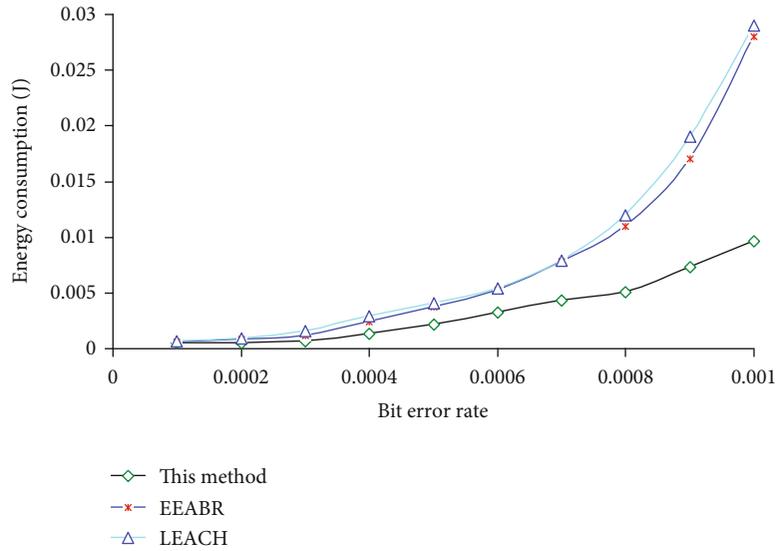


FIGURE 13: Variation of energy consumption with bit error rate under different routing protocols.

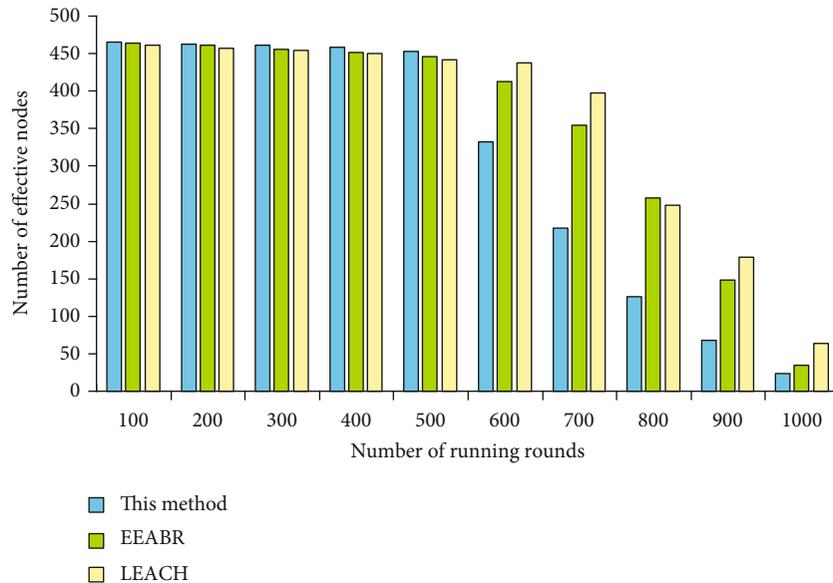


FIGURE 14: Variation of number of effective nodes with the number of running rounds under different routing protocols.

## 6. Conclusion

Wireless sensor networks had some limitations in routing protocol design, which led to large energy consumption of sensor nodes and short network running time. Therefore, based on the analysis of the working principle of wireless sensor networks, this paper summarized the wireless data transmission model and its characteristics and expounded the key technologies and application characteristics of wireless sensor networks. By establishing the energy balance model of sensor nodes, the construction method of energy balance routing protocol based on fuzzy control strategy was proposed, and the data transmission path was optimized based on the energy balance theory. Through experimental verification and comparative analysis, the results showed that the energy balanced routing algorithm proposed in this paper

can realize the balanced utilization of energy in the process of network operation. Compared with other routing protocols, the wireless sensor network routing protocol proposed in this paper had significant advantages in data transmission efficiency, data redundancy, energy consumption, and network running time. The method proposed in this paper can not only provide theoretical reference for the in-depth study of routing protocols and applications of wireless sensor networks but also provide technical support for promoting the application of wireless sensor networks in related fields.

## Data Availability

The labeled data set used to support the findings of this study is available from the corresponding author upon request.

## Conflicts of Interest

The authors declare that there are no conflicts of interest.

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