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An Efficient and Reliable Directed Diffusion Routing Protocol in Wireless Body Area Networks

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ABSTRACT Wireless body area networks (WBANs) are composed of several tiny sensor devices which are embedded on or implanted in the human body. They are designed to continuously transmit sensed physiological data and act as key infrastructures for remote healthcare monitoring and treatment. Considering the limited power supply, varying link connectivity, and complicated channel environment, the design of routing protocol in WBANs is challenging. The existing algorithms cannot fully satisfy the application requirements. Focusing on lower energy consumption, a directional diffusion routing protocol for WBANs is proposed in this paper. The concept of the gradient is introduced to indicate the direction and the rate of data transmission and the minimum hop count in directed diffusion is used as the criterion for establishing the gradient. Each node is required to maintain the gradient information of its neighbor nodes with the shortest path. Simultaneously, the residual energy is also considered to further improve the performance. The simulation results show that the proposed protocol has significantly lower packet loss rate and power consumption in both static and mobile scenarios. The reliability of the data transmission is improved and the networks life is extended effectively.

INDEX TERMS Directed diffusion, data centric, energy efficiency, gradient, reliability, wireless body area network.

I. INTRODUCTION

With the advancements in technologies such as sensor technologies, micro-electro-mechanical systems (MEMS), wireless communications, and computers, there has been motivation for rapid development of wireless communication technologies and low-power multi-function sensors. The development of these technologies has made the equipment compact and low-powered, providing a basis for the development of wireless body area networks (WBANs) [1]. WBANs are composed of wearable biosensor units or devices implanted in a human body, which places special emphasis on the size of such devices and low energy wireless communication between them. These sensor nodes are capable of collecting physiological signals of interest, such as electrocardiogram (ECG) data, blood pressure, blood sugar, body temperature, human motion or activity signals, and external environmental information of the human body, and are also capable of basic processing and transmission of the acquired data [2]–[4].

WBANs are the main application carrier of the human body, and are mainly applied to three types of market applications: health care services, human interaction applications, and assistance for the disabled. One of the most important uses of WBANs is in medical applications. A wireless sensing device is worn on the human body to collect and process medical vital signs data. Then, the data is uploaded to a data aggregation gateway, and is finally transmitted to a medical data monitoring center [5], [6].

Research on WBANs is still in the early stages. The design of a WBAN must consider the impacts of energy saving and data transmission reliability [5]. This is a huge problem and challenge for WBANs. International research institutes and organizations began studying WBANs very early,

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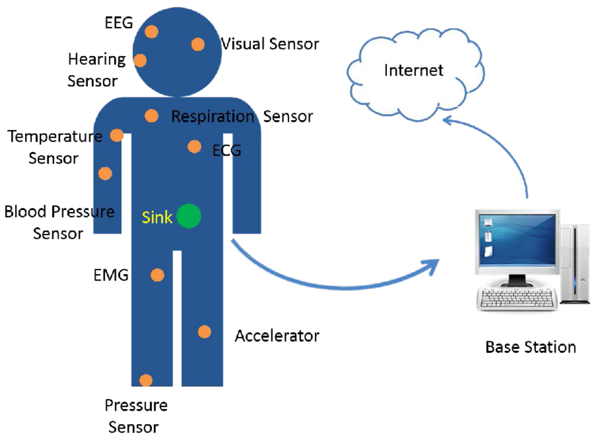

FIGURE 1. Wireless body area networks.

mainly to unify the use standards of WBANs. The main task of the established IEEE802.15 [6], [7] working group is to complete the standardization of the physical and media access control (MAC) layers of a wireless personal area network (WPAN). IEEE 502.15 TG6 [8] has released WBAN channel models in a variety of scenarios. These standards only support the WBAN standard in specific scenarios, and lack standards for more general, common applications. Research on WBANs focuses on data fusion, signal acquisition, content awareness, data security and privacy, and wireless network communication system technology [9]. Among them, wireless network communication research mainly concerns network architectures, low-power MAC [10] design and protocol design, reliable data transmission, and so on. The research on the physical layer mainly focuses on the optimization of the wireless channel model and minimizing the path loss. The research on the data link layer mainly focuses on determining an efficient multiple access protocol that satisfies the of low energy requirements of WBANs nodes and extends the network lifetime as much as possible. The research on the network layer mainly concerns finding a topology suitable for the WBAN. When the human body moves in a random fashion, it inevitably leads to random changes in the topology structure. Therefore, achieving a high reliability of data transmission is a major objective of the network layer [11].

