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The Control Strategy of Smart Home Product Based on Power Line Carrier Communication

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Abstract. Smart home provides people with a more convenient and comfortable lifestyle. It makes full use of technologies such as automatic control, artificial intelligence and sensor network to release people from cumbersome housework and better meet people's living needs. With the support of Internet of Things (IoT) technology, the interaction between smart home products and users has gradually changed from single to multiple channels, and remote control and product linkage have become more common interaction modes in the home environment. In this paper, the control strategy of carrier (PLC) communication is studied, and the communication routing algorithm of PLC in IoT considering the optimization of communication resources is proposed, which realizes the fast grouping and transmission path differentiation calculation of different types of home products. The dynamic routing algorithm is simulated and analyzed in a simulation model close to the real environment, which proves that the dynamic routing algorithm proposed in this paper improves the real-time, stability and load balance of PLC communication.

Keywords: Smart Home; Internet of Things; Power Line Carrier Communication
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1 INTRODUCTION

Smart home is based on residence, curtains, etc., by using modern control technology, computer technology and communication technology, thus improving home safety, convenience and comfort. With the emergence and expansion of smart homes, energy-saving automation, security, and medical monitoring. In this study, energy management methods were used to address energy consumption optimization issues. Recently, in the context of building energy efficiency, there has been a surge in interest in data fusion. Alzoubi [1] utilized the data fusion technology proposed in this study to calculate the accuracy and error rate of energy consumption prediction. The simulation results are being compared with the previously reported methods. Its prediction accuracy has also reached 92%, higher than any other technology previously reported. Smart home provides people with a more convenient and comfortable lifestyle. It makes full use of technologies such as automatic control, artificial intelligence and sensor network to release people from cumbersome housework and better meet people's living needs. Which achieve decision automation through intelligent methods that mimic human decision-making. Bzai et al. [2] elaborated on dozens of cutting-edge methods and applications to understand how ML and the Internet of Things work together, playing a crucial role in making our environment smarter. The maturity of mobile network and IoT also gave birth to the growth of smart home product design. Moreover, modern household products are gradually changing from function to intelligence, and users are not satisfied with the function of household products, but more demand that the products themselves have independent intelligent processing ability. Hassan et al. [3] analyzed a IoT smart kitchen project. A smart home solution based on Internet of Things technology has been proposed. The research aims to improve the efficiency and safety of kitchens. This project includes intelligent kitchen appliances, intelligent kitchen control systems, and intelligent kitchen management systems. Intelligent kitchen appliances include intelligent ovens, intelligent dishwashers, intelligent kitchen electrical controllers, etc. These appliances are connected to the smart kitchen control system through wireless networks, and their functions such as on/off, temperature, and time can be controlled through mobile apps or voice control [4]. The intelligent kitchen control system includes an intelligent kitchen electrical controller and an intelligent kitchen management system. The intelligent kitchen electrical controller can be connected to the intelligent kitchen control system through wireless network, and can control the switch, temperature, and time functions of the intelligent kitchen electrical appliances through mobile app or voice control. The intelligent kitchen management system can be connected to the intelligent kitchen control system through wireless network, and can monitor the status of the kitchen in real-time, including the use of kitchen appliances, energy consumption, etc. [5]. The intelligent kitchen management system can also optimize the operational efficiency of the kitchen through data analysis, such as adjusting the usage time and energy consumption of kitchen appliances based on user habits. Overall, the IoT smart kitchen project is a smart home solution based on IoT technology, which can improve the efficiency and safety of the kitchen and provide users with a more convenient and comfortable living experience. Through IoT, people can get all kinds of biological, physical and chemical information more freely and simply, and interact with machines and equipment more conveniently, and even set up communication and dialogue channels between machines, so that machines can work together and serve mankind better.

