A Collection Node Planning Algorithm of Power Wireless Private Network in Smart Grid

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Abstract. The power wireless private network is a wireless broadband access system that is deeply customized for the development of smart grid terminal communication access, and is integrated with the power dedicated 230 MHz spectrum to meet the wide coverage, large capacity, strong real-time performance, high security, flexibility and easy-to-expand of the power intelligent terminal, and provide integrated wireless communication private network solutions for various services such as distribution automation, electrical information collection, and precise load control. This paper proposes a data collection node planning algorithm in wireless power private network, which can realize the data measurement of large-scale intelligent power terminals at a small cost. Simulation results show the reliability of our algorithm.

Keywords: Power wireless private network · Smart grid · Adaptability

1 Introduction

1.1 A Subsection Sample

The power industry is the basic industry related to people's livelihood and the country's most important infrastructure [1–4]. In the current energy transformation, in order to accelerate the realization of energy transformation, higher requirements are placed on the smart grid. The wireless private network is the foundation of the smart grid, meeting the access needs of diverse, ubiquitous, intelligent, and large-scale equipment at the end of the grid. Power wireless private network can effectively provide security guarantee for the smart grid, effectively monitoring and acquisition of power grid and the communication between the user data, such as the state of the user terminal information, equipment operation parameters, control information and other data, and make timely response to abnormal data, sends out control instructions to maintain the normal operation of power grid [5–8]. However, with the rapid increase of the number

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of power users and the types of power consumption, the traditional user-by-user data collection method not only extends the time, but also tends to generate a large packet loss rate for the power consumption data with a long distance. As a result, many intelligent terminals in power distribution network deployment to convenient for data acquisition, deployment of data access nodes at the same time, it will be assigned to the corresponding data in the network, intelligent terminal access node for collection and analysis, and then transferred to the upper data processing center, such as data acquisition and monitoring control system, measurement data management system, etc. [9, 10]. By connecting the intelligent terminal with the upper data management system, the data access node can improve the real-time reliability of data acquisition in power distribution communication network. Therefore, effective planning of access nodes is the key to achieve reliable and complete information transmission between intelligent terminals and access nodes, which has a profound impact on maintaining safe and effective operation of distribution network [11–13].

At present, many researchers have begun to study the location of data access nodes in the power grid, and most of them choose the optimal location of access nodes mainly from the constraints of reliability and economy. However, in practical applications, we need to consider not only the cost and packet loss rate, but also whether the data transmission can arrive within the specified time and the network fault tolerance [11]. Therefore, this paper combines economy, reliability, real-time to select the best location of data access node, to ensure the effective operation of power wireless private network. In order to confirm the optimal location and routing table scheme of data access nodes in power distribution communication network, this paper proposes an access node planning algorithm for power wireless private network considering the economy of network construction, network delay, network reliability and network fault tolerance. Firstly, the mathematical models of network delay, network reliability and network construction cost are established respectively. Then, an access node planning algorithm based on immune algorithm is proposed. Finally, we use Matlab to verify our scheme, the experiment shows that the access nodes established by this method can maintain good network performance.

2 Access Node Planning Model

2.1 Power Wireless Private Network Introduction

The power wireless private network is mainly composed of a core network, a network management system, a base station and a wireless terminal. The specific network architecture is shown as Fig. 1.

Core Network Equipment (EPC). Responsible for terminal authentication, terminal IP address management, mobility management, etc., providing interfaces directly to the main service of the power service.

Network Management Equipment (eOMC). Responsible for remote configuration management and status monitoring of core networks, base stations, and wireless terminals.

