Research on Stability of Power Carrier Technology in Streetlight Monitoring System

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Abstract—Based on the analysis of low voltage power line carrier network topology and the characteristics of the communication channel, the concept of splitting the data bus is proposed in streetlight monitoring system. The secondary network bus strategy is adopted to solve the problem of signal relay in the control of streetlights. Because the network topology of the streetlamp control system is a complex and strong transition diagram, the traditional bus monitoring scheme is easily invalidated in the network. In this paper, the problem of optimal path planning in data transmission is realized by using an ant colony algorithm which has a strong adaptive ability.

Keywords-Power carrier; Signal relay; Adaptive routing forwarding; Ant colony algorithm

I. INTRODUCTION

In recent years, the government has actively promoted the construction of urbanization. With a large number of people quickly swarming into the city, the urban is becoming larger and larger. As a business card, the traditional street lamp control technology has been far from meeting the needs of modern city construction. The digital intelligence of street lamp control becomes the requirement of modern city street lamp construction. In order to realize the digital intelligence of street lamp control, the communication problem of street lamp control system must be solved firstly. At presently, the research of power carrier technology in streetlight monitoring system has become a hot pot. The power carrier technology has its special technological advantages, which is suitable for the communication of lamp control system. But the disadvantages of the power carrier technology are not to be ignored. This paper puts forward the information forwarding scheme based on data relay and adaptive routing, to improve the communication quality of street lamp control system.

II. THE SYSTEM TOPOLOGY OF STREETLAMP CONTROL

The network topology of street lamp control system is closely related to the location distribution of street lamps. Urban lighting systems are powered by independent transformers. The lamps used in one area are powered by a special transformer, and the street lamps are powered by it. Structure of streetlamp control network is a three-layer control network. It consists of monitoring center, concentrator and lamp control devices. The system topology is shown in figure 1. The communication network of street lamp control system is based on the digital communication network of the electric carrier. The communication sub-station is an important node, which mainly completes the transfer of information between the lamp terminal and the control center. Because of its special system structure and network model, the lamp control system has a certain technical problem to realize information communication with the power line carrier technology. Usually, the electric carrier communication is used between the lamp terminal and the concentrator. GPRS communication is used between the concentrator and the control center. The communication substation is usually set in the special transformer. The communication substation links all the light branches of this transformer. The problem of the carrier signal cannot pass through the transformer is effectively solved. The network topology of the street lamp control system is composed of radial structure and bus structure.

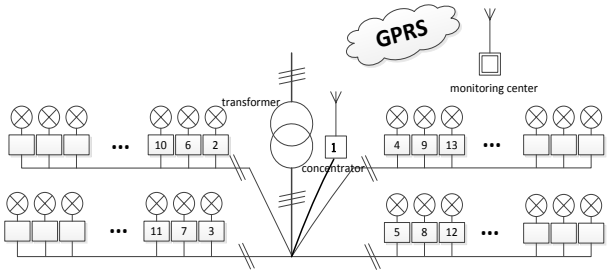

Figure 1. Streetlamp control system topology diagram

There are also significant limitations in the use of power lines as an information transfer medium. Low voltage power lines have the following problems: There are also significant limitations in the use of power lines as an information transfer medium[1]. Low voltage power lines have the following problems:

1) The electromagnetic environment is complex. The power line has poor shielding performance and is easily disturbed by external environment. There are a variety of noise disturbances on the power lines, which have strong time denaturation and different properties. It makes the electromagnetic environment of the communication channel extremely complex. The quality of the signal transmission is severely affected by electromagnetic interference[2].

2)The communication distance is limited. Signal transmission distance is the impedance characteristic of the electric power network and signal intensity attenuation restricts the. Signal transmission must consider the physical communication channel length and the impedance matching of the power supply grid.

3) The signal attenuation is serious. The attenuation of high-frequency signals on low voltage lines is a difficult problem to overcome by the power line carrier communication. Signal attenuation is affected by carrier frequency, interference in line, transmission distance. The reliability of signal transmission is affected by the random and fast effect of signal attenuation. [3]

III. THE RESEARCH OF THE RELAY PLAN

Due to the limited transmission distance of the low voltage power carrier module, a point-to-point communication cannot be carried out when the transmission distance reaches a certain level. Transmission signals can be badly distorted and can't even be transmitted efficiently. Therefore, relay transmission must be carried out by means of signal relay.