With the support of IoT, the interaction between smart home products and users has gradually changed from single to multiple channels, and remote control and product linkage have become more common interaction modes in the home environment. Smart home product design has also covered communication protocols, use environment, user needs, interactive behavior and many other aspects [7]. In the design and application of smart home, the main characteristics of its products should be made clear, so as to do well the product design according to the actual needs of users [8]. Only in this way can we effectively meet the actual design and application requirements of smart home products under the current IoT trend, so that smart home products can give full play to their technological advantages in people's daily lives and lay a good technical and social and economic development [9]. The existing smart home is mainly based on wireless communication. For the home system that needs intelligent transformation, it is often necessary to add many wireless sensors and wireless devices, and many wireless networks conflict with other wireless communication networks in the home [10]. PLC communication that uses power line as information transmission medium to transmit multimedia signals such as data, voice and images [11]. In this paper, an PLC in IoT communication routing algorithm considering the optimization of communication resources is proposed, which realizes the fast grouping and transmission path differentiation calculation of different types of household products.

With the continuous development and change of social economy and IT, and put forward higher requirements for the home environment and home products. With the rapid growth of the new Internet, the communication performance of IoT devices has attracted more and more attention. Communication technology, that is, PLC communication technology, and reconfigurable technology is the foundation of smart grid. When the power grid experiences a fault, it can control the impact of the fault to the minimum range and realize the rapid recovery of network routing. This paper puts forward the design strategy of smart home products based on intelligent IoT:

(1) This paper proposes a load balancing model based on ant colony optimization, which realizes fast grouping and transmission path differentiation calculation of different types of home products, and provides technical support for optimal control of smart home products.

(2) This model combines the adaptability, genetic rapidity and PLC channel characteristics of the ant colony optimization (ACO) algorithm to improve the rapidity, adaptability and optimization ability of the routing algorithm.

2 RELATED WORKS

Salih et al. [6] used IoT technology to monitor various parameters in the production process in real-time, such as temperature, humidity, pressure, flow rate, etc. Thus achieving automated control and optimization of the production process, improving production efficiency and product quality. The Internet of Things technology can intelligently manage and maintain industrial equipment and networks, reduce labor and maintenance costs, and improve the economic benefits of enterprises. The Internet of Things technology can monitor and analyze data in real-time during the production process, thereby predicting and avoiding quality issues during the production process, and improving product quality and stability. The Internet of Things technology can monitor and control industrial equipment and networks in real-time, thereby improving the safety and stability of production processes and reducing the occurrence of production accidents. In short, the application of IoT technology in the industrial field can improve production efficiency and reduce costs. Optimizing product quality and improving safety are of great significance for the sustainable development of enterprises. Shakya et al. [7] help designers and engineers better understand and optimize the design and performance of ground models. CAE systems can be implemented in various ways, with the most common being the use of computer-aided design (CAD) software and computer-aided engineering (CAE) software. CAD software can be used to create three-dimensional models of ground models and perform various design and analysis tasks. CAE software can be used to simulate the physical performance of ground models, including vibration, noise, heat conduction, etc. During the planning/design phase of the ground model, the CAE system can help designers and engineers better understand and optimize the design and performance of the ground model. For example, the CAE system can simulate the performance of ground models under different operating conditions and optimize design schemes by comparing the performance of different design schemes. In addition, the CAE system can also assist designers and engineers in simulation and optimization to ensure that the design and performance of the ground model meet the requirements. Overall, establishing a CAE system for ground models is very important as it can help designers and engineers better understand and optimize the design and performance of ground models, thereby improving their design and performance. Shi et al. [8] collected detailed information about assembly parts for DEM modeling. Including the size, material, shape, defect location, etc. of the parts. Then, DEM tools can be used to model the part in order to represent various aspects of the part in 3D space. When modeling, different modeling methods can be used, such as feature based modeling, entity-based modeling, etc. Feature based modeling refers to extracting and describing the features of a part, transforming it into a 3D model. Solid based modeling refers to the establishment of a 3D model by abstracting various aspects of a part into entities and representing their relationships as relationships between entities. Tlija et al. [9] achieved intelligent control and management of the home environment by connecting various smart home devices. This system typically includes various smart home devices, such as smart light bulbs, smart door locks, smart cameras, smart gateways, etc. These devices are connected to the smart home control system through wireless networks and can be remotely controlled through mobile apps, voice control, remote controls, and other methods. Torad et al. [10] believe that the advantage of IoT smart home systems lies in their ability to achieve intelligent control and management, improving the convenience and comfort of home life. Meanwhile, Xu and Zheng [11] improved the reliability and stability of the equipment. This system can also achieve interconnectivity between devices.

