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Efficient and Low delay Multi-hop MAC Protocol for Broadband Power Line Communication Networks

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ABSTRACT
For the problems of IEEE1901.1 broadband power line communication media access control MAC protocol, such as insufficient beacon timeslot utilization and excessive control overhead, this paper proposes efficient and low delay multi-hop MAC, ELDM-MAC protocol for BPLC networks. The beacon timeslot allocation mechanism based on node layer number is adopted, according to neighbor table and timeslot allocation information, the time when CSMA timeslot can be entered in advance can be calculated, which reduces the waste of beacon timeslot and improves the channel utilization. At the same time, the efficient broadcast mechanism of beacon frame based on topology information is used, the main idea is to delete the timeslot allocation information of nodes whose layer number is not greater than itself and the timeslot allocation information of non-descendant nodes whose layer number is greater than itself within two hops, which ultimately reduces the network control overhead. The simulation results show that ELDM-MAC protocol proposed performs better than IEEE1901.1 MAC protocol in channel utilization, average delay and control overhead, data transmission success rate, which can be preferably applied in practical scenarios of BPLC networks.

Keywords
BPLC, MAC Protocol, CSMA Timeslots, Beacon Timeslots

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I. INTRODUCTION

We ask that authors follow some simple guidelines. In Broadband Power Line Communication [1] BPLC is a communication method that uses power line as a signal transmission medium. BPLC is also called high-speed power line communication, which can achieve a data transmission rate of more than 1 Mb/s and has strong anti-interference ability. Broadband power line communication is widely used in the fields of power consumption information acquisition system [2], smart grid [3], smart home [4] and multi-meter centralized reading [5] [6] proposes an improved zero-setting method based on iterative elimination of nonlinear distortion for the nonlinear distortion problem caused by the traditional zero-setting method, which can effectively increase the resistance of the PLC system to impulse noise [7] proposes a Luby transform code applied in Power Line Communication PLC, which can significantly reduce the decoding overhead and time-consuming. At present, there have been some studies on the Medium Access Control MAC protocol for broadband power line communication [8] adopts the hybrid access technology of Time Division Multiple Access TDMA and Carrier Sense Multiple Access with Collision Avoid CSMA/CA in large-scale PLC.

The network can improve the stability of the network and the efficiency of data transmission, but it is not suitable for small-scale PLC networks and has certain limitations [9] proposes a unified MAC protocol that integrates power lines and wireless communication networks, and designs and unifies key technologies such as MAC time slot division, networking process and resource scheduling, but it increases the complexity of the system and is only suitable for certain under special circumstances, it is not universal [10] introduces the idea of cross-layer, and under the premise of ensuring QOS, a broadband power line cross-layer resource allocation scheme based on the QoS priority scheduling function of the MAC layer is proposed. The complexity of the system and the high requirements for the physical layer [11] proposes an improved adaptive P-persistent CSMA protocol. In the case of high load, by dynamically adjusting the probability P, the collision probability of data packets is reduced, but when the load is small, it will cause the channel Low usage, etc. In [12], considering that PLC is limited by the transmission distance, a PLC network forwarded by relay nodes is proposed, which is forwarded through relay nodes between the source node and the destination node to ensure the reliability of data transmission [13] proposes an adaptive MAC protocol based on user delay and channel conditions, which improves the throughput of the system by adjusting the data transmission rate and contention window size, but destroys the fairness of nodes [14] proposed an improved CSMA/CA algorithm, which is suitable for power line and wireless hybrid network scenarios. The algorithm is compatible with existing standards IEEE1901 and 802. Compatible with 11 CSMA/CA algorithms [15] conducted a comprehensive investigation on the latest technology of the PLC system MAC protocol. Currently, the MAC protocol used in the PLC system is mainly CSMA/CA, and a small part uses the TDMA protocol. The broadband power line communication standard IEEE1901.1 [16] issued by the IEEE Communication Association Power Line Communication Committee specifies the key technologies of the physical layer and the media access control sublayer. The draft [17] supplements the standard of the [16], adding test cases and test scenarios for the physical layer and the MAC layer. However, the study found that IEEE1901. 1 The MAC protocol has insufficient beacon slot utilization and excessive control overhead and other issues. In view of this, this paper proposes an ELDM-MAC Efficient and Low Delay Multi-hop MAC protocol, which can effectively improve the above-mentioned through a beacon slot allocation mechanism based on node hierarchy number and an efficient beacon frame broadcast mechanism based on topology information question.