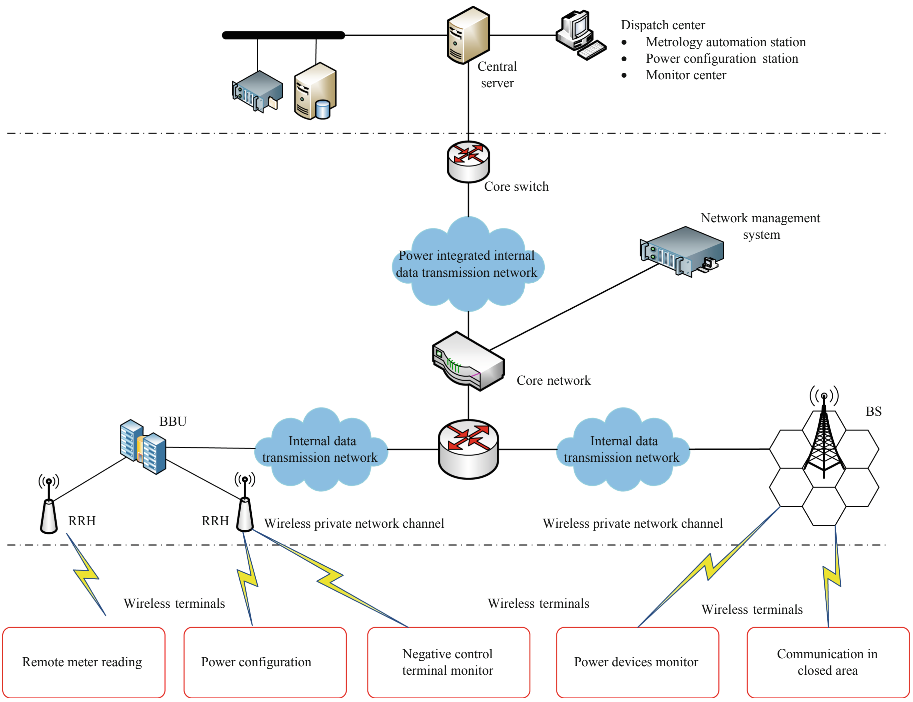

Fig. 1. Wireless private network architecture.

Base Station Equipment (eNodeB). responsible for communicating with wireless terminals through a spatial interface, and implementing functions such as resource scheduling, radio resource management, radio access control, and mobility management.

Wireless Terminal (UE). The wireless terminal provides wireless data collection and transmission, and can be directly embedded in a power terminal such as a power collection device and a load control.

2.2 The Role of Power Wireless Private Network in Smart Grid

Smart grids need to have high-speed, two-way, real-time power wireless broadband communication network support. The smart grid system has three parts, as shown in Fig. 2. One is the sensing layer, which is responsible for collecting all kinds of information of the micro grid (through various types of terminals such as smart meters, concentrators/ collectors, negative controls, RFID electronic tags, voltage and current transformers, etc.) The second is the network layer, which undertakes the transmission of information (wireless private network, wireless public network, wired private network, etc.); and the third is the application layer, which analyzes, processes, controls and decides on the collected various types of power grid information to achieve grid specificity. The intelligent application and service is located at the network layer and is responsible for the collection of big data.

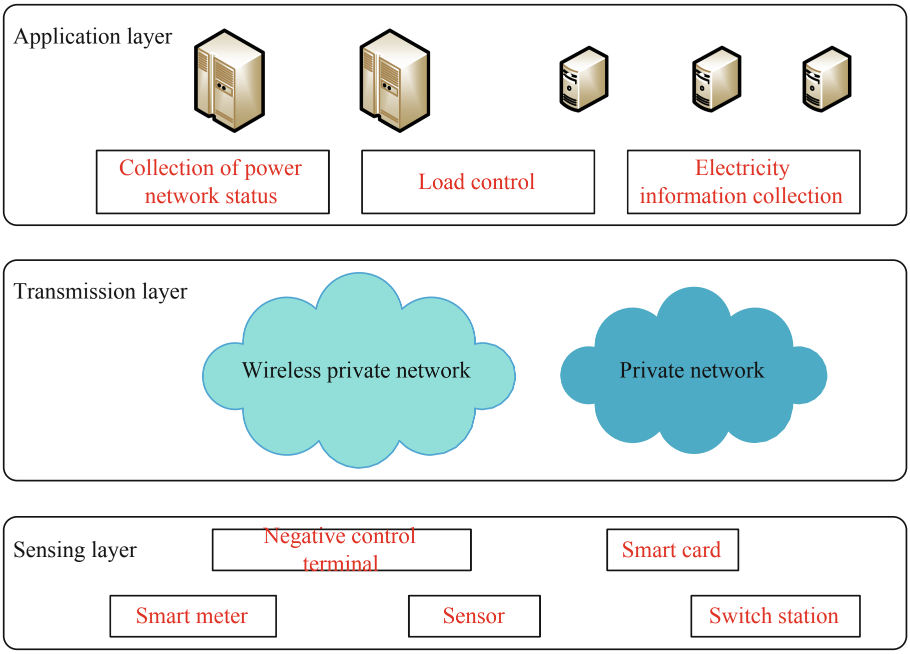

Fig. 2. The role of wireless private network.