By analyzing the application of IoT, this paper studies the communication routing algorithm of PLC in IoT considering the optimization of communication resources, realizes the fast grouping and transmission path differentiation calculation of different types of home products, and lays a theoretical and technical foundation for the design and research of smart home related products. The dynamic routing algorithm is simulated and analyzed in a simulation model close to the real environment, which proves that the dynamic routing algorithm proposed in this paper improves the real-time, stability and load balance of PLC communication.

3 CONTROL STRATEGY OF IOT SMART HOME SYSTEM

3.1 Application of IoT in Smart Home Products

Smart home items and applications are mainly reflected smart care, etc. Users purchase smart home items and smart home system services to realize the interconnection between smart home items, and process life data and execute control commands through the connection service platform. Humanization mainly refers to the diverse ways of interaction between users and products. Humanized design principles are embodied in the diversity of interaction between users and products. For example, smart door locks can choose different unlocking methods, such as fingerprint unlocking, password unlocking, door card unlocking and key unlocking, to meet different needs of users.

Two isolated networks can be connected by installing network connection modules on two network segments that need to be connected, and connecting the two network connection modules with network connection cables. Network signals can be transmitted to more distant places by means of network connection. Suitable for network meter reading, public networking, public equipment communication and other scenarios. Compatibility of smart home systems is very important. Incompatibility of systems will increase users' meaningless workload and affect user experience. In addition, the reliability of the system is also reflected in the power supply and system backup of home products, so as to ensure that smart home products can be applied to various complex environments. In the APPlication of home smart camera, users can bind it to the smart home control app on the mobile phone, and then directly monitor the actual situation at home through the mobile phone, so as to grasp the real-time dynamics at home.

In today's IoT trend, users' intelligent access control devices can also directly set the networking alarm function, and give an alarm in time in case of illegal damage, so as to ensure the safety of users. Compared with wireless media, PLC communication is safer and more stable, especially in information security, which eliminates security risks such as infiltration attack and man-in-the-middle cheating file replacement attack, so this paper chooses PLC communication technology as the basis of smart home. When used in smart home ecological environment, the shortcomings of PLC communication technology have also been greatly weakened. The application of PLC communication technology is divided into power line Ethernet isolator and power network Ethernet connector. These two applications are the basic applications to control the connection range of this system, which will solve the shortcomings of PLC communication, such as small transmission range, inseparable domain and uncontrollable, and are important basic components of this system.

3.2 Routing Algorithm of PLC in IoT Communication

In the whole smart home system, the smooth communication between all parts is the premise to ensure the stable and smooth operation of the whole system, so it is very important between all parts of the system. In the communication process, according to the use function design, the receiving end receiving the communication instruction generally needs to feedback data or signals to the sending end according to the instruction, so as to ensure that the sending end clearly knows the sending result of the communication instruction and ensure the smooth communication instruction. In the process of using the system, there is frequent communication between various parts. Due to some interference, the receiving end may fail to receive the communication instruction. In order to make the user get a better experience, the system should not immediately judge that the communication instruction failed and prompt the user, but can adopt certain methods to solve this problem. In this paper, a message retransmission mechanism is used to solve the problem that the receiver fails to receive the communication instruction, and the sender can retransmit the instruction when the receiver fails to receive the instruction. The process of message retransmission mechanism is shown in Figure 1.