1.2 Power Line Communication Technology and Related Work

The Power Line Communication is a term used to describe the technology designated to carry data by the power cables used to carry electric power. There is no additional wiring required other than the existing power cables, and this is the key advantage of PLC. There are two main types of PLC technologies Narrowband NBPLC and Broadband BPL [3]. Broadband technology utilizes frequency band between 1.8 MHz and 86 MHz and allows for data rates of hundreds Mbps. BPL is used in short range applications. It enables high speed data transfer in every electrical outlet in the home and could be used in applications like HDTV, Internet, and audio systems. Low frequency Narrowband PLC systems operates in frequency band below 500 kHz. In Europe this band has been limited to frequency range from 3 kHz to 148.5 kHz and divided into 4 frequency sub-bands. A-band: 3 kHz - 95 kHz - reserved for energy suppliers to monitoring or controlling the low-voltage distribution networks. B-band: 95 kHz - 125 kHz - can be used by consumer’s applications without any access protocol. C-band: 125 kHz - 140 kHz - reserved for home networking systems with mandatory CSMA/CA access protocol. D-band: 140 kHz - 148.5 kHz - for alarm and security systems without any access protocol. New proposed ELDM-MAC protocol we found 2 problems and then solved the problem, beacon slot allocation based on node hierarchy number. Efficient broadcast of beacon frames based on topology information in the previous works they don't describes these problem and the solution. The proposed ELDM-MAC protocol, Channel utilization, Data average delay, Control over head, and Data transmission rate is higher than the previous work.

II. Network Model and Problem Description

2.1 Network Model

The broadband power line communication network consists of a master node Central Coordinator, CCO, multiple proxy nodes Proxy Coordinator, PCO and multiple ordinary nodes Station, STA, which together form a multi-hop tree scene, as shown in figure 1

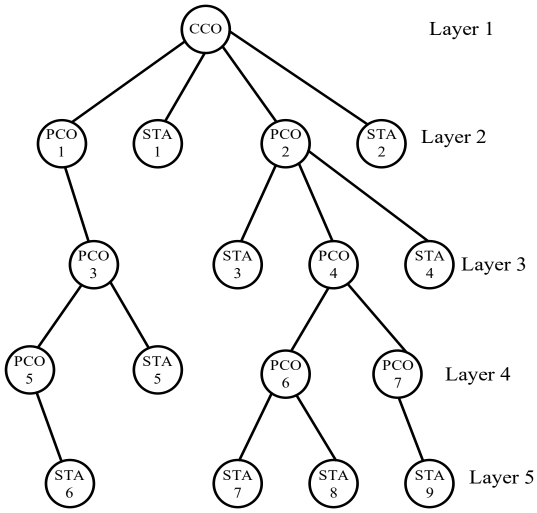

Figure 1. Network Scenario of PLC Networks

The broadband power line communication network divides the channel resources into one beacon period structure, as shown in figure 2. As can be seen from the figure, a beacon period is divided into beacon time slot, CSMA time slot, TDMA time slot and bound CSMA time slot, and the beacon time slot is divided into several non-competitive mini-slots by the CCO, which have been connected to the network nodes broadcast beacons in this time slot frame; nodes use CSMA/CA to compete for data transmission in the CSMA time slot; in the TDMA time slot, the CCO assigns some nodes with special services to access the channel in a non-competitive way; when binding CSMA Slots are allocated by the CCO to some special services, and use CSMA/CA to compete for channel

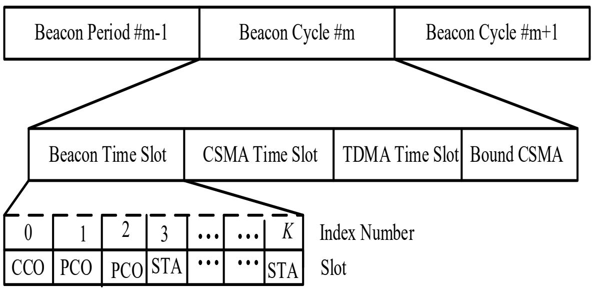

Figure 2. Beacon Period Time slot Allocation

The CCO broadcasts a beacon frame in the first time slot in the beacon time slot, and the beacon frame contains all the time slot allocation information of the beacon period. After the networked node receives the beacon frame, it takes out the destination address, forms a one-hop neighbor table, determines the time slot position arranged by the CCO for itself according to the time slot allocation information, and forwards the beacon frame; after the non-networked node receives the beacon frame , also determine the location of the time slot and form a one-hop neighbor table, send the network access request frame in the CSMA time slot, and forward it to the CCO by the networked node ACK frame. After the node joins the network, it sends 10 discovery list messages in each routing cycle. The discovery list message contains its own neighbor node information. The node updates the neighbor table after receiving the discovery list. At this time, the neighbor table contains one hop and two hops neighbor node.