In the past few years, there has been an inordinate amount of research on the routing protocols of wireless sensor networks (WSNs). The consideration of the maximum throughput and minimum routing overhead is often greater than the consideration of the minimum power consumption [12]. Even for low-power, self-organizing WSN network protocols, the path-finding is based on minimizing the consumption of node energy, and it often ignores other important parameters, such as the number of operations and the transmission and reception of valid bytes on the wireless link. Moreover, a WSN is also acceptable with the loss or reduction of some sensors. In WBANs, the number of devices worn on the patient should be minimized, considering the comfort of the patient. Most WSN protocols only consider networks composed of homogeneous sensors. In WBANs, this isomorphic assumption is evidently invalid, owing to the existence of the various biosensors and their different data transmission rates. In many cases of WSNs, the network is considered static, and conversely, there are various heterogeneous and mobile devices in WBANs. To guarantee the usefulness of the sensor, the communication of the controller also requires strict real-time constraints [13]. In a WSN, the accuracy of the moving distance is usually measured in meters or tens of meters, whereas a movement of several centimeters in WBANs needs to be carefully considered. In short, although many of the challenges faced by WBANs are very similar to those of WSNs, there are deep internal differences between the two that require special research [14].

II. RELATED WORK

Presently, the existing routing algorithms for WBANs can be roughly classified into three types: temperature-based, cluster-based, and cross-layer routing algorithms. When the wireless signal is transmitted around the body tissue or in the body, a certain amount of heat is generated, owing to the absorption of radiation by the human body tissue. When the signal transmission power reaches a first level and heat dissipation cannot be performed in time, heat will accumulate. An increase in the temperature of a part of the human body can seriously affect the comfort of the wearer, and even seriously affect the health of the wearer. Minimization of tissue heating is achieved by limiting signal transmission power and certain flow control algorithms. In the literature [15], Hongliang *et al.* proposed a biological effect model of biosensors on a human body in both near-field communication and far-field communication. The paper also proposes a cost-based rate allocation algorithm, further proving that the biological effects of wireless signal transmission can be controlled by power scheduling and flow control algorithms. Algorithms such as the thermal-aware routing algorithm (TARA) [16] and adaptive least temperature routing (ALTR) [17], are based on balancing communication between sensors. In TARA, a temperature rise caused by centralized data transmission is called a hotspot, and the purpose of the algorithm is to avoid selecting these paths for data transmission. However, TARA only uses the temperature in the network as a measure for algorithm design. The performance of the network and the packet loss rate generated by this algorithm cannot meet the communication requirements of WBANs. A temperature-based routing algorithm can be regarded as a weighted routing algorithm for a certain variable. From the perspective of usage, the design of the algorithm is reasonable, but it is difficult to ensure the reliability and efficiency of energy utilization.

A node cluster-based routing algorithm selects a cluster head from a large number of data nodes. The cluster head aggregates the node information in the cluster, and forwards it to the central node [18]. This routing algorithm can effectively solve a conflict problem in the network, and has a wide range of applications in the routing problems of a WSN. However, for WBANs, the number of nodes is small, and the types of data are different. The selected cluster heads are difficult to arrange evenly, resulting in uneven energy consumption by nodes in the network and possibly even the premature death of some nodes, leading to a failure of the entire network. ''Anybody'' is a clustering routing algorithm based on a low energy adaptive clustering hierarchy (LEACH) [19], [20]. The core of the algorithm is selecting an appropriate node from the nodes as a cluster head at intervals, to spread the loss in the network. LEACH assumes that all nodes are within the communication range of the central node. Anybody improves this by reducing the choice of cluster heads and selecting cluster heads from the nodes that make up the backbone. However, the author's main consideration is to determine the number of cluster heads based on the size of the network. The energy utilization and reliability of the network are not high. Another important issue is that in the simulation process, the typical application scenario is a sensor network with a large number of nodes. For WBANs with a small number of nodes, this may not be applicable.

Cross-layer protocols are usually combined from more than two layers, as a special protocol for a certain network. This method has received great attention in WSNs. Some people have applied this method to WBANs, to improve the network living space and communication performance [21]. Antonio *et al.* proposed a cross-layer energy saving strategy [22]. The strategy is based on the 802.15.4 standard. The time zone of different network atmospheres is transmitted in turn in each time zone, and the node farthest from the central node transmits data first. The wireless autonomous spanning tree protocol (WASP) [23] proposed by Bart *et al.* sets a spanning tree and time slots on a time axis. The assignment of internships is done in a distributed way, with each node sending its own WASP policy to its child nodes to inform them when they are allowed to send information. This strategy can achieve a good packet transfer rate, but its energy utilization is very low. With the introduction of the IEEE 802.15.6 standard, corresponding standards have been proposed for the physical and MAC layers of WBANs. It is extremely difficult to improve the WBANs according to the existing cross-layer protocol. It is also difficult to obtain a trade-off between reliability and energy efficiency.