2.3 Data Acquisition Model

Undirected graph is used to represent the network topology of the distribution communication network, where undercurrent and L represent the set of terminal nodes and link sets of the network respectively. The W in the terminal node set E is the number of terminal nodes. P represents all possible path sets from each set of terminal nodes to the location of access node, where P represents the route from terminal node I to access node j, with the number of hops n. As shown in the figure, the access node planning model diagram, where the black node is the data access node, connected with the upper data management center; the white node is an ordinary intelligent terminal node to assist in data measurement. Under this model, we consider the constraints of network construction cost, network reliability, network delay, network fault tolerance and other four aspects facing the selection of data access nodes (Fig. 3).

Network Construction Cost. In the planning problem of this section, it is assumed that the construction cost of network lines and common intelligent terminals is the same in different networks, and is set as C^L. Data acquisition location is the key to access node planning, and it needs to be protected when deployed, that is, to ensure its good

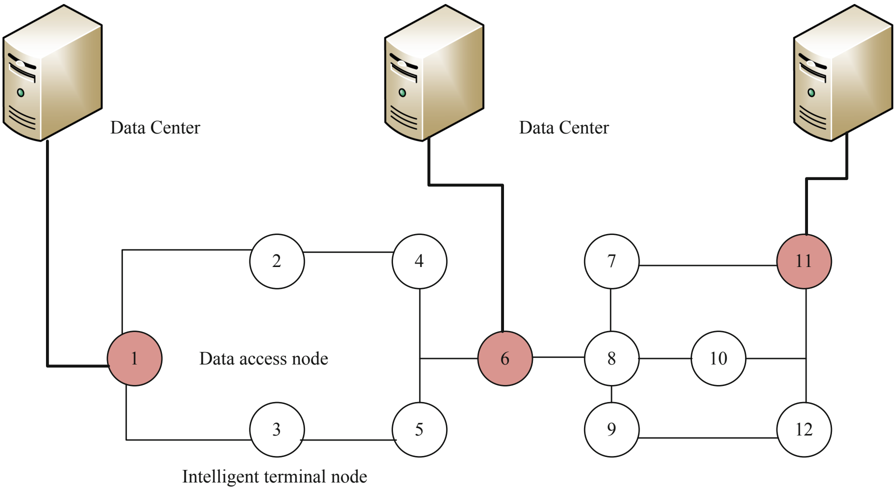

Fig. 3. Data acquisition model.

performance even in bad weather such as rain and snow. c_j represents the construction cost required to deploy the data access node at node j, and the construction cost of the entire network is:

$$C = C^L + \sum_{j=1}^{M} c_j * x_j \tag{1}$$

where $x_j \in \{0, 1\}$, $x_j = 1$ means node j is selected to deploy an access node; when $x_j = 0$, it means location j does not need to deploy an access node; and M means the number of candidate access nodes.

Network Reliability. r_v represents the reliability of communication link v, and the reliability of a communication link is generally the ratio of its normal working time in a certain period of time to the total time. This section sets that the link reliability obeys uniform distribution on [0.9, 0.99]. The reliability of the route $P_{i,j}$ between terminal node i and access node j is the product of the reliability of all links connected by the route, which can be expressed as:

$$r_{i,j}^{p} = \prod_{v \in p_{i,j}} r_v \tag{2}$$

In addition, we specify an access node for each terminal and give routing information between the two nodes. Therefore, after obtaining the overall information of the routing table, the average reliability of the network can be obtained:

$$\bar{R} = \frac{1}{N} \sum_{i=1}^{M} \sum_{i=1}^{N} y_{i,j} \cdot r_{i,j}^{p}, p \in P \tag{3}$$