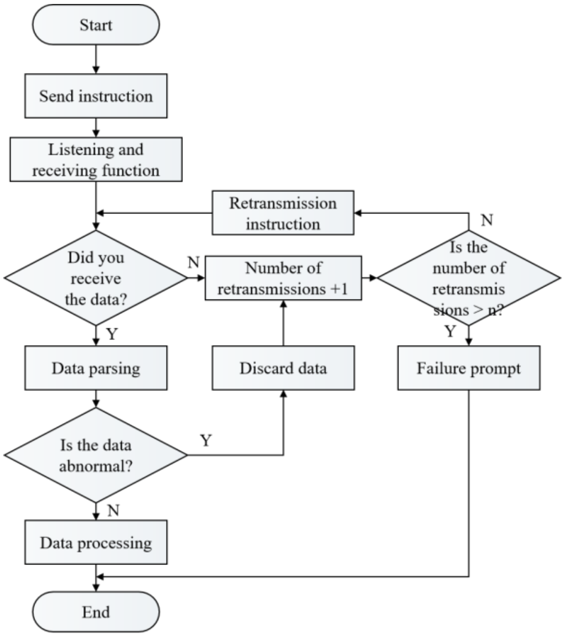

Figure 1: Flow of message retransmission mechanism.

PLC communication is a unique communication mode in power system. At present, it can be used to transmit voice, telecontrol data and remote protection signals. It is one of the important communication modes to ensure the safe, high-quality and economical operation of power grid and realize dispatching automation and management modernization. A small system with a small amount of data does not need a special architecture in the background. It only needs to integrate all applications, files and databases to ensure the stable operation of the whole system, and all parts can be directly called to deploy all parts of the background system together, which can effectively save deployment cost and time. The communication optimization process of PLC in IoT based on ACO algorithm is shown in Figure 2.

When the available bandwidth of the network m is $i \in B_m$, the revenue that the service can obtain is set as $a_m(i)$. The available bandwidth is a benefit index, so the benefits it brings are:

$$a_m(i)=\frac{i-b_{\min}}{b_{\max}-b_{\min}}, i \in B_m \tag{1}$$

Let $v_m(i)$ be the total revenue that the service can get when the available bandwidth of the network m is i:

$$v_m(i)=a_m(i)+\sum_{j \in B_m} P_m(i,j) v_m(j), i \in B_m \tag{2}$$

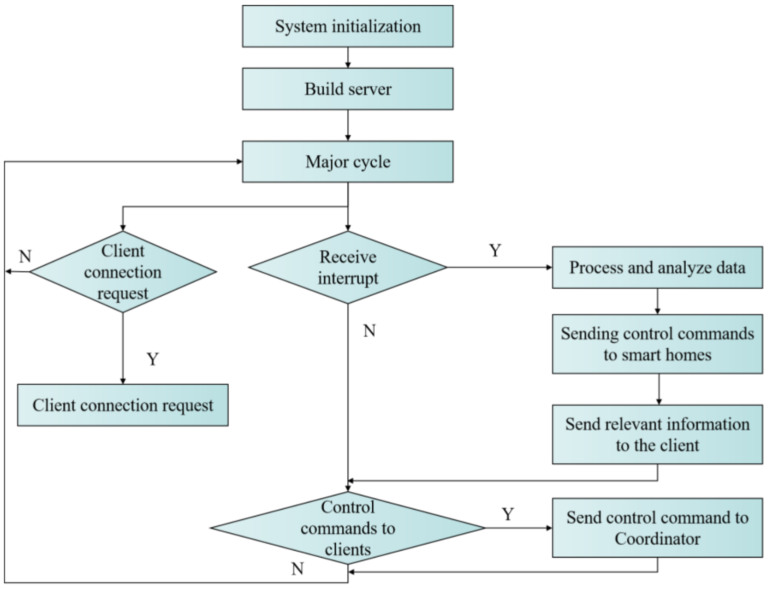

Figure 2: Communication optimization of PLC in IoT.