Therefore, in this study, we improve a directional diffusion routing protocol for WBANs, and establish a gradient with a minimum hop count and the remaining energy of the node, so that it can meet the requirements of the WBANs in terms of reliability and energy consumption. The rest of this article is organized as follows. In the next section, we introduce the routing mechanism of the directed diffusion protocol, including interest broadcast, gradient establishment, detection data transmission, and path enhancement. The fourth section proposes a method for improving energy consumption in the directed diffusion protocol. The fifth section describes establishing the analog network, and analyzes and compares a simulated structure to illustrate the performance advantages of the improved protocol. Finally, we summarize the contents of the full text.

III. DIRECTED DIFFUSION PROTOCOL

Directed diffusion [24] is a query-based routing mechanism and a typical data-centric routing mechanism. An aggregation node defines different interest messages of different task types and target areas according to different application requirements, and it establishes routes by broadcasting the interest messages to the network. The intermediate node forms a gradient from the data source point to the sink node by accepting, forwarding, and establishing an interest table. Then, it automatically generates multiple paths from the data source to the sink node. According to the criteria of selection optimization, the aggregation node selects an optimal path from among the multiple paths by a path enhancement mechanism to form a data transmission path. Finally, the data source node transmits data to the sink node through this path [24], [25].

A. NAMING MECHANISM

The nodes in WBANs do not have a globally unique number identifier. Each sensor node only knows the neighboring nodes, and does not know all of the sensor node information as a whole. Therefore, to ensure that the data generated by the source node can be transmitted to the task of the monitor and to manage nodes, there is a need to associate interests and collected data in a reasonable way. The directed diffusion protocol is a data-centric routing protocol. All task data is named by a naming mechanism. This naming scheme is a simple list of pairs of attributes and values, so that the interest messages can be matched [24], [26]. For example, a tracking task for human body temperature may be described as given in Table 1.

TABLE 1. Description of interest.

Parameters	Values
Type	temperature
Interval	50ms
Duration	20s
Rect	[-100;100;200;400]

TABLE 2. Data description.

Parameters	Values
Type	temperature
Interval	truck
Location	[127;200]
Intensity	0.7
Intensity	0.80
Timestamp	00 : 12 :25

The description of a task is called an interest, and a similar naming scheme is used for the response to the interest. Thus, for example, a sensor to detect a wheeled vehicle may produce the data as given in Table 2.

In WBANs, to accomplish a task, the first step for a directed diffusion protocol is to design a naming scheme that selects a simple attribute-valued data-based interest and name. In general, each attribute has an associated range of values.

B. INTEREST AND GRADIENT

Interest is used to indicate the task of the query, and indicates that the network user is interested in data in the monitoring area, such as the temperature, blood pressure, or heart rate, or other information of the human body [27]. A query task propagates as an interest through the WBANs and broadcasts interest messages through the aggregation node. In a directed diffusion protocol, the gradient is an important concept. A gradient is the direction established on each node that receives an interest. The gradient direction is established to facilitate receiving interest from neighbor nodes. The data packets on a node can be forwarded through different neighbor nodes of the node. Therefore, each neighbor node corresponds to a path selection, and each path has a different path. The path attributes, such as delay, minimum node energy, and minimum hop count [28], are the data structures that characterize and store the values of these attributes. Simply put, a gradient is a path selection in which a node in a network sends data to a neighboring node.

C. DIRECTIONAL DIFFUSION PROTOCOL ROUTING MECHANISM

1) INTEREST PROPAGATION

First, a task is built into an interest through the naming mechanism. For each task, the aggregation node periodically broadcasts interest messages to neighbor nodes in the network. In the initial stage of the network, because of the stage of exploration, the purpose of interest spreading in the network is only to try to detect whether there is an event source [24], [29]. Therefore, the matching interval of the matching events included in the interest is relatively long, so that there is excessive traffic. Usually, the interest message contains parameters such as task type, target area, data transmission rate, and time. Each node stores a list of interests locally. For each interest, there is an entry in the list that records task-related information, such as neighbor nodes, data transmission rates, and the timestamp of the interest message for establishing the node convergence [30]. The node passes the gradient relationship of the data. Each entry also has a field to indicate the valid time value of the entry. After this time, the node deletes the entry. Each interest may correspond to multiple neighbor nodes, and each neighbor node only corresponds to one gradient information. Secondly, when a node receives an interest message, the node queries the local interest list to determine whether there is an entry with the same parameter type and the received interest message. If so, it determines whether the neighbor node exists, and if it does, it updates the timestamp parameter. If it does not exist, the sending node is added to the neighbor node of the entry. If there is no same parameter type, then a new entry is created to record the new interest message. If the interest message is accepted and forwarded, the message is discarded.

2) GRADIENT ESTABLISHMENT

During the propagation of the interest message, the protocol establishes a reverse data transmission gradient from the data source node to the sink node on each sensor node, hop-by-hop. The gradient field establishment phase is actually performed simultaneously with the query diffusion phase. When a node receives query information from a neighboring point, if there is no identical query record in the current query cache, a new record is added, and it includes the specified point of the neighboring point [24], [32]. The path attribute is also the time stamp of the gradient. When an interest is transmitted throughout the network, the gradient from the source node to the receiving node or base station is established. Once the source node collects data of interest to the receiving node, it transmits through this gradient route.