2.2 Problem Description

(1) After sending the beacon frame, the node cannot enter the CSMA time slot immediately, and needs to wait until the end of the beacon time slot before entering the CSMA time slot. The node is in a waiting state during the period from sending the beacon frame to the CSMA time slot, and cannot obtain any channel resources, resulting in insufficient use of beacon time slots and waste of channel resources, reducing channel utilization.

(2) Since each node cannot know the topology information of the entire network, the content of the time slot allocation information will not change during the broadcast process. After each node receives the beacon frame, it will unconditionally forward the time slot allocation information of all nodes, resulting in many invalid time slots. Slot allocation information continues to be broadcast by nodes, making the control overhead too large.

III. ELDM-MAC

For IEEE1901.1 The MAC protocol has problems such as time slot waste, large control overhead and low channel utilization. 1 The MAC protocol has been improved as follows: One is to propose a "node-based layer" The new mechanism of "Beacon Slot Assignment for Level Number" allocates beacon time slots in order of node level number from small to large. After the node broadcasts the beacon frame, it calculates the time that will not interfere with the transmission of the beacon frame. Enter the CSMA time slot; the second is to propose a new mechanism of "efficient broadcast of beacon frames based on topology information", that is, to simplify time slot allocation messages through topology information, so that nodes no longer broadcast redundant and invalid time slot allocation messages

3.1 Beacon slot Allocation Based on Node Hierarchy Number

The core idea of the beacon slot allocation mechanism based on the node hierarchy number think: The CCO allocates time slots according to the node's level number from small to large. The smaller the level number, the higher the position in the beacon time slot, and the CCO is the 0th level; The beacon frame is broadcast in the time slot; the networked node obtains the time slot allocation information after receiving it, determines the position of each time slot segment, and broadcasts the beacon frame in the time slot arranged by the CCO; after sending the beacon frame, the node checks its own Neighbor table, wait for its neighbor nodes to send beacon frames before entering the CSMA time slot in advance. During this period, the node will not collide with the node that needs to send the beacon frame that has been arranged by the CCO, which improves the utilization of the time slot. The specific operation steps of the new mechanism are as follows.

Step 1: Before the CCO generates the time slot allocation information field, it allocates beacon time slots according to the order of the node's level number from small to large. The beacon frame is broadcast in the first time slot of the time slot

Step 2: After the node receives the beacon frame, it takes out the destination address field of the beacon frame and updates the one-hop neighbor table. Obtain the length of the beacon period and the position of the beacon slot, CSMA slot, TDMA slot, and bound CSMA slot based on slot allocation information. If the node is not connected to the network, the node uses the CSMA/CA method to compete for the channel to send the network access request frame in the CSMA time slot; otherwise, go to Step 3.

Step 3: The node calculates the CCO according to the time slot allocation information and arranges the time slot position for itself to send the beacon frame, and sends the beacon frame in this time slot. After sending the beacon frame, the node checks its two-hop neighbor node according to its neighbor table. If there is a two-hop neighbor node, go to Step 4; otherwise, go to Step 5.

Step 4: Find out the maximum time slot index number of the two-hop neighbor node in the time slot allocation information, and calculate the time after the node sends the beacon frame to the node with the maximum time slot index number sends the beacon frame: T, after the time T, the node can use the CSMA/CA method to compete for the channel and enter the CSMA time slot in advance.

The operation flow of the new mechanism of beacon slot allocation based on node hierarchy number is shown in Figure 3. Node can use the CSMA/CA method to compete for the channel and enter the CSMA time slot in advance.

