Researching, building the routing algorithm in Zigbee networks

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ABSTRACT

Zigbee wireless network built on IEEE 802.15.4 standard is becoming one of the most popular wireless networks in modern IoT devices. One of the disadvantages of Zigbee networks is the short transmission distance between devices. This paper focuses on researching and comparing routing algorithms in Zigbee networks, thereby building the optimal routing algorithm in the existing system. The paper's objective is to form the basis for making Zigbee tree and mesh networks, which improves the transmission distance for Zigbee networks better than the star network.

Keywords: Zigbee Routing; Zigbee Technology; Zigbee.

1. INTRODUCTION

A routing protocol is a process of choosing the right path for data to go from a source to a destination. This process encounters some difficulties in route selection, which depends on the network type, channel characteristics, and performance indexes [1].

ZigBee's routing mechanism is designed at the network layer. Data packets are encapsulated at the DLL (Data Link Layer) and through the physical layer to be forwarded to the RD (Routing Device). The RD will unpack the data packet at its data link layer, check the information for the subsequent transmission for its transmission destination, and repackage the data packet for transport. The end device (ED) will first have to unpack the data packet at its data link layer. After that, the data packet continues to be opened at the network layer and transferred to a higher layer.

Frames are routed by ZC (ZigBee Coordinator) and ZR (Zigbee Router) through the PAN (Private Area Net). Zigbee End Equipment (ZED) does not participate in packet forwarding. These devices have a Many-to-one relationship in the Zigbee network, which is shown in Figure 1.

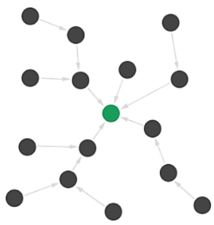


Figure 1. *Many-to-one in Zigbee networks [2].*

Source Routing is an appropriate concept for static networks because it provides routing information through previously defined network configuration records. Using this routing concept shortens the time to route through the network successfully.

For dynamic networks that need to provide the ability to change in the network topology, a ZigBee device may leave the range of the ZR associated with it and may link to the network via another ZR.

In many use cases, there will exist a node (a node - a device in the network) in the PAN network, which collects the data of all other devices. This node is called a central or aggregation device. Without any optimization, all devices in the network need to initiate an RREQ to get routing information towards the primary device. Therefore, the ZigBee specification has defined an optimal routing model for such cases called many-to-one routing. The central device initiates the routing packet, which is to be broadcasted in the network. Each network router will create a corresponding entry table on the packet routing route to the central device.

2. RELATED WORK

2.1. The Ad-hoc On-Demand Distance Vector Routing Algorithm – AODV

AODV routing is a pure route acquisition algorithm. It can be understood as follows, the nodes in the network that are not on the communication route do not maintain any information about the way and do not participate in the cyclic routing process [3].

The primary purpose of the algorithm is to broadcast routing packets only when necessary or required; this is done to distinguish between local communication management and general communication protocol management and promote packages about changes in the local link to neighboring mobile nodes (those that need information). A route discovery process is established when a source node needs to connect to another node, and the source node does not contain route information.

Disadvantages of AODV routing protocol

Due to the demanding nature of the AODV routing protocol, several problems are associated with high routing costs and packet loss. In addition, the issue of power consumption is one of the main problems, but it is not fully addressed in the ZigBee specification. However, the nature of both the discovery and maintenance process creates several problems that lead to the energy consumption of the nodes, affecting the life of the network.

Some disadvantages of AODV routing protocol in route to destination establishment:

- Evaluating difficulty priority: The number of hops is used as a priority figure for AODV routes and ignores other vital statistics.

- Duplicate messages: Sometimes, the intermediate node can receive from the same RREQ source with fewer hops. The RREQ message must be forwarded again, contributing to congestion and increasing transmission delay and energy consumption.

- High route discovery latency: Route discovery may take longer when nodes send random messages; therefore, a waiting period is required until the second path is established.

2.2. The tree algorithm

Zigbee Tree Routing Protocol is a network layer and data link layer protocol that uses "connection state" packets to format a single tree network, as well as an extended tree network. This type of network is essentially a self-organizing and self-supporting type to limit network failure to an acceptable level of failure; more specifically, because this is a self-organizing network, it can also repair itself when there is a problem at a certain network node. Network nodes choose a node as the root of the tree and create branches freely. Then, the branches grow independently and connect to other units using the original device (Designated Device-DD).