where $y_{i,j} \in \{0,1\}$, $y_{i,j} = 1$ means that the traffic of terminal node i is forwarded by routing $P_{i,j}$ under the normal state of all the devices, while $y_{i,j} = 0$ means that it is not forwarded by routing $P_{i,j}$. In order to ensure that the initial terminal node can transmit information to the specified access node through only one route, the design constraints are as follows:

$$\sum_{j=1}^{M}\sum_{i=1}^{N} y_{i,j} = 1 \tag{4}$$

Network Delay. In the network, the end-to-end delay is to node to a message in the source system and purpose of the time required to pass between two applications, mainly including a packet through a routing table to reach the purpose of access nodes each node traversal by data processing time (including the queue time) and in each transmitted on a communications link the sum total of time consuming. Therefore, in order to simplify the calculation in this section, we only calculate one packet transmitting time after k jump sent to the access node, ignoring forward consume time by purpose access nodes to the upper data management system. The sum of time delay can be calculated of a packet from a terminal node transmitted to the upper data management system by:

$$t_p^k = k \times t_{tra} + t_{pro} \times \sum_{p=1}^{k} l_p \tag{5}$$

Where, t_{tra} refers to the transmission delay on the link, and k is the total hops of the routing table. t_{pro} refers to the delay of packet in processing state, and l_p refers to the queue length when packet is ready state. It is assumed that there is no difference in nodes and links. Therefore, the average delay of transmitting one packet from each terminal node to the upper data management system is:

$$\bar{t} = \frac{1}{n}\sum_{i=1}^{n}(k \times t_{tra} + t_{pro} \times \sum_{p=1}^{k} l_p) \tag{6}$$

Based on the above three constraints, the mathematical model for the optimization of access node location of distribution communication network is as follows:

$$\begin{aligned} &\min C = C^L + \sum_{j=1}^{M} c_j \cdot x_j \\ &s.t. \quad \bar{R} \geq \varphi \\ &\qquad \sum_{j=1}^{M}\sum_{i=1}^{N} y_{i,j} = 1 \\ &\qquad \bar{t} \leq \lambda \end{aligned} \tag{7}$$

where, φ and λ refer to the reliability and the threshold of information transmission delay required by the business of a distribution communication network.

It can be seen from the formula (7) that the proposed access node location planning problem is a multi-objective optimization problem, and the heuristic algorithm can solve this problem in a limited time. Among them, the immune algorithm is not only simple and flexible in application, but also can use "vaccine" to represent the access node location strategy. Moreover, the algorithm will not fall into the local optimal solution, but can search for the global optimal solution. The steps of the access node location planning method of distribution communication network based on immune algorithm are as follows:

Step 1: Parameter setting. According to the network size of distribution communication network, the population size is set as 100, the number of vaccines extracted in each iterative evolution is 15, and the probability of crossover and mutation are 0.9 and 0.05, and the maximum number of iteration optimization is 300. According to the structure of distribution communication network, the coding length L, similarity parameter ε, reliability, and the threshold of network delay are determined.

Step 2: Initialization. The network data of distribution communication network are imported to randomly generate the initial antibody groups in the location planning scheme of access nodes, and the iterative evolution times are set as 0.

Step 3: Antibody evaluation. The affinity between the access node location planning scheme and the problem model and the affinity between different schemes are calculated for the antibody concentration and the expected reproduction probability.

Step 4: Make a vaccine. The affinity between the access node location planning scheme and the problem model is sorted in descending order, and the fixed gene fragments from the first N_m antibodies are taken as vaccines.

Step 5: Form a parent subgroup. The reproductive probability of antibodies in this algorithm is sorted from high to low, and the first $N_R - N_m$ antibodies are extracted as parent subgroups.

Step 6: Group renewal. The new antibody group in Step 5 is mutated and updated, and the vaccine is added to form a new generation antibody group according to the affinity ratio.

Step 7: If $t > M$, then the optimal solution is output; Otherwise, let $t = t + 1$, go to Step 3.