The calculation of $v_m(i)$ adopts an iterative method. Definition:

$$v_m^{(0)}(i) = a_m(i), i \in B_m \tag{3}$$

Then there are:

$$v_m^{(k)}(i) = a_m(b) + \sum_{j \in B_m} P_m(i, j) v_m^{(k-1)}(j), k \geq 1 \tag{4}$$

The iteration is terminated when the following formula is satisfied:

$$\sum_{i \in B_m} \left[v_m^{(k)}(i) - v_m^{(k-1)}(i) \right]^2 \leq \varepsilon \tag{5}$$

At this time, the total revenue value is the final value, and the final value is used for comparison in network selection.

According to the improved ACO algorithm, the global updating of pheromones is carried out according to formulas (1) and (2) after all ants have built the schedule, which reflects the optimal path keeping strategy:

$$T_{ij} \leftarrow (1-\rho) T_{ij} + \rho \Delta \tau_{ij}^{bs} \tag{6}$$

$$\Delta \tau_{ij}^{bs} = \begin{cases} 1/T_{bs} & (i, j) \in \text{Global optimal schedule} \\ 0 & \text{Otherwise} \end{cases} \tag{7}$$

The local pheromone update is carried out according to formulas (3) and (4) after each ant builds the schedule, so that the pheromones on the path are continuously volatilized, which is beneficial to search for new solutions:

$$\tau_{ij} \leftarrow (1-\xi) \tau_{ij} + \xi \Delta \tau_{ij} \tag{8}$$

$$\Delta\tau_{ij} = 1/T \tag{9}$$

T_{bs} is the total duration of the global optimal schedule, and T is the total duration of the schedule built by ants in one iteration. ρ and ξ represent the volatilization rate of pheromones, so that the updated pheromone amount is between the old pheromone amount and the newly released pheromone amount.

When choosing the optimal route, a multi-objective function is formulated according to the difference of transmission service requirements of different service types, so that the service can optimize the use of communication resources globally and meet the multi-service quality requirements in one route. The received signal r_n and locally stored P symbols are both quantized by single bit for cross correlation:

$$Q_1(n) = \sum_{i=0}^{L-1} sign(r_{n-i}) sign(t_{L-i}) \tag{10}$$

Quantize the P symbol stored locally by single bit, then cross-correlate it with the received signal r_n, square it, and then normalize it with the power of the signal:

$$Q_2(n) = \frac{\left|\sum_{i=0}^{L-1} r_{n-i} sign(t_{L-i})\right|^2}{\sum_{i=0}^{L-1} |r_{n-i}|^2 \sum_{i=0}^{L-1} |sign(t_{L-i})|^2} \tag{11}$$

Single-bit quantization of locally stored P symbols, cross-correlation with received signal r_n, and normalization with absolute value;

$$Q_3(n) = \frac{\sum_{i=0}^{L-1} r_{n-i} sign(t_{L-i})}{\sum_{i=0}^{L-1} |r_{n-i}|} \tag{12}$$

$$f : R^n \to R \tag{13}$$

$$y_i = f(x_i) \tag{14}$$

Where: R^n is the factor that affects the power line carrier communication. According to the improved ACA, the establishment of the power line carrier communication optimization model seeks the following expression:

$$f(x) = \sum_{i=1}^{k} (a_i - a_i^*) K(x, x_i) + b \tag{15}$$

$$K(x, y) = \exp\left|-\frac{\|x - y\|^2}{2\sigma^2}\right| \tag{16}$$

After the communication module is connected to the power line communication network, it will send an address request frame to the server. In this request frame, the communication module will explain to the server whether its working type is smart plug, universal remote controller or sensor module. After receiving the request, the server will automatically respond, reply to an unused hardware address, and record the type of the communication module, so as to obtain relevant data or send control instructions in subsequent communication.