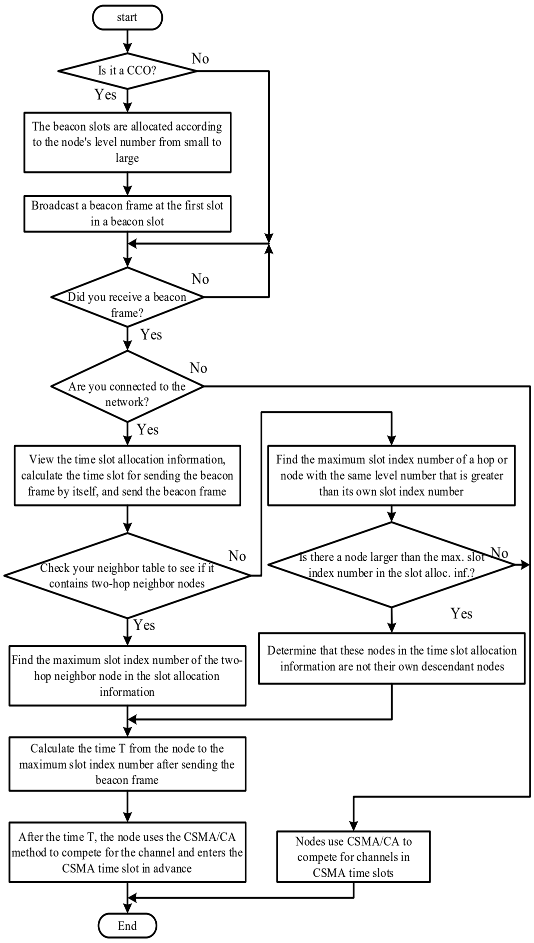

Figure 3. Beacon slot Allocation Process Based on Node Hierarchy Number

Step 5: When the node does not have two-hop neighbor nodes, check the time slot allocation information and find out the one-hop node or the largest time slot index number of the node with the same level number that is greater than its own time slot index number. slot allocation information Check whether there is a node larger than the maximum time slot index number in it, if not, the node uses the CSMA/CA contention channel to access the channel in the CAMA time slot; otherwise, go to Step 6.
Step 6: If there is a time slot allocation information of a node larger than the maximum time slot index number, it is judged that the remaining nodes are not the descendants of its own node, and the computing node reaches the maximum time slot index after sending the beacon frame. The time after the node in the quotation mark sends the beacon frame is T. After the time T,

3.2 Efficient Broad cast of Frames Based on Topology Information

Step 1: During the beacon period, before the CCO generates the time slot allocation field, the CCO is sorted in ascending order of the node hierarchy number. Allocate beacon slots in turn to each node that has joined the network to send Beacon frame, the node with a smaller level number is positioned earlier in the beacon slot, and the beacon frame is broadcast in the first slot of the beacon slot.
Figure 4 shows the operation flow of the new mechanism for efficient broadcast of beacon frames based on topology information efficiency. The specific operation steps of the new mechanism are as foll
The core idea of efficient broadcast mechanism of beacon frame based on topology information think: CCO allocates beacon time slots in ascending order according to the hierarchical number of nodes, and CCO broadcasts beacon frames in the first time slot of beacon time slots; after the nodes that have joined the network receive the beacon frames, they allocate beacon time slots according to the time slot The information calculates the time slot for sending the beacon frame by itself, and according to the topology information, deletes the time slot allocation information of the node not greater than its own level number and the non-descendant node larger than its level number and within two hops, reducing unnecessary Node time slot allocation information broadcast, shorten the length and content of beacon frames, and improve access .
Step 2: After the ordinary node receives the beacon frame, it takes out the destination address and updates its neighbor table. According to the time slot allocation information, it calculates the time slot and the position of

the beacon time slot, CSMA time slot, TDMA time slot and bound CSMA time slot for sending the beacon frame by itself.
Step 3: Before broadcasting a beacon frame, an ordinary node first checks the location of its own time slot allocation information, and if there is time slot allocation information of other nodes before its location, delete these level numbers not greater than The time slot allocation information of the node with its own level number; if there is more time slot allocation information than the node with its own level number, then further check the neighbor table. If there are nodes in the neighbor table that are the same as the time slot allocation information, it can be known that these nodes are Its own descendant node; otherwise, delete the slot allocation information of the non-descendant node whose level number is larger than its own and is within two hops.
Step 4: After checking and deleting the time slot allocation information that satisfies the conditions, the ordinary node finds that there is no time slot allocation information of its own descendant nodes, and judges itself as an edge node. If it is an edge node, go to Step 5; otherwise, go to Step 6.