Disadvantages of tree routing protocol

The ZigBee tree routing algorithm considers only the relationship between the relay node and the parent nodes and the child nodes between the nodes but ignores the neighbors. So, there are some problems; even if the destination node is in the sending node's communication domain, the data packets must be transmitted to the destination node along with the tree topology but not directly to the destination node. In addition, if several nodes frequently need to transfer data, these nodes may soon run out of battery, resulting in reduced network life [4].

2.3. The Hierarchical Routing Algorithm – (HERA)

In the HERA algorithm - a hierarchical algorithm, data generated at the sensors (end devices) is transferred to the sink and routed along with the branch to the root (gateway) according to a parent-child relationship; that is, all nodes in the network only pass data to its parent node. On the other hand, for data transmission between two sensors or from a sink to a sensor, packets are routed up or down the tree according to the destination address by exploiting the decentralized address evaluation scheme Zigbee only provides. Routes to the destination are determined before a sensor node needs to perform routing [5].

The HERA algorithm helps minimize the exchange of information because it utilizes MAC binding procedures. The HERA algorithm is simple, lightweight, and does not require large memory for routing tables [5].

3. PROPOSED METHOD

3.1. General description

Figure 2. *Zigbee network architecture.*

The article builds an appropriate routing algorithm in Zigbee networks for the real problem that gateway and repeater use power from the adapter (with backup battery), so it may not care much about the power issue of those devices. Terminal devices (ED - sensors) only use power from lithium batteries, so they should minimize energy use with these devices; they are often in idle mode, only waking up periodically to check sensor parameters or have a wake-up effect from the sensor. The terminal device will send a network maintenance packet for a certain period; after receiving the response message, it will go to sleep mode. Nodes in the network rarely change locations.

There are four types of packets used in the proposed Zigbee network. The first is the RRID (Route Request ID) packet; this is the network registration packet. The second is the RREQ (Route Request) packet; this is the routing packet. The third is the RRDT (Route Data) packet, which is the data transmission packet. The last one is the ACK packet (Acknowledgment); this is the feedback packet.

3.2. General system requirements

For Zigbee networks, there are three general requirements that must be satisfied. Firstly, the packet's route is the shortest, with the smallest number of hops (if the number of hops is equal, choose the route with the optimal received signal strength indication (RSSI). Secondly, the processing time for incoming and outgoing packets must be the fastest (optimization of packets and handling). Thirdly, the density of packets emitted by the system must be minimal (avoid occupying bandwidth and interfering packets with each other when transmitting and receiving). Finally, Node will register its routing network, and when it fails, it has to reroute.

3.3. The pathfinding algorithm

The system applies the HERA pathfinding algorithm with some modifications to suit the application of the system. In the existing system, packets from sensor nodes will be sent to the IP address and ID of the destination node. Each device will have a unique ID identifier. With IP, the nodes have their IP, the IP of the Gateway is the IP of the network, the Repeaters have a shared IP.

Compared with the original HERA algorithm, the proposed algorithm has the following adjustments. Information exchanged in the algorithm is bidirectional from ED to GW and from GW to ED. The routes in the algorithm are managed by GW combined with load balancing to optimize the management of information flows for the network. Therefore, some routers in the network are not necessarily the most optimal, but overall the system will work the most stable. The system has a self-repair function (described in the experiment section) when the route is broken. Packets in the network are classified, which optimizes processing time at repeaters and GW, helping to reduce transmission latency. RRDT packets must have a response when sent for confirmation. If there is no response, proceed to send RREQ to the nodes to get back the route information (for uplink packets, downlink packets, reporting an error to GW for rerouting) and then send data back. Routing is mainly processed on the GW (with a separate processor and memory from the Zigbee module), which is shown as follows. Firstly, Gateway will have path information of each node (Gateway -> node), ID list, and a total number of steps, RSSI to the hierarchical node list. Secondly, the Gateway will stratify the node based on the number of steps (transmission level) and the received signal strength of each node to the Gateway. The algorithm determines which route with the smallest number of hops will be selected; if there are the same transmission hops, the route with the most optimal RSSI received wave strength will be selected (here, because RSSI has a negative value so the smaller the displayed value, the more optimal the RSSI). Thirdly, Nodes store information about the nearest node that has been routed. Finally, when receiving data from the Gateway through the node, the number of steps must be updated for optimization.