4 RESULT ANALYSIS AND DISCUSSION

The ultimate value of smart home products is to serve consumers. In addition to the functions of the products themselves, the continuous service of the products will bring consumers a deeper experience. Smart home network center shields the differences between different networks, provides a unified communication method, and connects different media networks into a whole, which makes it possible for the unified linkage control of equipment. When the network overload forms a congestion bottleneck area, the nodes in the bottleneck area can adopt the corresponding dropping strategy only by looking at the packet loss level of differentiated services. It also further ensures the fast response processing ability of the algorithm when the traffic is suddenly congested. In order to reduce energy loss, the node management in PLC communication routing algorithm in this paper adopts sleep and call mechanism. Figure 3 shows the relationship between packet generation rate and order parameters.

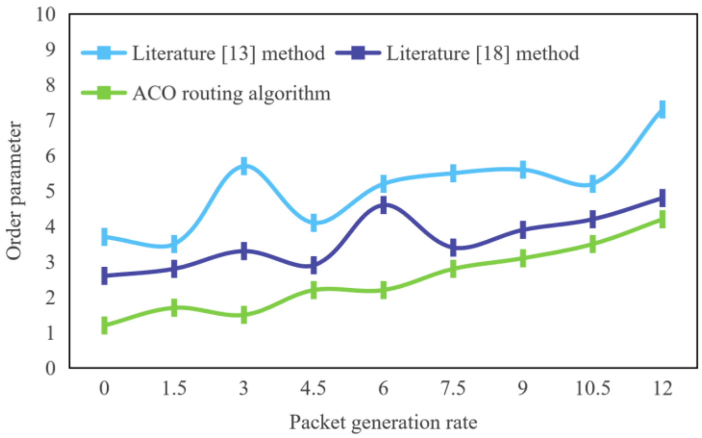

Figure 3: Relationship between packet generation rate and order parameters.

The process of obtaining the best path by routing algorithm is essentially the process of constructing the optimal solution. During the execution of the algorithm, several possible optimal solutions will be constructed, and one of them will be quickly selected as the optimal solution. In order to get the optimal solution quickly, when constructing the alternative optimal solution, we should exclude some obviously irrelevant paths, reduce the unnecessary search direction and control the search direction of the sending node.

The concentrator sends a path detection command when the network is idle, which mainly tests the communication delay of each target node. The concentrator sends test data packets, and each target node returns data packets. The concentrator counts the delay of each target node's return data packets, and evaluates the advantages and disadvantages of each path. If the delay of some paths is too large, it means that there must be some paths with poor channel states, so these paths are probably not optimal paths and need to be searched again. This paper compares the PLC communication routing algorithm with the traditional routing algorithm, and analyzes the packet loss rate of PLC communication routing algorithm under different malicious nodes. The simulation results are shown in Figure 4.

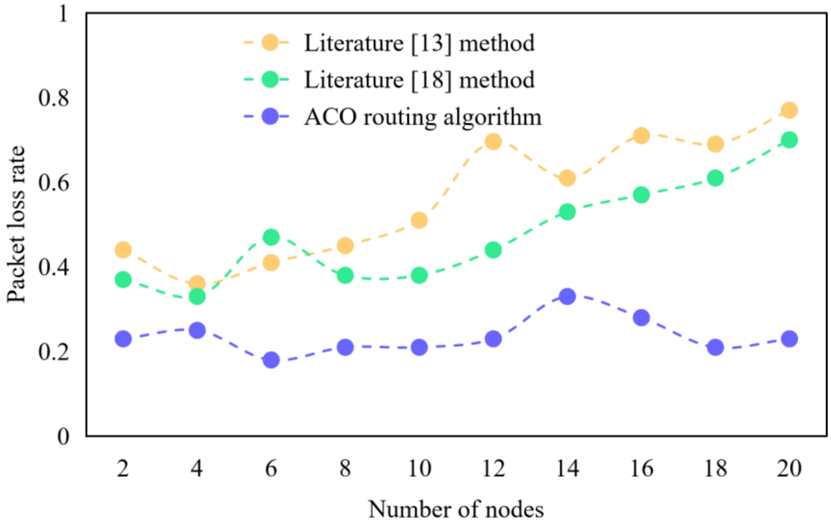

Figure 4: Network packet loss rate with different malicious nodes.