3) SEND PROBE DATA

When the sensor node collects data matching the interest, it sends the data to the neighbor node on the gradient. As the gradient has been established according to the attribute of a certain path in the flooding interest message stage, the node follows the gradient. The data transfer rate sets the rate at which the wireless sensor module collects data. As the interest message may be received from multiple neighbor nodes, the node sends data to the multiple neighbor nodes, and the sink node may receive the same data as it passes through multiple paths [31]. During the probe data forwarding phase, after receiving the probe data forwarded by other nodes, the intermediate node first queries the entries of the interest list. If there is no matching interest table entry, the data is discarded. If there is a corresponding interest item, the data buffer pool corresponding to the interest is checked, and the data buffer pool is used to store the recently-forwarded data. If there is a copy matching the received data in the data buffer pool, the data is discarded; otherwise, the corresponding neighbor node information is checked, and the probe data is forwarded [33].

4) REINFORCE PATH

From the stage of transmitting the probe data, we know that there may be many paths for the probe data sent from the data source node and received by the sink node. Thus, the method for selecting a path for data transmission from the inside is through the directed diffusion protocol. The path enhances the mechanism to select the optimized path. The enhanced gradient is called a data gradient. However, the data gradient is different from the detection gradient established by the interest propagation phase [24]. The path enhancement mechanism can be based on various options for choosing the optimal path. There are many standards for path enhancement: choosing the node that sends the most data in a certain

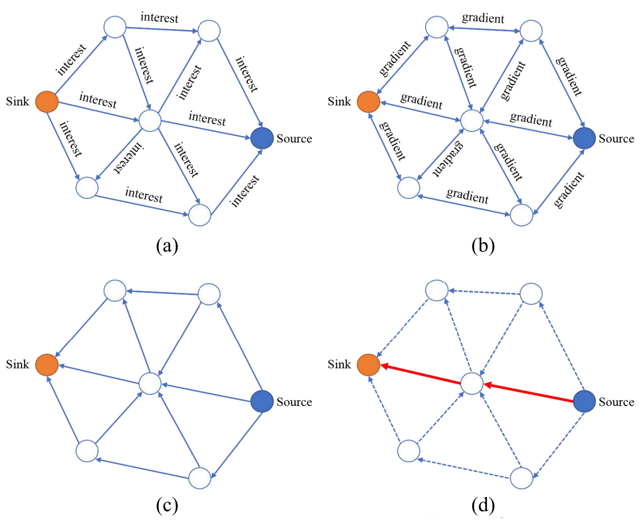

FIGURE 2. Simplified schematic for directed diffusion. (a) Interest propagation. (b) Gradient establishment. (c) send probe data. (d) Reinforce path.

period of time as the next hop node for path enhancement; choosing the node with the most stable data transmission as the next hop node for path enhancement; or choosing based on the transmission delay. As the path-enhanced next hop node, the minimum hop count to the data source node may be selected as the path-reinforced next hop node, or the node with the largest remaining energy value may be selected as the path-reinforced next hop node. Here, we assume that the next hop node is selected based on the largest remaining energy value of the node [28], [29]. Then, the sink node sends a query message with a larger "gradient" to the neighbor node with the largest remaining energy value, and receives the "information". The adjacent node of the enhanced selection also strengthens the neighbor node whose maximum residual energy value is selected, and diffuses query information with a larger "gradient" value, so that a path with the largest "gradient" value is finally formed. The data source node can transmit data along the enhanced path at a higher data transmission rate, and other paths with smaller remaining energy values can be used as an alternative paths to enhance network reliability. However, there may be multiple paths generated by this enhanced mechanism, and data transmission for multiple paths consumes energy [34].

IV. IMPROVEMENTS IN DIRECTED DIFFUSION PROTOCOL (ENDD)

As mentioned above, because the energy used by a sensor node is from a battery, balancing the energy consumption between nodes and maximizing the lifetime of the network are also important issues in routing protocol research. The research on the energy consumption between the nodes of the balanced sensor network will help to improve the overall effectiveness and availability of the system and will improve the average working time of the whole WBAN. This is in line with an important objective of the design of a sensor network routing protocol, i.e., to reasonably and efficiently use the energy of each sensor node in the network to prolong the survival time of the network.

