Research on automatic network based on low voltage power line carrier

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Abstract. To improve the power line communication distance, shorten the networking time and the reliability of the system communication, a method based on the clustering algorithm to change the network time and based on the distance between nodes is proposed in this paper. Firstly, the physical structure and logical topology of the low-voltage power line network are described in details. Then, the clustering algorithm and the method of route reconstruction are described. Finally, the method is simulated and analyzed. The results show that the proposed method can not only reduce network time, but also improve the communication stability of nodes within the network.

1. Introduction

Compared with other wired communication, power line communication has the following advantages: wide distribution, no re-wiring and small construction difficulty. There is a protective layer on the outside of the power line, such as walls or leather tube, small damage and easy post-maintenance. Of course, power lines also have some problems, such as limited transmission band, small baud rate, access equipment random, channel of line noise, signal attenuation [1-3] and so on. At present, many people at home and abroad use the dynamic relay to achieve the expansion of the network, while improving the stability of the network, such as References [4-7]. Ran Q H, et al [8] combined with the carrier meter reading system centralized network structure, and proposed a cross-clustering path search algorithm, Zhao J W, et al [9] proposed an ant colony network algorithm based on channel quality and service requirements, and Peng Q W and Zhang H [10] proposed a routing algorithm based on neighbor relation table. But few people on the basis of the network time to optimize the study. To improve the stability of the network and the reliability of network communication, this paper proposes a method to randomly change the communication time slice based on the distance between nodes, which can reduce the time of networking and improve the number of networking times in per unit time.

2. Topological structure of low voltage power line carrier communication network

The low voltage power line carrier communication network consists of a concentrator (master node), terminal collectors (slave nodes) and terminal collectors (power line network). In the meter reading process, the concentrator and terminal collectors are of a master-slave relationship, and the communication mode is half-duplex mode. The system is placed on the low voltage side of the zone transformer and the data collection and processing for the entire power line network is shown in figure 1. As the three-phase transformer makes the secondary side of the three-phase circuit between the
independent, one of the communication reliability and communication time need be studied in the research process [11].

![Figure 1. Three-phase low-voltage power line communication network physical topology.](image)

3. Low voltage power line ad hoc network theory

3.1. Networking instructions

Supposing that a low-voltage power line network has \( n \geq 1 \) nodes, for the introduction of the initialization algorithm, it needs to define the following some aspects: (1) the physical address of the master node is 0, slave of nodes physical address from 1 to \( n \); (2) as much as possible to make the nodes within the network to achieve the connection, which reduces the network time and the number of clusters and layers; (3) after obtaining the logical ID, exit the current logical address allocation competition [11]; (4) node and node communication time is called time slice. Each node has its own time slice, and it has a one-to-one correspondence with the logical number of the node [12]; (5) the smaller the logical ID number, the higher the priority of its communication; (6) there is no solitary phenomenon in the network.

3.2. Networking steps

**Step 1:** The master node sends a routed broadcast (route broadcast), with \( 1 \leq m \leq n \) nodes receiving the broadcast. The node response determines the order of the response based on the distance traveled by the node to the central node (channel quality is the same). According to the above points, when the master node receives a response from a slave node, then it assigns a logical ID to the slave node, and the node exits the round address assignment. The remaining \( m-1 \) slave nodes also allocate logical addresses in this way. Specify this slave node as logical layer 1.

**Step 2:** Initialize Layer 2. Since the smaller the logical ID of the slave node, the higher the communication priority. When the network is configured for the second layer, the master node broadcasts the slave node from logical ID of 1, and then the slave node responds to the master node and the cluster head logical ID is 1. The logical ID allocation is performed for the nodes of the logical layer 2 according to the allocation method of step 1 [13].

**Step 3:** If the second layer of the implementation of the network, all nodes in the network are put to join, it means that the initialization is completed, the performance of the phenomenon when the re-stratification is empty response. At this point, the network initialization is complete and the logical layer of the network is 2. The cluster head in the network is the slave node of the first layer, and the number of the corresponding cluster members is \( g_1, g_2, \ldots, g_m \).

If the slave node is not all added to the network at this time, it needs to continue the initialization of
the network until all the slave nodes are found. In this way, all nodes in the network establish a routing relationship. The cluster structure is shown in figure 2.

![Figure 2. Schematic diagram of clustering.](image)

According to the above analysis, two special cases will appear after the initialization: (1) the master node can communicate with all the slave nodes directly, without relay, and the logical structure of the network is star; (2) and the cluster head can only communicate with neighboring nodes, and the nodes of the whole network are in a series state.