3 Simulation

In order to verify the effectiveness of the proposed access node location algorithm based on immune algorithm, we conduct a simulation experiment on the system with 20 nodes at least, and the simulation software is Matlab. In this algorithm, the encoding length is set as 20, the similarity parameter $\varepsilon = 1$, the reliability of communication link $r \in [0.9, 1]$, the node data transmission rate is 32 Kbps, and the cost of building a data access node is assuming as 10000. The change of network construction cost with network reliability is shown in Fig. 4.

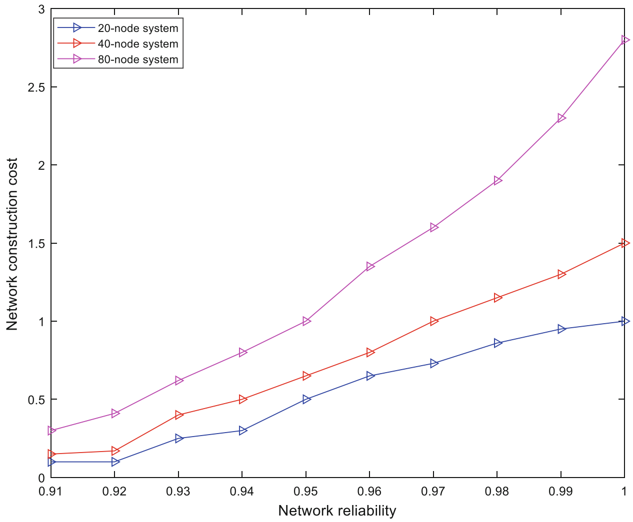

Fig. 4. Network construction cost changes.

As can be seen from the figure above, first of all, assuming that the network runs normally and only considering the network reliability constraints, the value of φ is adjusted from 0.9 to 1 to calculate network construction cost. According to the figure, the construction cost and reliability are similarly proportional to each other. When the reliability requirements of the network increase, the communication quality requirements in the network become higher, so more data access nodes are needed to collect data information to prevent data loss and damage at a distance. At the same time, when the number of nodes doubles, the network cost is less than the doubling growth, it can be predicted that the average cost of large-scale network is lower than that of small-scale network.

Next, end-to-end delay is studied. As shown in Fig. 5, end-to-end delay decreases with the increase of data rate and network reliability. When the network reliability is high, it means that there are more access nodes, so the number of hops of data forwarding between terminal nodes and access nodes can be reduced, thus reducing the time of data transmission.

It can be seen from the above results, under the guide of our algorithm, with the increase of access nodes, can not only measure for more terminals, at the same time can effectively reduce the network delay, reduce the time of data transmission, when the number of nodes doubles, the network cost is less than the doubling growth, shows the good of our algorithm.

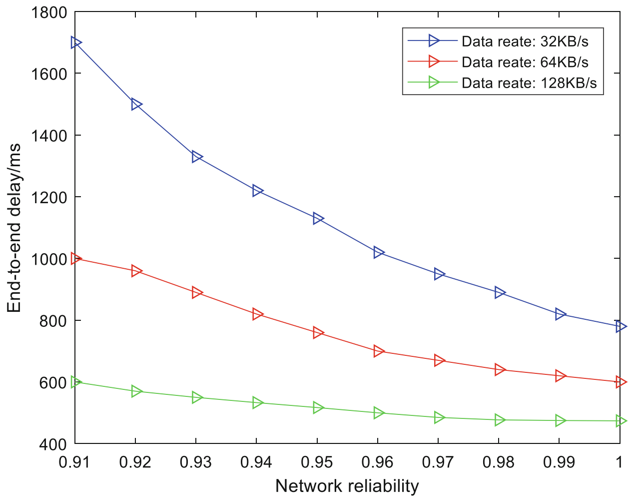

Fig. 5. Network construction cost changes.

4 Conclusion

Power wireless private network is an integrated wireless communication private network aiming at the deep customization and development of intelligent power grid terminal communication access requirements, realizing the integration of power distribution automation, power information collection, precise load control and other businesses. This paper proposes a data measurement node access planning algorithm in wireless power private network, which can realize the data measurement of large-scale intelligent power terminals at a small cost. Simulation results show the reliability of our algorithm.

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