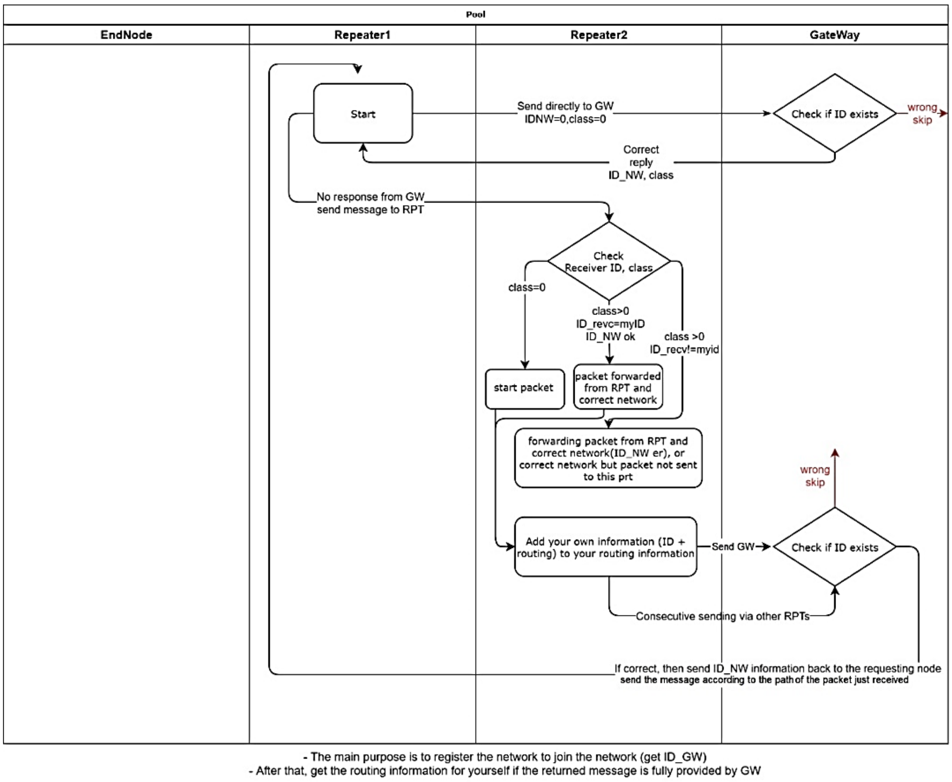


Figure 3. *End Device sends a packet to join a network.*

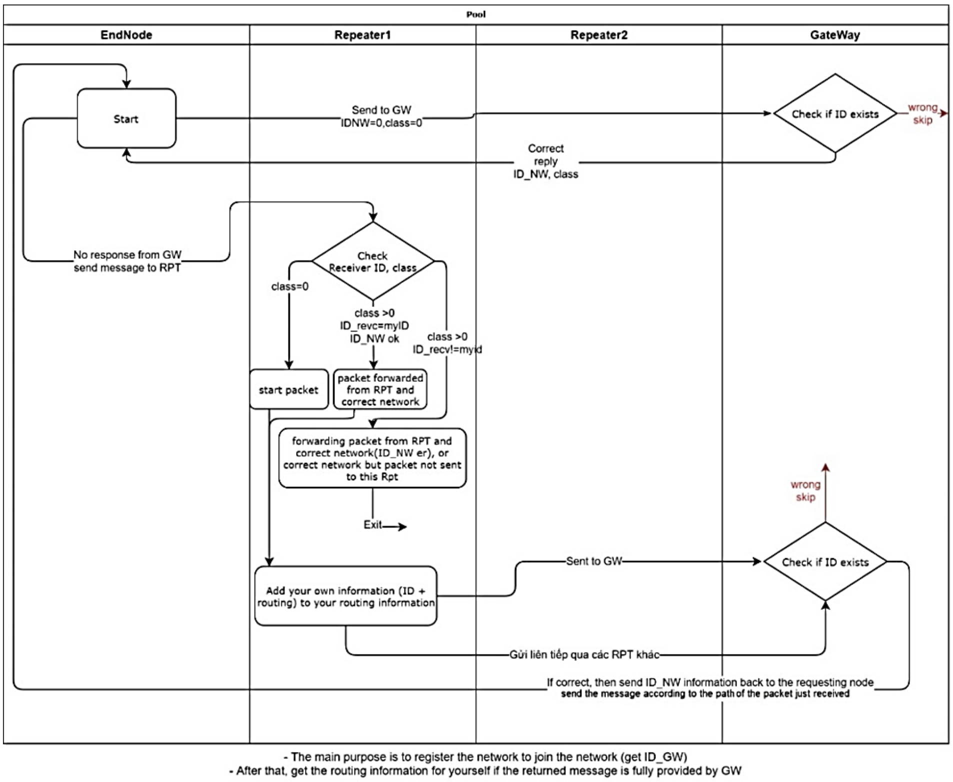


Figure 4. *Repeater sends a packet to join a network.*

The operation of the algorithm is shown through the following stages. The operation of the algorithm is shown through the following stages. In the first stage, the End Device joins a network, and it sends the network joining packet to the GW; if the packet has no response, it sends it to the neighboring RPTs. This is shown in figure 3.

In the second stage, Repeater joins a network; it sends the joining packet to the GW; if the packet has no response, it sends it to the neighboring RPTs. This is shown in figure 4.