3.3. Network maintenance principles
As the equipment can be arbitrarily inserted and removed, the physical and logical structure of the node changes constantly, resulting in the network routing relationship’s change, and when the network channel is good or bad, the network maximum effective communication distance will accordingly change, which will also make the previous the routing relationship change. In order to ensure the network of robustness and improve the network's survivability, the need for network maintenance and maintenance principles are as follows:

(1) When the network is running normally, if the cluster does not has the data communication, the cluster head will initiate the local route detection to judge whether there is any abnormality in its own cluster; (2) when the network is in the idle state, the master node will initiate the entire network detection command; (3) when the node appears to exit or join the network, the central node makes the local network carry on routing reconstruction.

3.4. Principles of network reconfiguration
It is assumed that there are n nodes in the power line, and there are m clusters after initialization. If one of the cluster heads finds that the cluster member which belongs to the cluster is not responding, it indicates that the cluster member is not in the network. The cluster head will report this information to the master node, and the master node will delete all the routing tables associated with the node. The master node reorganizes the cluster [8].

3.5. Simulation results and analysis
It is assuming that, in a power line system, there are 59 sets of electrical equipment which can be simplified as a node by Matlab simulation. The network is simplified to (-10,10), (-10,10) area. (1) After the network is initialized, the master node logical ID is 0 and the logical number of the slave node is from 1 to 58; (2) as the power line channel quality follows the number of access to the power equipment changes, which will cause the maximum effective communication distance change (3) when the maximum communication distance is constant, the closer the distance between the nodes, the more the communication will form the link, so that the logical ID is smaller; (4) when the channel between two nodes is poor, it can be considered that the communication distance between the two nodes increases; (5) the nodes are randomly distributed in the region, and each node, at least, can communicate with one node.
The following is simulation of the different communication distance of the situation. When the maximum effective communication distances of the nodes are 5 m and 7 m, the clustering algorithm initialization structure is shown in figure 3. The two labels in the figure represent their physical ID and logical ID (in parentheses).

![Figure 3](image-url)

**Figure 3.** Simulation results of different maximum effective communication distances: (a) Maximum communication distance 5 m and (b) Maximum communication distance 7 m.

The following conclusions can be drawn: (1) The use of non-overlapping clustering method to achieve low-voltage power line routing, including node relay, receive and send all the required functions; (2) when the effective communication distance of the nodes on the power line changes, the original routing relationship changes dynamically according to the distance; (3) when the channel of nodes are good, the maximum communication distance will become larger, which will make the cluster of the level and the number of network reduce. As shown in figure 3(a), the node path with the physical address of 30 is: 0 (0) → 6 (1) → 13 (17) → 21 (36) → 30 (58), a total of 5 layers of network, and in figure 3(b), it is in the range of 0 (0) → 13 (16) → 30 (44), a total of 3 layers of network. The cluster head is 20, and the number of network is 36 in the figure 3(a), while they are 16 and 30 in the figure 3(b); (4) as shown in figure 3(a), the physical ID of 49 and 48 of the two nodes in the network initialization phase, the two competing to report the physical ID of the probability of cluster should be the same, but if the 48 → 42 channel is poor, then 49 will be reported ahead of 48. Therefore, according to the simulation results, clustering algorithm can achieve automatic relay and dynamic routing.

4. **Improved clustered routing timing assignment**

4.1. Traditional timing assignments

In the initialization phase of the cluster algorithm, it is necessary to consider the allocation of the logical number according to the node. A non-overlapping clustering algorithm is adopted by this paper. In the case of single channel, which only one node can transmit data in the channel to avoid the collision of signals in the channel. The algorithm requires that the time interval at which the adjacent nodes of any logical ID send channel should meet:

\[ T_i = T_1 + T_2 + T_3 \]  

(1)

\( T_1 \) represents the time information sent; \( T_2 \) is the data processing time; \( T_3 \) is the redundancy time. Where the time consumed by \( T_2 \) and the settling time of \( T_3 \) are in the order of microseconds. Therefore, in order to simplify the algorithm, the carrier signal transmission time is taken as the total
The problem of channel timing assignment in clustering algorithm is mainly to solve the fastness of networking, and to ensure that the channels are not collided, and the timing protocol is simple.