Defining a set of nodes N and G in the wireless sensor network to form a directed graph $G = (N, R)$. For any one node $n \in N$, k_n is a set of neighbor nodes of n nodes, $|k_n|$ is the total number of neighbor nodes of n nodes, $|N|$ is the total number of nodes in the network, and the average number of nodes is as follows.

$$k = \frac{1}{|N|}\sum_{n\in N}|k_n| \tag{1}$$

Defining C_s as the energy consumption of the information sent by the node, and C_r is the energy consumption of the information received by the node, and assuming that the total number of data source nodes and sink nodes are respectively, the energy consumption for forwarding the probe data is as follows.

$$f_s = C_s\sum_{i\in k}|k_i| \tag{2}$$

Then the energy used to receive the probe data is

$$f_r = C_r\sum_{i\in N}|k_i| \tag{3}$$

Therefore, in the stage of transmitting the probe data, the total energy consumption of transmitting the probe data and the average consumption of the nodes are expressed as follows.

$$f = C_s\sum_{i\in k}|k_i| + C_r\sum_{i\in N}|k_i| \tag{4}$$

$$\bar{f} = \frac{C_s\sum\limits_{i\in k}|k_i| + C_r\sum\limits_{i\in N}|k_i|}{N} \tag{5}$$

Assuming the nodes are evenly distributed, and $C_s = C_r$, then $k_n = k$,

$$\bar{f} = \frac{C_s\sum\limits_{i\in k}|k_i| + C_r\sum\limits_{i\in N}|k_i|}{N} = 2C_sk \tag{6}$$

From the above analysis, it can be concluded that the average energy consumption of the node during the probe data forwarding process is proportional to the number of neighbor nodes k. Therefore, if the minimum hop field can be established during the phase of transmitting the probe data, then the data follows the minimum hop count. Thus, sending in this manner can reduce the average energy consumption of the node. In the process of gradient establishment, the minimum hop count from the sensor node to the sink node is used as the criterion for establishing the gradient. The minimum hop field *goodhop* and the remaining energy field are added to the packet header of the directed diffusion protocol (the remaining energy field is used for the subsequent transmission of the probe data phase). Each node in the network stores two arrays of *Low_neighbor* and *High_neighbor*. *Low_neighbor* is used to record the set of neighbor nodes of the next hop, and *High_neighbor* is used to record the set of neighbors of the hop, on the hop.

A. DETERMINATION OF THE MINIMUM NUMBER OF HOPS

Step 1: After each node in the network is deployed, the minimum hop count of the sink node is set to 0, and the minimum hop count of other nodes is set to infinity. Step 2: After each node is initialized, the sink node starts broadcasting interest messages to the network, and a node receiving the interest message compares its own minimum hop count with the minimum hop count transmitted in the received interest message, to save the neighbor node message. For example, when a node B receives an interest packet sent by a node A, it compares its minimum hop count with the minimum hop count transmitted in the received interest message.

1) If the minimum number of hops in the interest message packet sent by A, plus 1, is less than the minimum hop count of B, then *Low_neighbor* and *High_neighbor* of B are cleared. The minimum hop count is incremented by 1 in the interest message packet as its own minimum hop count, and A is added to its own *Low_neighbor*. The remaining energy value of A is recorded, and then the process turns to step (2). If A sends the interest message packet, the minimum hop count plus 1 is equal to the minimum hop count of B. A will add its own *Low_neighbor*, record the remaining energy value, and then will turn to step (2). If the minimum hop count in the interest message packet sent by A minus 1 is equal to the minimum hop count of B, A is directly added to *High_neighbor*, and the packet is discarded; if the minimum hop count in the interest message packet sent by A is less than 1 and the minimum hop count of B, A is directly added to *High_neighbor*, and the packet is discarded.
2) The node B forwards the interest message to the neighbor node. The minimum hop value in the interest packet is the new minimum hop value, and the remaining energy value is the remaining energy value of B.

In this way, the detection data transmission gradient of the plurality of minimum paths is established according to the minimum hop count, the remaining energy value of the next hop is saved, and the enhancement gradient is prepared for transmitting the probe data. In the interest message broadcast phase, the minimum hop gradient is established according to the minimum hop count, so that the probe data does not need to be sent to all according to the reverse process of the interest message. Rather, the minimum hop path is used for transmission, thereby reducing the energy. The process of establishing the minimum hop count is shown in Figure3.

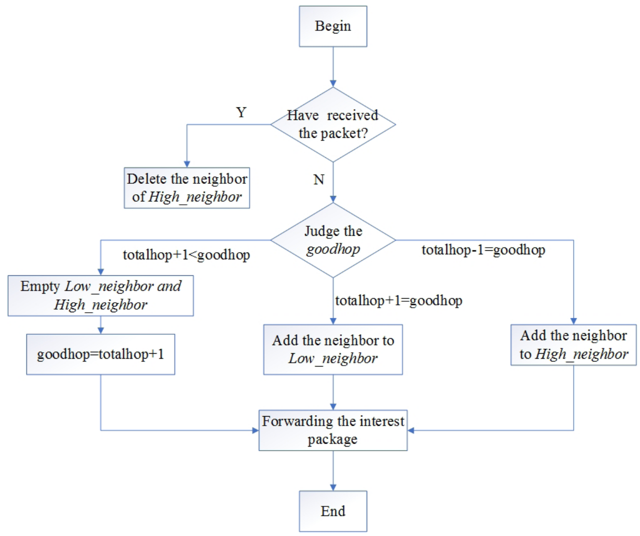

FIGURE 3. Establishing the minimum hop count.

