Eng Int Syst (2024) 4: 299–308
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Engineering
Intelligent Systems

Optimization and Performance Evaluation of Wireless Network Topology Based on Electrical Data

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This paper explores topology optimization and conducts a performance evaluation of wireless networks based on electrical information data. The effectiveness of the topology optimization method based on electrical information data was verified. By applying the FW-PSO algorithm, which is a combination of the Frank-Wolfe (FW) algorithm and Particle Swarm Optimization (PSO), the performance analysis was carried out. The FW-PSO algorithm adopted two attack methods: High-Degree (HD) and Lowest-Degree (LD), and the performance of the FW-PSO algorithm was analyzed. The optimal values of natural connectivity of FW-PSO algorithm, PSO algorithm, DE (Differential Evolution) and feasible direction algorithm reached 9, 8.5, 8.2 and 2 respectively. Simulation results indicate that FW-PSO is more robust than DE and PSO. The FW-PSO algorithm is capable of greatly improving network performance, including transfer rate, energy consumption, security, and other functions.

Keywords: electrical information data, wireless network topology, performance evaluation, structure optimization, particle swarm optimization

1. INTRODUCTION

Electricity is an essential resource for the development of modern society. With the continuous expansion of socialist modernization construction, people's dependence on power resources has been increasing dramatically, leading to frequent overloading of the daily operation of the power system. This has also affected people's productivity and living conditions. Therefore, it is necessary to accelerate the development of electrical engineering automation. Furthermore, the operation efficiency of electric power system can be improved, so that the social development can be promoted and economical and social demands can be met.

Data analysis is becoming increasingly important in modern industries. Driven by the development of information and communication technology, and with the widespread installation of intelligent meters and sensors, traditional transmission and distribution networks have added an information layer for data collection, storage, and analysis. Zhang et al. (2018) summarized the technique of big data analysis and intelligent grid. These researchers first discussed the properties of big data, intelligent grid and mass data collection, as well as the basic concepts and procedures of typical data analysis. Emphasis was placed on advanced applications of various kinds of data analysis techniques in the area of smart grids. The gathering of massive amounts of data from the electrical system, meteorological information system and geographic information system, can bring many benefits to the current energy system, as well as improving customer service and social welfare in the age of big data. However, in order to apply big data analysis in the smart grid, numerous problems need to be addressed and overcome, including the issues of cognition and collaboration [1]. Renewable energy reduces greenhouse gas emissions and can generate economic benefits. At present, the energy network is moving towards smart grids. One of the major objectives of intelligent grid in the future is to achieve a 100% renewable energy system.

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In addition, the power generation of a single renewable energy power plant is usually smaller than that of conventional fossil fuel power plants, and there are many types of technologies being used. Rehmani et al. (2018) provided an overview of the latest work in smart grids and also discussed ongoing projects globally seeking to incorporate renewable energy into sustainable development strategies [2]. In the future mobile communication network, using double-clad fiber to further increase the transmission power of the optical fiber power supply link, Matsuura et al. (2020) modified the link design to obtain a higher feed power from the double-clad fiber. In addition, in order to increase the power required to drive the remote antenna unit, a specially customized photovoltaic power converter was used for direct conversion of optical energy into electricity. The photovoltaic power converter could input light sources with a power of more than 20w, and the solar-cell efficiency was more than 50% [3]. The increasing cost of energy, the current loss of the grid, the risks associated with nuclear power generation, and changes in the environment around the world are pushing for a change in traditional methods of power generation. Globally, people are seeking to increase their reliance on renewable energy sources.

The existing topology optimization methods for wireless sensor networks simplify the assumption of fixed communication radii between network nodes, and are not suitable for deployment in complex terrain IoT networks. Oroza et al. (2021) proposed a data-driven topology optimization method using Bayesian link classifiers that were trained on the features of the exported terrain and were used to measure the quality of the link. Classification was used to predict the locations where good network connections could be created in a given region with complex terrain characteristics. The positions of numerous candidate wireless nodes in the entire domain were given, and an undirected weighted graph of potential connectivity across domains was constructed using a classifier. A new improved cyclic joint algorithm was applied to generate a minimum network with two-point connections, and it was applied to the undirected weighted graph of potential network element positions. This ensured a survivable network design while maximizing the probability of having good links in the final network [4]. Along with the demand of data center resources, the number of data servers is also growing. However, the cost and inflexibility of the traditional wired connection between the servers is high. Thanks to smart optimization and other technologies, Cao et al. (2019) studied the application of high-speed wireless topology in wireless data centers, established a radio propagation model based on heat maps, and also discussed the issues of line of sight and interference. By taking into account the objectives of coverage, propagation intensity, the topology optimization issue was formulated as a multi-objective optimization problem. To find a solution, the world's most advanced multi-objective optimization algorithm and multi-objective optimization algorithm were used. This method utilized existing prior knowledge and had certain parameter adaptability. The experimental results indicated that parallel operation was effective in optimizing results and efficient in terms of time consumption [5]. Wireless data center network is a new generation of data center technology. Intelligent architecture optimization and management are crucial for wireless data center networks. Wireless sensor networks can effectively monitor environmental parameters and any habitats that require investigation. In some cases, regular monitoring of critical environmental parameters is essential for prompt responses and the protection of life and property. The purpose of this study was to prove that the exact distance between nodes was important for different applications. Networks in different geographical areas and distances between nodes are deployed to assess and analyse performance indicators, such as number of messages received, end-to-end average delay (seconds), throughput (bps), and jitter (seconds). Furthermore, the influence of distance between nodes on the performance of wireless sensor networks is determined. In a particular monitoring application, the most appropriate distance between nodes is chosen.