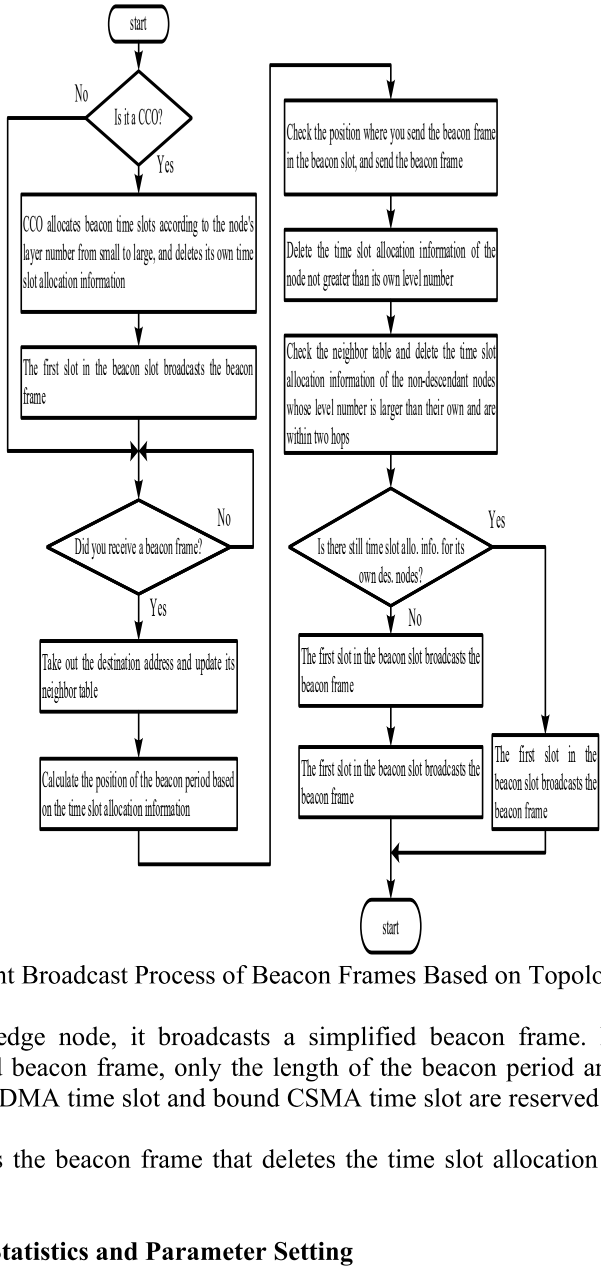

Figure 4. Efficient Broadcast Process of Beacon Frames Based on Topology Information

Step 5: If the node is an edge node, it broadcasts a simplified beacon frame. In the time slot allocation information of the simplified beacon frame, only the length of the beacon period and the length of the beacon time slot, CSMA time slot, TDMA time slot and bound CSMA time slot are reserved , the allocation information of time slots without beacons
Step 6: The node broadcasts the beacon frame that deletes the time slot allocation information that meets the conditions.

4 Definition of Simulation Statistics and Parameter Setting
The main simulation statistics selected in this chapter include throughput, control overhead and delay of location information exchange, and the number of time slots obtained by nodes.
Simulation Statistics and Definitions

1. **Channel Utilization.** Refers to the channel utilization ratio of the time spent by a node occupying a channel for effective data transmission to the network running time**.** U represents channel utilization**,** t_t represents

transmission time, and also tp represents signal propagation time and the calculation formula is shown in equation 1.

$$U = \frac{t_t}{t_t + 2tp} \times 100 \qquad (1)$$

2. **Data average delay.** Refers to the average of the data packets from the application layer of the source node to the application layer of the destination end time consuming, the unit is S, and the calculation formula is shown in formula 2.
   In the formula, *N* represents the number of data frames sent by the application layer, and E_i represents the time taken for the i data frame to travel from the source application layer to the destination application layer.

$$E = \frac{\sum_{i=1}^{N} E_i}{N} \qquad (2)$$

3. **Control overhead.** Refers to the amount of data generated by the exchange of communication control information between nodes in the network, the unit is Mbit, and the formula is**.** In the formula 3, *O* is the control overhead; n is the number of communication control information exchanges between nodes; di is the data volume of the i node information exchange.

$$O = \sum_{i=1}^{n} d_i \qquad (3)$$

4 **Data Transmission Success rate.** It refers to the ratio of the number of data packets received by the destination node to the number of data packets sent by the source node. The calculation formula is shown in Equation 4.
   where R_i represents the number of packets received by the i node during the network running time, P_i represents the number of packets sent and received by the i node during the network running time, and *N* represents the number of nodes in the network.