Because of the limits of the distribution of street lamps, the network transmission structure of the street lamp control system can only be bus structure. The forwarding of a lamp terminal signal can only be resolved by signal relay. It is especially important to ensure that the signal is real-time and stable during transmission. Based on this, this paper designs a two-level bus transport solution to solve this problem. The so-called secondary bus transmission refers to the separation of signal relay and signal transmission according to the characteristics of the power carrier technology. [4]

A. Network node topology analysis

Since there are more lamps on the same circuit branch, the remote street lamp terminal cannot establish direct data link with concentrator. The relay transmission of the signal to the control terminal at the remote side of the branch is required. By selecting the suitable relay nodes, the transmission scheme is adopted to establish the data link between the concentrator and the lamp control terminal. [5] The schema topology is shown in figure 2.

As shown, a remote power carrier branch that requires signal relay. Establish the data link between node 12 and concentrator 1 by using node 3, node 6, and node 10 as the relay. The signal from the node 12 is passed through the relay to the concentrator 1. This will solve the problem of the short supply of power carrier technology.

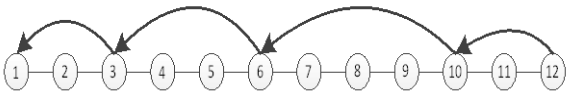

Figure 2. The relay partition topology of the street lamp

B. Subnet partitioning principle

When the number of street lamps in a branch is larger, it is not reasonable to transfer the signal from each terminal to the concentrator through the relay node. If every street lamp terminal establishes a data link directly through the relay and concentrator, this will lead to a significant reduction in signal transmission efficiency and increased communication latency. It will not meet the real-time traffic requirements of the streetlamp control system. In order to solve this problem, the concept of communication subnet in computer network communication was introduced in the lamp control system. A physical subnet is divided into multiple logical subnets by routing Repeaters. A node in each subnet serves as a relay node for data communication. The data from each control terminal is uploaded to the relay node and then uploaded to the concentrator by the relay node. The data routing protocol is used to separate subnets. Each logical subnet has a relay node. The repeater in the logical subnet is responsible for the forwarding of all terminal nodes in the subnet. Continuous transmission is adopted between the relay devices.

In order to guarantee the independence and stability of the data signals between the subnets, the frequency of transmission between the subnet is different from that in the subnet. In order to improve the security and stability of the information transfer, the relay and terminal signal transmission is separated. All nodes in each subnet transmit data over a fixed frequency. The adjacent subnets communicate in different frequencies to avoid the interference of signals between neighboring regions. The relay nodes communicate with a particular frequency, which is different from the frequency of communication within the region. In order to establish the data link between the concentrator and the control terminal, the repeater and the repeater are using point-to-point communication.

IV. RESEARCH ON ROUTE FORWARDING RULES

The routing protocol of the data forward must be studied if the relay scheme of the reasonable power line carrier is established. The geographical distribution of streetlamps leads to the monitoring network of streetlamps only as a bus network. There is only one communication channel. But we can choose different relay nodes, which can change the path of data transmission. According to the data routing protocol, the communication network independently selects the data forwarding path. This improves the availability of data transmission paths and the stability of data transfer. By means of data relay and data routing, the carrier's communication distance can be improved[6].

In the street lamp communication network, each street lamp acts as a node, and any two adjacent nodes are within the range of power line carrier communication. If there is only one data path between adjacent nodes, then the street lighting network can be regarded as an undirected graph G=(V,E), Where V represents the set of all valid communication nodes, and E is a collection of valid paths between any two nodes in the network.Dij represents the communication distance between node i and j, that is, the number of hops between the node i and the node j, and $i,j \in V,(i,j) \in E$, Wij indicates the probability that ants will connect directly to node j from node i. In a street light network with n node, the number of effective paths N from

the most remote node n to node 0 can be calculated by the network topology of the street lamp:

$$N = 1 + (n-2) + \frac{(n-2)(n-3)}{2} + \frac{(n-2)(n-3)(n-4)}{6} \quad (1)$$

Path planning requires a stable communication channel between the concentrator and any terminal devices. Because the communication channel of the street lamp system is easily disturbed, the noise distribution in the channel is random. It leads to the selection of the signal's relay device for diversity. The topology of the communication network can also be complex and variable.In order to adapt to the complex diversity of the network topology of lamp control system, the routing algorithm should be adaptive. The routing algorithm should choose the appropriate forwarding path according to the control requirement, so that the communication can be real-time and stable. The optimal path selection algorithm in the control system mainly has the ant colony algorithm, the flood algorithm and so on. How to select the relay node is the core of the study.