B. SEND PROBE DATA AND ENHANCE PATH BASED ON REMAINING ENERGY

Node density is one of the important features of wireless sensor networks. Therefore, in the stage of sending data probe packets, each node needs to forward data packets to multiple neighbor nodes. As the number of data source nodes increases, the nodes continue to forward data packets. As the number increases, the amount of consumed energy increases. When a node is not energetic, it causes packet loss and retransmission, which consume additional energy. The direct diffusion (DD) protocol does not consider the remaining energy information of the node. Therefore, as the network runtime increases, the total number of packet loss of the network increases, and the consumed energy value increases. If the residual energy problem is considered in the stage of establishing the probe data gradient, the node that selects the remaining energy to transmit the data establishes the probe gradient before the node forwards the data packet, according to the energy value required to forward the data packet and the previous hop node. The remaining energy value determines whether to forward the data packet to the node, thereby reducing the packet loss more effectively, and reducing the energy consumption of the network [36].

For example, assume that the energy consumption for sending one byte is 1 mJ. When the data source node detects a message of interest, it first sends the probe data, and pre-calculates the energy value to be transmitted according to the data size. Assuming that the data source node needs to send 60 bytes of data, the transmission energy of each node must be 60 mJ, so the path selection for sending the probe data should also consider the remaining energy value of the node on the minimum hop path. The detection data is transmitted when the residual energy value is greater than 60 mJ, so that the packet loss owing to insufficient energy can be reduced for the subsequent data transmission process.

The entire process of sending probe data is as follows. If a node wants to send a probe data, it first searches in *Low_neighbor* for the neighbor node whose residual energy value is larger than 60 mJ. After the neighbor node receives the probe message, if the probe data message has not been received, the remaining energy value of the sending node is added to *High_neighbor*, and the probe data is forwarded. If this probe data message has been received, the remaining energy value of the sending node is added in *High_neighbor*, and the data packet is discarded.

After receiving the probe data, the sink node selects an optimal path enhancement. In this study, the enhanced path is selected according to the node with the largest remaining energy value. In this way, it is possible to avoid concentrating too much on one path of data transmission, resulting in excessive consumption of node energy on the path, and in a decrease in the overall network lifetime. After receiving the probe data packet, the sink node compares the remaining energy of the node with *High_neighbor* after a set threshold time, and selects a node with large residual energy to strengthen. After the node receives the enhanced information, it establishes a reinforcement gradient, which is also compared with *High_neighbor*. The remaining energy of the node is selected by the node with the largest remaining energy to strengthen, and the process is repeated until the data source node is reached.

The process of sending probe data according to the remaining energy of nodes is shown in Figure4.

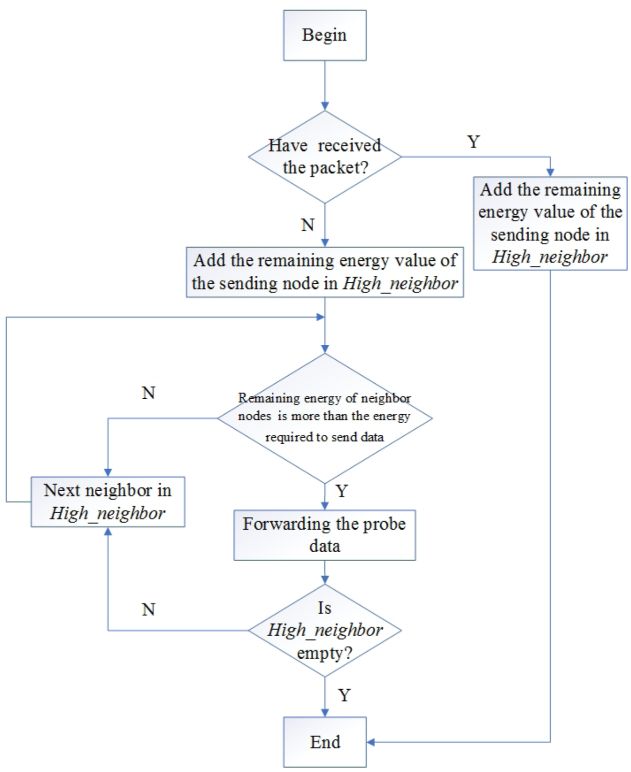

FIGURE 4. Sending probe data.