Sharma et al. (2019) found that the distance between nodes significantly affected the performance indicators such as the number of messages received, the average latency, the throughput, and the jitter. These researchers found that the distance between the sensor node and the grid topology could provide the best performance by varying the distance from the network. Finally, it was concluded that optimal performance is achieved by providing maximum (208) and maximum throughput (2544.34 bps). It can also provide minimum end-to-end delay (14.45 seconds) and minimum jitter (6.67 seconds). After analyzing and evaluating, the nodes are separated by 30 meters, and the terrain area is $300\text{m}^2 \times 300\text{m}^2$, substantially improving and optimizing the performance of the network [6]. Wireless sensor networks are one of the most promising techniques for monitoring critical environments.

Traditional topology optimization methods often require a large amount of computing resources and time, resulting in low efficiency. In addition, such methods usually only consider the communication performance of the network, making it difficult to comprehensively consider other factors. The article would also explore the topology optimization and performance evaluation of wireless networks based on electrical information data.

2. WIRELESS NETWORK TOPOLOGY OPTIMIZATION AND PERFORMANCE EVALUATION SCHEME

2.1 Sources and Collection Methods of Electrical Data

Electrical data includes all kinds of data produced in the course of electric power system operations, such as voltage, current, power, etc. These data can be collected through various sensors. The source of electrical information data is shown in Figure 1:

Power grid technology is the basic foundation and main object of electrical engineering automation technology. In keeping with ongoing developments in society, relevant theories, practices, and the performance of equipment are also developing In view of the overall development of

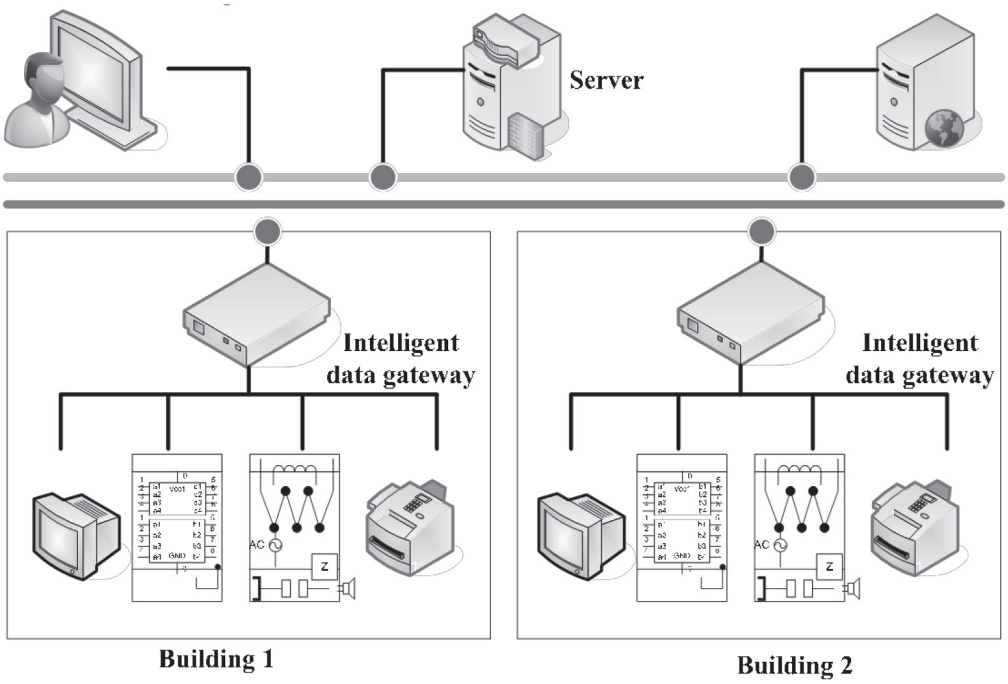

Figure 1 Model showing source of electrical data.