A. The basic principle of ant colony algorithm

Ant colony algorithm (ACA), also called ant colony optimization (ACO), is an emerging algorithm developed in recent years. It is primarily through the transfer of information between ant groups to find the optimal path. The principle is a good adaptive feedback mechanism. The ant colony algorithm uses a single artificial ant to find the optimal solution. When an ant completes its complete search, it will release pheromones on the path it passes. At the same time, more ants are given the pheromones to strengthen some of the route. In order to avoid stopping the search, the pheromones on the path will evaporate as a factor[8].

The algorithm is a heuristic stochastic optimization algorithm. Adopt positive feedback mechanism to achieve distributed global optimization. The continuous update path of the pheromones will eventually converge to the optimal path. The algorithm does not require a large number of probability calculations or a complex mathematical model to predict the system. The algorithm is used to improve the reliability and robustness of the communication system. The routing problem (RP) is one of the typical applications of this algorithm.

B. Establish the carrier communication mathematical model

Ant colony algorithm is applied to the carrier wave communication routing for diameter and the choice of relay points, first of all, according to the characteristics of the ant colony algorithm and carrier communication channel characteristics, to establish an appropriate mathematical model. The carrier communication based on the streetlamp control system has the characteristics of the spacing of the nodes and the distance between any two communication nodes. The distance between each two nodes can be normalized, and the distance between each node is 1. The communication distance between any two nodes is calculated from the location of the nodes. Each node is remembered as an element I in the ant colony algorithm. Bi(t) means the number of ants in the element I at time t. τ(ij) means the information on the t time path (I, j). N represents the number of nodes in the entire network. M is the total number of ants in the colony. Tabuk is the path the ant has traveled.

Lamp control communication has the nature of one-way non-return. A mathematical model for the carrier communication in street lamps is described using a directed graph. Using a lamp network with eight nodes as an example, the colony algorithm for carrier communication has shown in figure 3. There is a line segment indicating the distance between any two nodes, and the length is marked on the line segment. The data on the carrier communication of the street lamp control system can only be transmitted in one direction. When the concentrator sends data to the lamppost as a concentrator, only the left is valid for the line segment. When the lamp terminal sends a reply message, it is available to the right of the line segment.

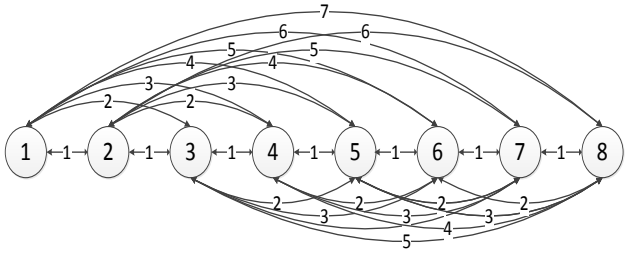

Figure 3. A directed graph of carrier communication ant colony algorithm

C. The implementation of ant colony algorithm

Considering the particularity of the power carrier communication network, it is necessary to improve the classic ant colony algorithm to achieve the control requirement of the street lamp control system. In the initialization phase of the network, the pheromones on each path are equal and set τ(ij) = const. The optimization of ant colony algorithm is achieved through a directed graph. The ant routing algorithm based on ant colony optimization has three phases, routing detection, routing selection and routing maintenance of [9].

1) Routing Detection

In the routing phase, a data packet are generated by the source node, which is called search ant. When the ant find a path, it leaves pheromones on every node passing by. When the ant reaches the destination node, it will produce a backward ant. The backward ant return the pheromone written by the search ant to the source node, and then the search ant death.

By formula (4), it can be seen that at least N of this iteration is needed when the network completes a traversal. In order to avoid excessive iterations and increase the time of travel establishment, the relay nodes in the network should be as few as possible. In the condition of data transmission error rate, the communication distance from any node j to concentrator node 0 needs to be minimum.Then:

$$D_{0j} = \{\min\{D_{0j}\} \mid D_{0j} \in V\} \quad (2)$$

During the routing phase, the main task of the artificial ant is to find the repeater node, which makes the D0j value the smallest, in N efficient paths. When routing is established, the m artificial ant is randomly placed on m different nodes. Each ant finds a local optimal solution within its own search scope. And find the optimal path in the region. When searching for the optimal path, the artificial ant k is placed in the node i, and the probability of the node j as the next node is :

$$P_{ij}^{k} = \frac{(\tau_{ij})^{\alpha}(\eta_{ij})^{\beta}}{\sum_{l \in U_j^k}(\tau_{ij})^{\alpha}(\eta_{ij})^{\beta}} \quad (3)$$