In the stage of establishing a gradient of the broadcast interest packet, because the gradient is established according to the minimum hop count, it may occur that the established gradient cannot satisfy the data transmission request of the data source node, and that one or more nodes in the path searching for *Low_neighbor* cannot find the remaining energy. A node that satisfies the energy required to transmit the data should be identified to these nodes to keep these nodes inactive, and a message should be sent to the sink node to inform it to broadcast another interest message and establish a new gradient. As the nodes that cannot satisfy the condition are in the inactive state at this time, they directly discard the interest packet after receiving the resent interest message. For other nodes, the gradient will be established again according to the broadcast mode of interest.

When the number of nodes is large and the network is relatively large, there may be many data source nodes in the network. Therefore, there may be duplicate nodes on the enhanced path of each pair of data source nodes and sink nodes. Thus, at one moment, a path is established according to the remaining energy and data transmission is performed according to the path. However, if one or more of the nodes participate in the transmission of other data at the next moment, energy is consumed. Thus, after the node forwards a data packet, it should update itself with the remaining energy value, and send a message to the neighboring node of the previous hop to inform of the updated remaining energy value. If the remaining energy value is lower than the minimum threshold at this time, then the node can be considered to be exhausted, and the node should be placed in an energy-depleted state (in which the node does not participate in any work). After receiving the message, the neighbor node finds the node in *Low_neighbor*, and updates the remaining energy value of the node. If the remaining energy value of the node is not enough to send data, then the next node with sufficient remaining energy is sent in *Low_neighbor* to transmit the data, the path is strengthened, and the original path is no longer strengthened.

V. SIMULATION AND RESULT ANALYSIS

Network simulator (NS)-2 is a free software simulation platform for source code of network technology. It can be easily developed by researchers using network technology. Nowadays, it contains modules that are very robust. It covers all aspects of network technology. Therefore, NS has become a type of network simulation software widely used in academia. In the published academic papers on network technology, the most widely-used articles give simulation results, and the research results obtained by this method are also generally accepted by the academic community. The simulation done in this study also uses NS-2 [35].

NS-2 was developed by the defense advanced research projects agency (DARPA)-supported virtual internet testbed (VINT) project, and by UC Berkeley. It is an event-driven and object-oriented network simulation tool that has a virtual clock. All simulations are driven by discrete events.

A. SCENE AND PARAMETER CONFIGURATION

In this study, two simulation environments are configured: node stationary and node moving. A total of 15 sensor nodes,

TABLE 3. Simulation parameters.

Parameters	Values
No. of Nodes	15
Terrain Area	2m× 2m
Queue	Queue/DropTail/PriQueue
PHY and MAC models	IEEE 802.15.4
Antenna	Antenna/OmniAntenna
initenergy	2J
txPower	0.066J
rxPower	0.0395J
idlePower	0.0035J
transmission distance	1m
Listening distance	1.5m

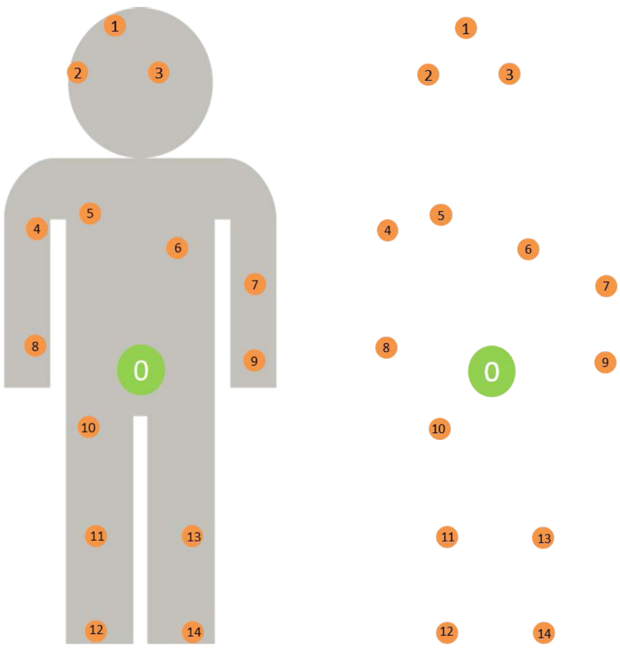

FIGURE 5. Nodes distribution.

with one being a sink node, are placed on the human body. The specific parameters are shown in the Table 3.

B. SIMULATION RESULT PERFORMANCE COMPARISON

Through the above simulation parameters, the directional diffusion protocol and the improved directional diffusion protocol (ENDD) are simulated in the static and mobile environments of the node, respectively. The flood protocol is used as a reference, and the simulation data is made into a line graph by MATLAB. The performance of the two protocols is analyzed and compared using the end-to-end total delay, packet loss rate, energy consumption, and number of surviving nodes.