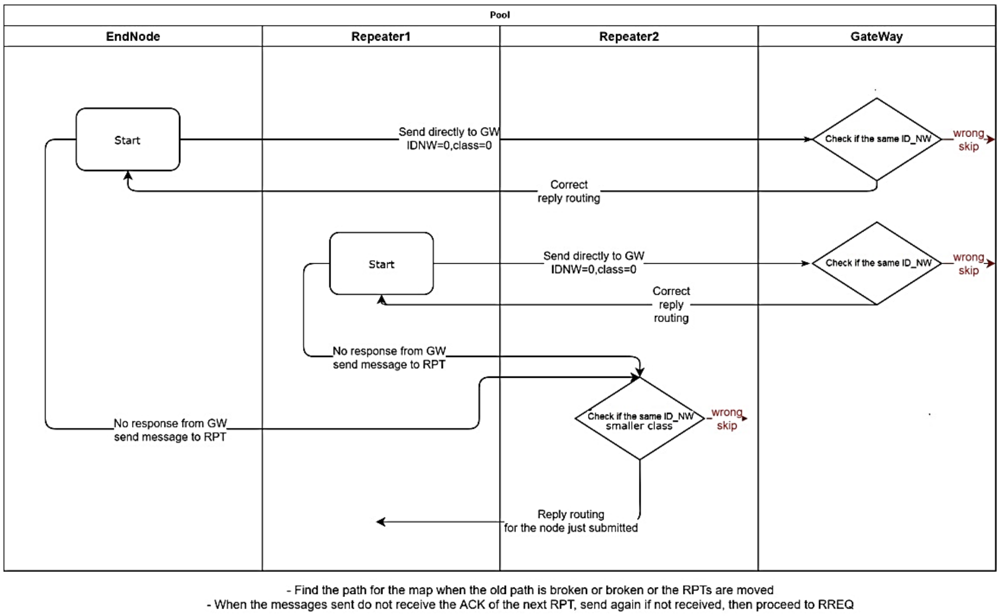


Figure 5. *Routing in a Zigbee network.*

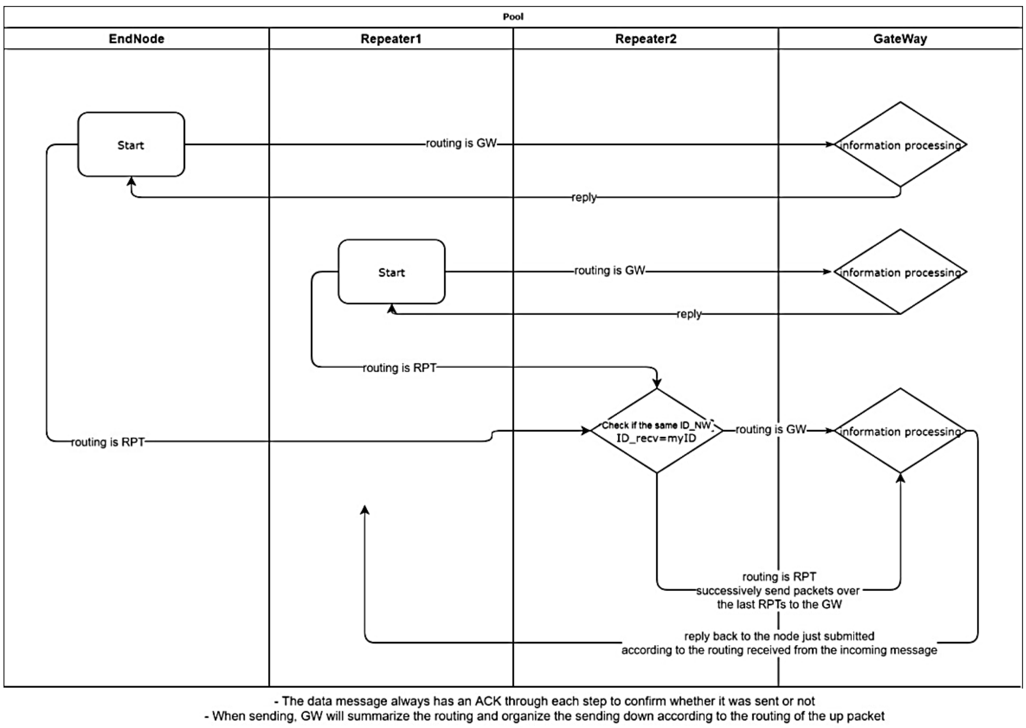


Figure 6. *Data packets transmission in a Zigbee network.*

In the third stage, the routing packet, ED, or RPT will send the routing packet to GW if received a response from GW, then that is the most appropriate route; if no response is received, ED or RPT will send the packet to neighboring RPTs, after receiving the response it will update the shortest route to GW. This is shown in figure 5.

In the final stage, the data packet will be sent according to the specified route; if no response is received, the device will send a routing packet; after finding the appropriate route, the data packet will be sent. This is shown in figure 6.

3.4. Algorithm evaluation

The algorithm meets the requirements when building a Zigbee network. The nodes in the network are routed and can repair the route on their own when something goes wrong. The network is also scaled up quickly and demonstrated in section 4 on experiments.

Terminals that are not involved in the routing process should save energy. Combined with a reasonable load balancing and the time slotting algorithm, the network will be very stable.

The destination node's IP is included in the sending packet to avoid sending in a roundabout like a tree routing algorithm. The repeater only forwards the package, does not play the role of packet processing, so it reduces the transmission delay.