As can be seen from the data in Figure 4, with the increase of the quantity of malicious nodes, the packet loss rate of the network increases gradually, but compared with the other two PLC communication routing algorithms, the packet loss rate of this PLC communication routing algorithm increases slowly.

The pheromone volatilization coefficient is the key to the negative feedback mechanism of ACO algorithm. The higher the volatilization coefficient, the faster the pheromone elimination on the path and the stronger the negative feedback mechanism. On the contrary, the slower the pheromone elimination on the path, the weaker the negative feedback mechanism. The main reason for optimizing ACO algorithm is to reduce some invalid path exploration and improve the efficiency of routing path construction. The purpose of designing heuristic factors is to make more targeted node selection in the process of constructing the optimal path. The relationship between packet generation rate and sequence parameters is shown in Figure 5.

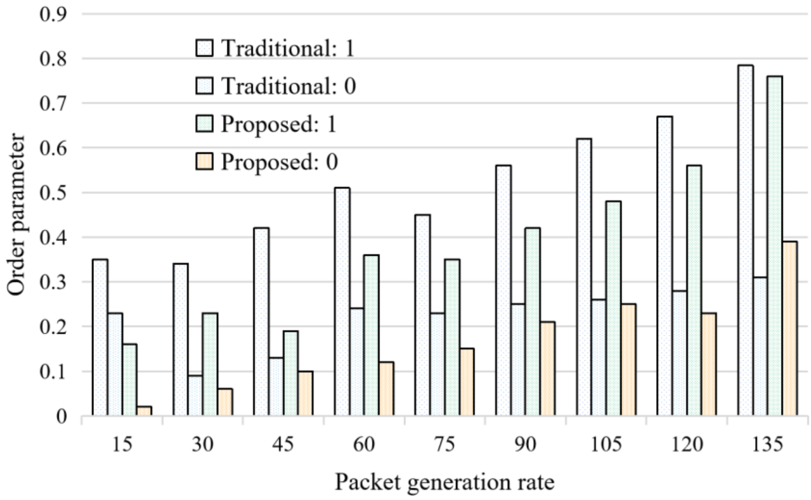

Figure 5: Relationship between packet generation rate and sequence parameters.

It can be found that the routing strategy in this paper is obviously superior to the local information routing strategy. The PLC communication network is highly time-varying, and new nodes are often added to the network. At this time, the new nodes must automatically report their addresses and related information to the concentrator, and the concentrator should add the new node addresses to the routing table.

According to the principle of PLC communication routing algorithm in this paper, the congestion degree of all nodes on the path is well considered in the process of data packet transmission, so that nodes with serious congestion can be avoided in time and effectively. The effectiveness test results of different algorithms are shown in Figure 6.

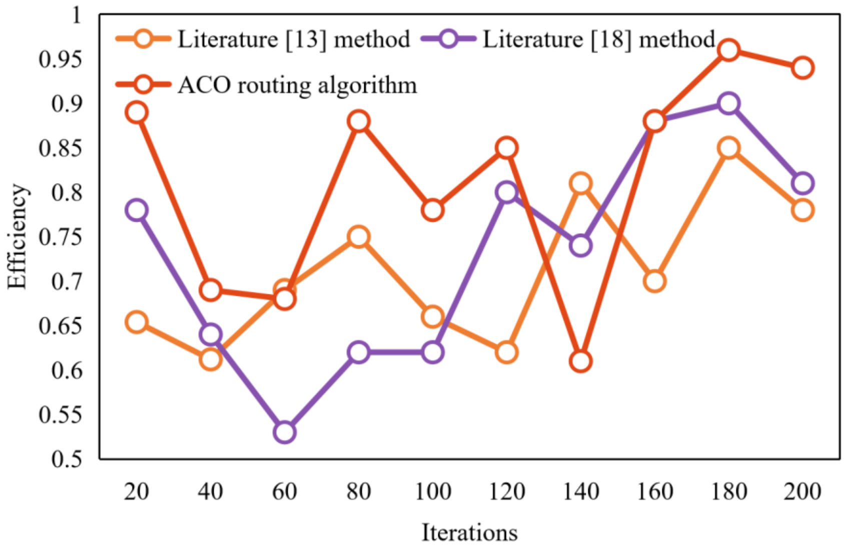

Figure 6: Effectiveness test results of different algorithms.