$$S = \frac{\sum_{i=1}^{N} R_i}{\sum_{i=1}^{N} P_i} \qquad (4)$$

5 Simulation Verification and Result Analysis

In order to verify the performance of ELDM-MAC protocol, this paper adopts Opnet modeler 14. 5 Simulation tools are used to simulate and verify the ELDM-MAC protocol, and IEEE1901.1 is selected. The MAC protocol is used as a reference protocol to analyze the performance of channel utilization, control overhead and average data delay protocol to analyze the performance of channel utilization, control overhead and average data delay.

5. 1 Simulation Scene and Parameter Settings.

Based on Opnet modeler 14.5 Simulation tools, simulating a network scenario of 1 master node, 10 to 50 agents and common nodes. The BPLC network scenario consists of a master node, multiple proxy nodes, and multiple common nodes. The communication range between nodes is 800 m. There are 8 topological levels of the network. The specific simulation parameter settings are shown in Table 1.

Table 1 Main Simulation Parameters

Parameters/Units	Numerical value
Simulation scene/km2	8×8
Number of nodes/piece	10～ 50
Carrier frequency/MHz	10
Node communication radius/m	800
Beacon slot length/s	1
CSMA slot length/s	1
Transmission rate/(Mb·s-1)	10
Packet length/b	4096
Simulation time/s	60

The master node broadcasts the beacon frame in each beacon period, the node obtains the time slot allocation information after receiving the beacon frame, and continues to broadcast the beacon frame. In the simulation verification, by setting different numbers of network nodes and repeating the experiment 50 times, the average value of channel utilization, data average delay and control overhead is obtained to verify the effect of the number of nodes on channel utilization, data average delay and control overhead, etc. Impact of performance metrics. Since TDMA and bound CSMA time slots have no specific use, they are not considered in the simulation process, that is, the beacon period only includes beacon and CSMA time slots.

5. 2 Simulation Results Analysis.
1 Channel Utilization
Channel utilization refers to the ratio of the time spent by a node occupying a channel for effective data transmission to the network running time. Figure 5 shows the ELDM-MAC and IEEE1901.1 under the condition of different number of nodes. The channel utilization of the two MAC protocols. It can be seen from the figure that with the increase of the number of nodes, the channel utilization rate is significantly improved. This is because the channel has not yet reached saturation, but as the traffic increases, the channel tends to be saturated, and the channel utilization rate increases. The channel utilization rate of ELDM-MAC protocol is higher than that of IEEE1901.1 MAC protocol.

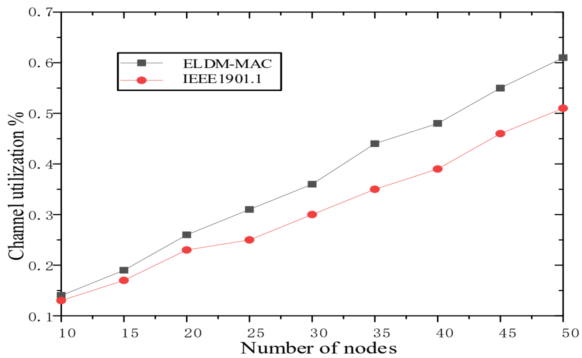

Figure 5. Channel Utilization

Since the beacon slot allocation based on the node hierarchy number is used in the ELDM-MAC protocol, after the node sends the beacon frame in the time slot designated by the CCO, the node calculates the time when it enters the CSMA according to its neighbor table and time slot allocation information. The time of the slot, instead of the IEEE1901.1 MAC, it only occupies one slot in the beacon slot to send the beacon frame, and its idle time has been waiting for the arrival of the CSMA slot, and the ELDM-MAC protocol will make itself advance. Into the CSMA time slot, the node competes for the channel through CSMA/CA. During the beacon time slot, the time that the node occupies the channel for data transmission is increased, the waste of the beacon time slot is reduced, and the channel utilization rate is improved.

2 Data Average Delay
The average data delay refers to the average time taken from the generation of the data frame to the successful reception of the destination node. Figure 6 shows the ELDM-MAC and IEEE1901.1 under the condition of different number of nodes. The average delay of the two MAC protocols. It can be seen from the figure that the average delay performance of the proposed ELDM-MAC protocol is better than that of IEEE1901.1 MAC protocol. This is because the ELDM-MAC protocol uses a new mechanism of beacon slot allocation based on the node hierarchy number, so that the node can enter the CSMA slot to transmit data messages as soon as possible, so that the node has enough time slots to transmit data packets, thereby reducing the number of data messages delay.