The disadvantage of the algorithm is that if the nodes in the route change their position slightly, making the old course become the nonoptimal route, the packet will still be transmitted on that route, not rerouted. This is acceptable because the network system rarely changes the location of the nodes, and the frequent rerouting consumes the energy of the network nodes.

4. EXPERIMENTS

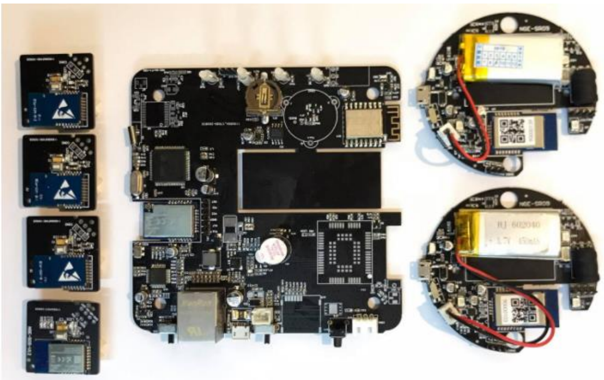


Figure 7. *Test devices.*

Description: Set up a Zigbee network consisting of 1 GW, 2 RPTs, and 4 Nodes, as shown in figure 9. Devices using Zigbee module with IC CC2530 of Ti company, nodes using 3V battery, Gateway and Router using 5VDC source and have a backup battery. On the nodes, the router has a Test button attached to send information to the Gateway. When the Gateway receives a notification from any node, the Zigbee module will send back an RSSI value representing the received wave strength; this value has a negative sign, so the more significant the value, the smaller the received wave strength. The step value (transmission level) is taken as the priority value, then the RSSI value in the experiment. The IDs of the devices participating in the test are:

Gateway: 1000888

RPT1: 90000138

RPT2: 90000139

Node 1: 80000102

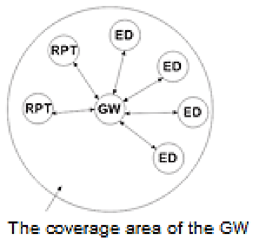
Node 2: 80000103

Node 3: 80000104

Node 4: 80000105

- Scenario 1 – Network Accessibility Test: Moving the above nodes into the GW coverage area. Click the Test button on the nodes, see the results on the routing table.