Pass the data packet to other idle nodes, gradually relieve the congestion degree of nodes with serious congestion, and finally realize the balance of IoT load of the whole smart home product. If a small quantity of nodes join the network, it is not necessary to modify the original routing table, but only need to update the routes of the newly joined nodes into the routing table. However, the routing of the newly added node only needs to add the node within the range allowed by the quantity of relay hops on the routing of the node directly communicating with it.

The load of dynamic access line can't guarantee to match the characteristic impedance of the line, which causes signal reflection and standing wave effect. The input impedance of low-voltage power line network will change sharply with the change of time and place. Therefore, it is difficult to match the output impedance of transmitting equipment with the input impedance of receiving equipment, and the energy of signal coupling to power line will be very small, resulting in large coupling loss, which brings considerable difficulties to the design of communication system. Figure 7 is a comparison of packet loss rates.

By comparison, it can be seen that the packet loss rate of the two algorithms increases with the increase of communication distance. The mixed routing algorithm has a low packet loss rate and a slow growth rate. This is because the hybrid algorithm introduces ant colony optimization mechanism to avoid premature convergence. Power line channel is a time-slow channel, and the overall channel parameters remain basically unchanged in a relatively short period of time. If the dimension of the space is small and the characteristics of the channel can be well described, an estimator with low complexity and good performance can be obtained.

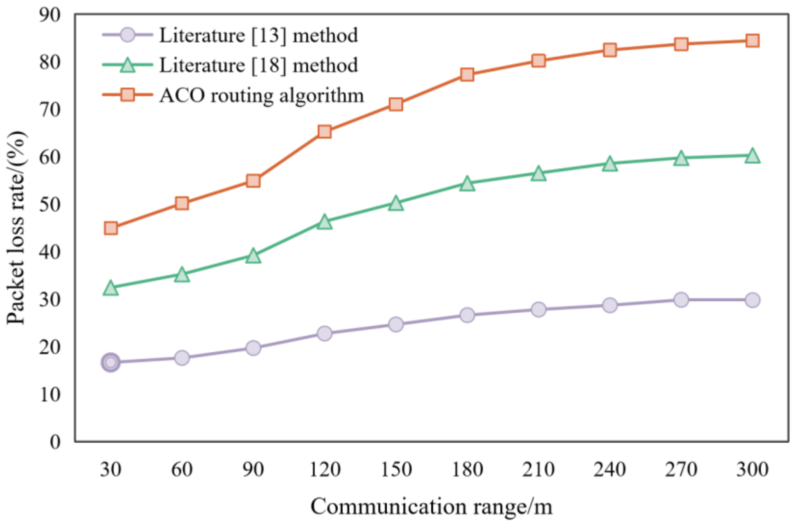

Figure 7: Comparison of packet loss rates.

5 CONCLUSION

With the support of IoT, the interaction between smart home products and users has gradually changed from single to multiple channels, and remote control and product linkage have become more common interaction modes in the home environment. The design of smart home products has also covered many aspects, such as communication protocol, use environment, user needs, interactive behavior and so on. In this paper, a load balancing model based on ant colony optimization is proposed, which can realize the fast grouping of different types of home products and the calculation of transmission path differentiation, and provide technical support for the optimal control of smart home products. The mixed routing algorithm has a low packet loss rate and a slow growth rate. This is because the hybrid algorithm introduces ant colony optimization mechanism to avoid premature convergence. The introduction of IoT realizes the real-time collection, transmission, processing, integration and feedback of information among various smart homes, and predicts user behavior through big data calculation in the cloud, getting rid of the previous mechanical processing of user input instructions, and truly changing users' lives with intelligence.

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