The traditional algorithm is meant that after the central node sends the broadcast, the node receiving the network broadcast will send the response frame to the master node according to certain time rules, and then the master node sends the logical ID number to the corresponding slave node. For example, nodes 1, 3 need $1 \times T_i$, $3 \times T_i$ time interval to send a reply, and obtain the master node assigned logical ID. Similarly, the rest of the logic layer is such a distribution process.

From the above allocation process, we found that the method based on the non-overlapping clustering algorithm is based on the expense of the network time to simplify the agreement to ensure the reliability of communication. However, in order to be able to more quickly in the power line environment and faster network, and have to ensure the reliability of communication, the existing timing allocation must be improved.

4.2. Change the timing of the allocation

Improved algorithm: It can be seen from the time slice $T_i$, which was decided by the carrier signal,

$$L = v \times T_i = v \times T^i$$  \hspace{1cm} (2)

Where $v$ is the communication speed of the carrier and $L$ is the communication distance between the two nodes. For a carrier, the speed of the carrier is constant, so we can be between the two points of the communication distance $L$ instead of time as a research object, of course, the time can also be representative of the distance as a research object.

The maximum communication distance of figure 3(a) is 5 m, and the corresponding communication time interval is $T_i$. And the communication distance between nodes is randomly distributed within 5 m, regardless of whether the communication distance is the largest 5 m or other, the time interval will be $T_i$, so in order to speed up the network time, the node can communicate with the node to do the distance: When communication distant between nodes is $0 \leq L < 2.5$ m, then the communication time interval is changed to $T_i/2$; when communication distance between nodes is $2.5 \leq L \leq 5$ m, the time interval is the original $T_i$. Thus, for nodes with small node spacing, the communication time of the communication channel extension system will not be occupied for a long time, and the communication protocol will not be complicated and the original network channel will not be changed.

4.3. Simulation results and analysis

![Figure 4](image.png)

**Figure 4.** Time-consuming comparison of two timing assignments at different maximum communication distances.
Figure 4 shows the simulation results under the conditions with different maximum effective communication distances. The Y-axis represents the number of time slices $T$, and the X-axis indicates the maximum communication effective distance.

According to the simulation results, we can conclude that: (1) After the improved timing allocation, the networking time is much smaller than that before the improvement, but the complexity of the routing protocol increases, and it is necessary to add a definite time whether $T_i$ or $T_i/2$. Because each time the node and the communication between the nodes, you need to return to the time required to determine the time slice value. (2) Whether it is improved before or improved after the timing of the distribution method, the power line network communication channel interference by the smaller time, the network will be shorter. (3) Time-consuming time of basic clustering time as the communication distance between nodes increases, the clustering time is time-consuming is not significant. This is because when the node's effective communication distance is 14.1 m, the network structure is only the main node and slave nodes, no cluster head. All nodes will be in

$$\left(1 + 2 + \cdots + 58\right) \times T_i = 1711T_i$$

of the time to complete network. When the effective communication distance of the node is 5 m, according to figure 3(a), the distributions of nodes in the network are the first layer of 15 nodes, the second layer of 16 nodes, the third layer of 16 nodes, and the fourth layer has a node. If the second layer of the node to the main node to return frame data, such as 13 (17), need to go through $17 \times T_i + T_i$ time to return to the main node. This shows that the second layer of the node from the main node to communicate with the time than the first layer of a $T_i$, the same reason, the third layer to more than $2T_i$, and so on. However, the number of nodes in the second and following clusters is small, resulting in a significant reduction in the time-consuming time when the communication distance increases.

When the network time is shortened, the number of initiating networking of the primary node increases in a certain period of time, which increases the update of the master node from the nodes in the network, such as deletion, addition and other updates. This can be used to update the nodes routing relationship, improve the master node and slave node communication success times, and improve the network anti-jamming.

5. Conclusions
By analyzing the characteristics of low voltage power line network, the idea of clustering stratification is used to improve the communication distance of low voltage distribution network. Based on the initialization of the network, the routing relationship of all the nodes in the network is obtained. When the network appears abnormal circumstances, the network maintenance strategy is started to achieve the stability of the relationship between network nodes. The method is mainly used in the data link layer, so it does not need to consider the original physical characteristics, only needs to consider the algorithm of programming, with a strong versatility. Although the traditional non-overlapping clustering algorithm's timing allocation method can make the communication some simple, to avoid the channel communication conflict, but the network time there is too much waste, in order to improve the network anti-jamming, proposed a node distance of the improved timing allocation method. According to the theory and simulation, it is proven that the improved timing allocation method can not only complicate the communication protocol, but also shorten the networking time obviously.

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