The results are displayed in Figure 8:



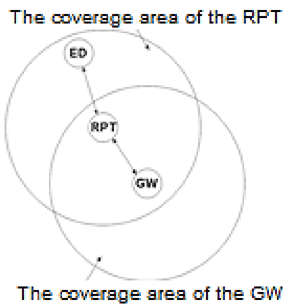
TT	Tim	NRcv	Ping	Time	LV2	Rsi	LV1(GW)	Rsi
1	0	37	1784	14:36:26	90000138	0	1000888	27
2	0	29	2004	14:36:31	90000139	0	1000888	24
3	0	12	7627	14:36:33	80000100	0	1000888	33
4	11	17	7848	14:36:37	80000101	0	1000888	24
5	11	14	8071	14:36:39	80000102	0	1000888	32
6	19	21	8277	14:36:58	80000103	0	1000888	64
7	20	9	8525	14:36:35	80000104	0	1000888	34
8	11	2	8740	14:36:45	80000105	0	1000888	20

Figure 8. *Results of joining the network of nodes.*

Initially, the routing table did not contain any nodes, but after testing, the routing table was full of devices participating in the network. Thus, nodes are added to the network easily.

- Scenario 2 – Testing the node's ability to repair its route: Moving node 4 into RPT 2's coverage area and out of GW's coverage area to create transmission failure from node 4 to the GW. Click the Test button on node 4 and see the result on the routing table.

The results are displayed in Figure 9:



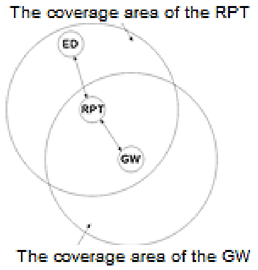
TT	Tim	NRcv	Ping	Time	LV3	Rsi	LV2	Rsi	LV1(GW)	Rsi
1	49	3	8592	14:39:13	80000105	0	90000139	65	1000888	57
2	6	5	8583	14:39:22	80000105	0	90000139	69	1000888	57
3	11	7	8573	14:39:32	80000105	0	90000139	71	1000888	57
4	20	9	8571	14:39:34	80000105	0	90000139	73	1000888	57
5	20	11	8570	14:39:35	80000105	0	90000139	74	1000888	57
6	20	13	8568	14:39:37	80000105	0	90000139	71	1000888	57
7	16	15	8541	14:40: 4	80000105	0	90000139	81	1000888	57
8	16	18	8540	14:40: 5	80000105	0	90000139	82	1000888	57
9	47	20	8537	14:40: 8	80000105	0	90000139	68	1000888	57
10	10	22	8532	14:40:13	80000105	0	90000139	67	1000888	57

Figure 9. *The node's routing results when transmission line error occurred.*

When moving the ED node out of the GW coverage area, usually, that node will not be able to join the network; the old route has been broken. Thanks to RPT 2 forwarding the packet to the GW, that ED can still send the packet to the GW, forming a new route from the ED to the GW. As such, the route is self-repairing. Node 4 to RPT 2 to the GW creates a new communication route.

- Scenario 3 – Testing RPT's ability to self-repair route: Moving RPT 2 into RPT 1's coverage area and out of the GW's coverage area to create transmission failure from RPT 2 to the GW. Click the Test button on RPT 2 and see the results on the routing table.

The results is displayed in Figure 10:



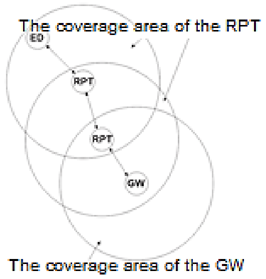
TT	Tim	NRcv	Ping	Time	LV3	Rsi	LV2	Rsi	LV1(GW)	Rsi
1	7	39	1386	14:46:49	90000139	0	90000138	70	1000888	58
2	7	40	1380	14:46:55	90000139	0	90000138	57	1000888	57
3	7	41	1375	14:47: 0	90000139	0	90000138	58	1000888	57
4	7	42	1371	14:47: 4	90000139	0	90000138	61	1000888	57
5	6	43	1364	14:47:11	90000139	0	90000138	58	1000888	57
6	6	44	1361	14:47:14	90000139	0	90000138	60	1000888	57
7	6	45	1359	14:47:16	90000139	0	90000138	60	1000888	57
8	6	46	1357	14:47:18	90000139	0	90000138	60	1000888	56

Figure 10. *RPT routing results when transmission line error occurred.*

When moving the RPT 2 node out of the GW coverage area, RPT usually will not be able to join the network; the old route is broken. Thanks to RPT 1 forwarding the pack to the GW, RPT 2 can still send the packet to the GW, forming a new path from RPT2 to the GW. As such, the route from RPT2 was self-repaired.