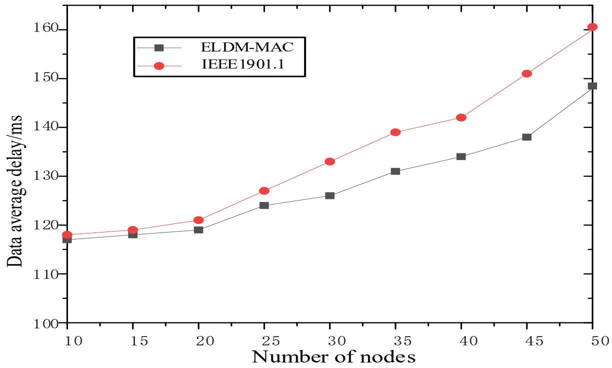

Figure 6. Data Average Delay

3 Control Overhead

Figure 7 shows the control overhead of the ELDM-MAC protocol and the IEEE1901.1MAC protocol. It can be seen from the figure that the control overhead under these two protocols increases with the increase of the number of nodes, compared with IEEE1901.1 MAC protocol, ELDM-MAC protocol reduces network control overhead through a new mechanism for efficient broadcast of beacon frames based on topology information. When each node broadcasts a beacon frame, the node only broadcasts its descendant nodes within two hops and all time slot allocation information of nodes greater than two hops. The redundant time slot allocation information is no longer broadcast, and the time slot allocation information is deleted. Unnecessary related fields shorten the length of the beacon frame and reduce the control overhead.

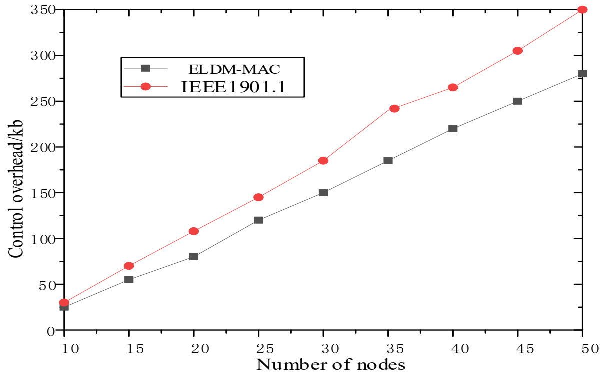

Figure 7. Control Overhead

4 Data Transmission Success Rate

As shown in figure 8, when the number of nodes is small, the data transmission success rate of the two protocols is very high, as the number of nodes increases, the success rate of data transmission decreases gradually with the increased of the number of nodes however the three declines are quite different. ELMD-MAC and the IEEE 1901.1 standard have dropped significantly, the ELMD-MAC can ensure a high data transmission success rate even in the scenario with a high number of nodes.

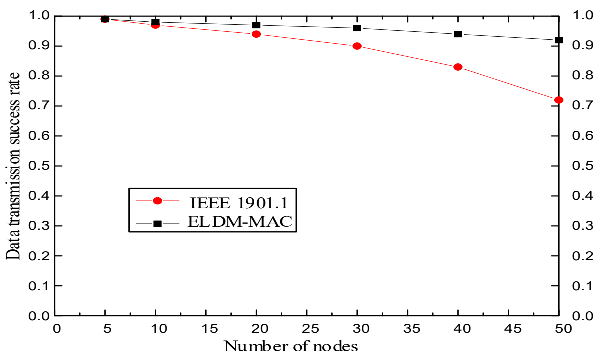

Figure 8. Data Transmission Success Rate

VI. Conclusion

In this paper, a multi-hop MAC protocol with high efficiency and low delay is proposed for broadband power line communication network. On the premise of ensuring the reliability of data transmission, the ELDM-MAC protocol effectively reduces the waste of beacon time slots and improves the channel utilization through the beacon time slot allocation mechanism based on the node hierarchy number; the beacon frame based on topology information is highly efficient The broadcast mechanism effectively reduces the nodes broadcasting invalid time slot allocation information and reduces the control overhead of the network. Opnet modeler 14. 5 The simulation results show that the ELDM-MAC protocol is better.

ACKNOWLEDGMENTS

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