In the formula, τ_{ij} means the pheromone concentration on path (i,j) at time t, and η_{ij} is the problem heuristic information value. In communication networks, η_{ij} is positively related to the distance between two nodes. The number of nodes skipped at each time is the maximum, and the number of hops Dij is the minimum during communication. The further the node is from the source node, the more likely it is to be selected. Each node has a route forward table. The routing table is based on this node's address code and the difference between this node and the next node address, and the following formula should be satisfied:

$$s = \begin{cases} \arg_{u \in allowd_k} \max\{[\tau(r,u0)]^{\alpha} \cdot [\eta(r,u0)]^{\beta}\} & if \quad q \le q_0 \\ \arg_{u \in allowd_k} \max\{[\eta(r,u0)]^{\alpha}\} & else \end{cases} \quad (4)$$

$$(ID_u - ID_r) \cdot (ID_d - ID_u) > 0 \quad (5)$$

In the formula, $\eta(r,u) = \|ID_u - ID_r\|$, ID_r is the node where ants are explored. ID_u is an alternative destination node in the area where ants are explored. $\tau(r,u)$ is the pheromone content that exists on the selected node. $\eta(r,u)$ is the physical distance between the source node r and the destination node u. Due to the limited communication distance of each node in carrier communication, it is necessary to set a suitable destination node according to the specific situation, so as not to waste too much routing setup time.

When the bit error rate reaches the upper error limit, the target node modification mechanism will be triggered. Move the destination node to the previous node where the ants arrive. The ants are generated from the node and return the pheromone to the source node. The current node is considered as the optimal node and the pheromone and table list are updated.

2) Route Selection

The optimal relay node in the whole network has been determined at the route discovery phase. Routing is forwarding according to the selection table of each node. In the forwarding process, the pheromone of the forwarding node is constantly strengthened, and a positive feedback mechanism is formed, so that the subsequent data forwarding is always in the optimal state. Pheromone update formula:

$$\tau_{ij}^{new} = (1-\rho)\tau_{ij}^{old} + \sum_{k=1}^{m} \Delta\tau_{ij}^{k} \quad (6)$$

In the formula, $0 < \rho \le 1$ is the volatilization rate of pheromone traces; $1-\rho$ is the survival rate of pheromone traces; $\Delta\tau_{ij}^{k}$ is the pheromone increment relea. And satisfy the following formula:

$$\tau_{ij}^{k} = \begin{cases} \frac{Q}{L^k} & \forall (i,j) \in T^k \\ 0 & else \end{cases} \quad (7)$$

In the formula, Q is constant; T^k is the tour completed by the first k ant, and its length is L^k; L^k is defined as the total length of all the edges contained in T^k.

The routing option is to determine the next step based on the routing table information of each node. Each node records statistics about its status and the transition probability of its neighbors. Each node maintains its current estimate of the best path. If a node receives a message, it first looks for the node's path information in its own routing table. If there is, forward this information directly to the destination node. If not, the data is sent to the next neighbor node based on the probability transfer information in the routing table. The packet is forwarded from the source node to the destination node via a limited route forward. In the process of forwarding, the value of the information element in the table is strengthened, and a positive feedback mechanism is formed to improve the forward probability of the optimal node. After numerous mathematical iterations, each node can choose the best forward path and continuously reinforce the process. [10]

3) Route Maintenance

The optimal path from the source node to the destination node has been established, so there is not necessary to set up a special packet for routing maintenance. Routine packets will be able to complete the management maintenance of the path. In carrier communication, the channel environment is complex, and the disturbance of the channel is likely to cause a large change in the transmission distance of the node. Some nodes may suddenly drop out of the streetlights network, causing the data link to be blocked. This requires certain measures to maintain the communication stability of the entire network system. For ant colony algorithms, when some nodes are found out of the network, the information

element of the node is marked as 0. The node will select the other path from its routing table, and the data will be forwarded. Eventually, another possible forward path is formed and the path is enhanced to complete the switch. If the street lamp network has a wide range of interference, the communication node has an uncontrollable data link. The active node will restart the routing discovery, reroute the routing selection, and complete the network's self-organizing self-recovery. [11]

V. CONCLUSIONS

According to the above analysis, the application of low voltage power carrier on lamp control system has certain complexity. The physical connection of the streetlamp control system limits the topology of the communication network. The power carrier communication network structure of the street lamp control system can only be the bus structure. Signal relay must be carried out for carrier signals transmitted over long distances. This relates to the selection of the relay and the forwarding path. In this study, the proposed secondary bus transmission scheme was proposed. In order to manage the large network of network nodes, the relay is divided into different logical subnets. Different levels of the bus use different frequency transmitting signals. Different frequency transmission signals are also used between different logical subnets. In order to improve the reliability of signal relay, the method of data routing between relay is adopted. The ant colony algorithm is the optimal choice for the subnet division and route relay.

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