As shown in Figure6, i.e. the simulation results of the node at rest, we can see that ENDD has improved in terms of packet loss rate, power consumption, and network lifetime. In (d), it can be seen that the DD protocol begins to die at 370 seconds, and at 470 seconds, the network completely fails. The ENDD does not show a dead node until 490 seconds, and the network fails at 530 seconds. In (a), the flood protocol has

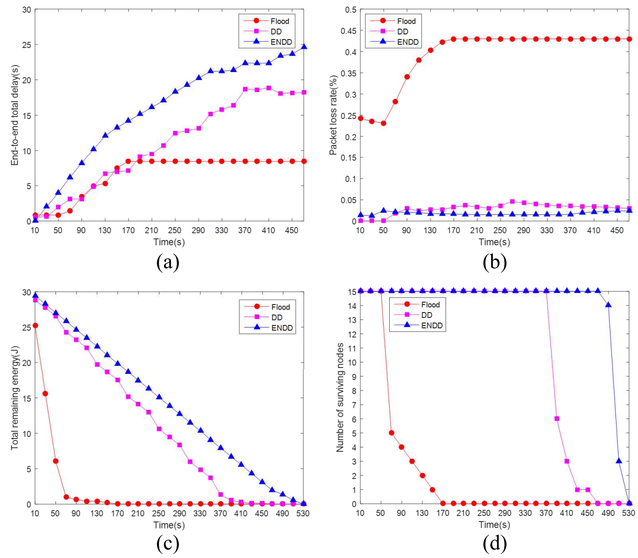

FIGURE 6. Nodes fixed scene. (a) End-to-end total delay. (b) Packet loss rate. (c) Total remaining energy. (d) Number of surviving nodes.

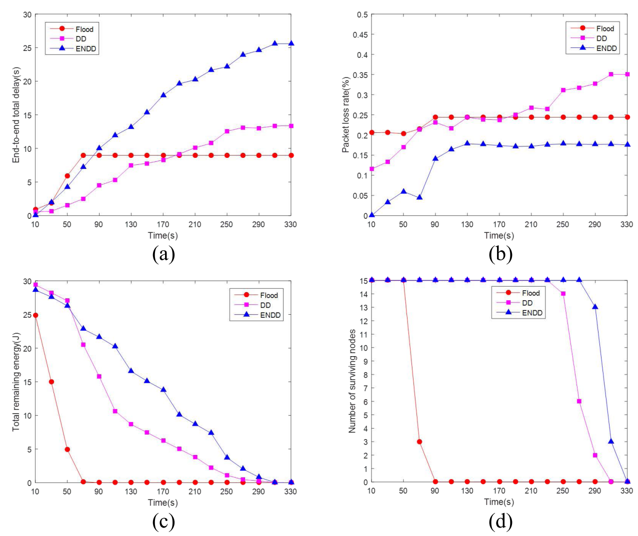

FIGURE 7. Nodes moving scene. (a) End-to-end total delay. (b) Packet loss rate. (c) Total remaining energy. (d) Number of surviving nodes.

the lowest latency. This is because the flood protocol uses the broadcast to send packets without complex routing discovery algorithms and topology maintenance. The delay does not change at 170 seconds, owing to excessive energy dissipation. The ENDD delay is higher, because the improved DD uses a method to establish a gradient based on the minimum hop count and residual energy. This increases the complexity of the routing mechanism, and adds some additional control overhead.

As shown in Figure7, because of the movement of nodes, the packet loss rate and energy consumption of the network are increased, and the survival time is shortened. However, as compared with the DD protocol, ENDD still has a good improvement in terms of packet loss rate, power consumption, and network lifetime.

VI. CONCLUSIONS

With the continuous development and advancement of wireless sensor technology, it is not surprising that wireless sensors have been applied to medical service systems. Nevertheless, there are still many technical problems to be solved. WBAN systems are still being produced and used on a large scale. The biggest problem is the limited energy problem, followed by the reliability of data transmission. These two problems become the bottleneck of a mature wireless network technology. The improved protocol is based on the original protocol algorithm. The improved protocol, although adding some additional control overhead, establishes a gradient by finding the minimum hop count, and strengthens the optimal path according to the change of the remaining energy value of the node. This improves the original protocol by strengthening the path and excessively using the optimal path, causing premature exhaustion of energy in some nodes. The improved protocol has an evident energy saving effect and the packet loss is significantly reduced, thereby prolonging the working time of the node and improving the survival time of the entire network. Although some real-time performance is sacrificed, there is still certainly research value for applications in WBANs where the delay is not high.

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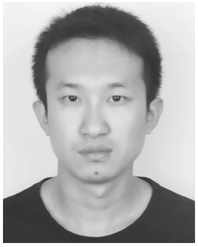

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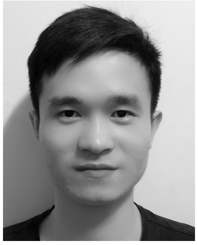

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