- Scenario 4 – Testing data transmission over multiple RPTs: Moving node 4 into RPT2 coverage and out of the GW and RPT1 range. Click the Test button on node 4 and see the result on the routing table.

The results are displayed in Figure 11:



TT	Tim	NRcv	Ping	Time	LV4	Rsi	LV3	Rsi	LV2	Rsi	LV1(GW)	Rsi
1	136	29	7454	15:17:44	80000105	0	90000139	57	90000138	64	1000888	59
2	25	31	7451	15:17:47	80000105	0	90000139	57	90000138	63	1000888	57
3	10	33	7445	15:17:53	80000105	0	90000139	59	90000138	61	1000888	57
4	20	35	7443	15:17:55	80000105	0	90000139	57	90000138	62	1000888	57
5	20	37	7440	15:17:58	80000105	0	90000139	55	90000138	61	1000888	56
6	20	39	7438	15:18: 0	80000105	0	90000139	56	90000138	62	1000888	58
7	20	41	7435	15:18: 3	80000105	0	90000139	54	90000138	61	1000888	55
8	20	43	7432	15:18: 6	80000105	0	90000139	55	90000138	64	1000888	64
9	20	45	7430	15:18: 8	80000105	0	90000139	55	90000138	63	1000888	60

Figure 11. *Routing results of nodes over multiple transmission hops.*

As such, the route from node 4 has been self-corrected. In the node connection diagram, it is easy to see that the communication distance between node 4 and the GW has been greatly increased; instead of node 4 can only send messages within the coverage area of the GW. The test results show that expanding the network (adding nodes or repeaters to the network) is very easy to do.

5. CONCLUSION

The test shows that the routing algorithm has increased the transmission distance in the Zigbee network many times (in the test, it is over 2 RPTs), and the network scalability is easy to implement. The routing algorithm in the Zigbee network has contributed to solving the problem of connection distance for the Zigbee network, helping designers to build the Zigbee mesh network. The algorithm is suitable for applications that use Zigbee transmission lines such as IoT, smart home, etc. When the number of nodes in the network increases, the number of packets sent to the GW will increase; therefore, it is necessary to combine load balancing and time slotting algorithms to send to the nodes.

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REFERENCES

[1]. Noman Shabbir, Syed Rizwan Hassan, *"Routing Protocols for Wireless Sensor Networks (WSNs)",* 10/2017.

[2]. https://www.digi.com/resources/documentation/Digidocs/9000194213/concepts/c_many_to_one_routing.htm.

[3]. Husien. A. S, *"Power Sensitive Routing Algorithm for ZigBee Wireless"*, 12/2015.

[4]. P. Tianhong, L. Ji, *"Neighbor Table Based Tree Routing in ZigBee Wireless Networks"*, 2013.

[5]. Tommaso Melodia, *"Routing in ZigBee: benefits from exploiting the IEEE 802.15.4 association tree"*, 2007.

TÓM TẮT

NGHIÊN CỨU, XÂY DỰNG THUẬT TOÁN ĐỊNH TUYẾN
TRONG MẠNG ZIGBEE

Mạng không dây Zigbee được xây dựng dựa trên tiêu chuẩn IEEE 802.15.4 đang trở thành một trong những mạng không dây phổ biến nhất trong các thiết bị IoT hiện đại. Một trong những nhược điểm của mạng Zigbee là khoảng cách truyền nhận giữa các thiết bị ngắn. Bài báo này tập trung nghiên cứu, so sánh các thuật toán định tuyến trong mạng Zigbee, từ đó xây dựng thuật toán định tuyến tối ưu nhất trong hệ thống thực tế. Mục tiêu của bài báo là hình thành cơ sở để xây dựng mạng Zigbee hình cây, hình mesh, giúp cải thiện khoảng cách truyền cho mạng Zigbee tốt hơn mạng hình sao.

Từ khóa: Định tuyến trong mạng Zigbee; Công nghệ Zigbee; Zigbee.