electric power systems, and with the support of network technology, the scale and coverage of the power grid continue to expand, and the level of power grid technology standards is also improving with the development of technology [7–8]. Because of the large areas that need to be covered, it is necessary to determine the electricity demand prior to constructing the power network. According to the actual situation, automation technology modules must be added to the power grid to ensure that the efficiency and quality of electricity transmission can fully meet industry needs as well as the everyday needs of individuals. Technical personnel must also strengthen the management of various regional power grids, take corresponding technical measures based on the actual dispatching situation of the power grid, and allocate adequate power resources with different development levels to prevent the occurrence of low voltage platform areas.

Along with the development of smart grid and Information Technology (IT), a great deal of data is produced by an electric power system [9].

As a new resource, power big data can help power companies to improve their efficiency and refine their operational and management practices. The development of big data technology can help update and change the IT platform by: improving data storage and real-time processing capabilities; strengthening the analysis and use of unstructured data; and improving the ability to discover value from a large number of data sources.

In the application of power big data, large-scale correlation analysis needs to be carried out on energy data, meteorological data and other types of data in industrial fields [10–11]. This is integrated with external industrial data. Ultimately, in-depth mining and analysis of power big data would greatly improve its usefulness.

In the power industry, big data can be obtained from a variety of sources that provide information on power generation, transmission, transformation, distribution, power consumption and dispatching. The big data can be grouped under three broad categories: data on the operation and development of the grid, the market information of the electricity company, and the operation data of the power company.

The characteristics of electric power big data are: the amount of data is huge, and the collection of electric energy of residential users is carried out on an hourly basis. There are more than 10 data items collected each time, and every day there are billions of items pertaining to the use of electric energy by residents alone. Data can be structured, semi-structured, or unstructured. Unstructured data consists of the video data produced by numerous video surveillance devices in each substation, voice data from customer service and customer communications, image data generated by drone inspections, and all kinds of electronic files in the process of circulation of the office system [12–13]. The value density is relatively low. In power networks, the detection and monitoring data and the operation of the power network are mostly normal data. Only a few of the unusual data are of high value. The abnormal data signals the need for maintenance of the system. High speed computing: Running and controlling a power system, for example, requires a huge amount of data to be processed in a matter of seconds, thereby providing support for control decisions.

2.2 Evaluation of Wireless Network Topology Structure

There are three main types of structures for wireless communication systems: star-shaped, tree-shaped, and network-shaped. In the star structure, all nodes are connected to a

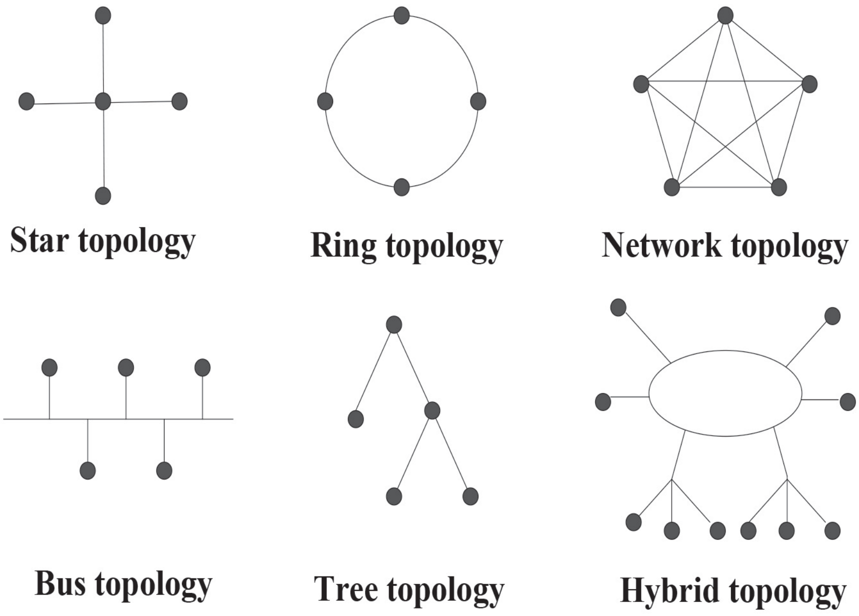

Figure 2 Structure of network topology.

central node which is responsible for forwarding data. In the tree structure, all of the nodes are associated with the root node, which is responsible for the transmission of data [14]. In a mesh structure, all nodes are connected to each other, and data can be transmitted through multiple paths.

Topology is a subject based on geometry. According to its original meaning, some properties of geometric figures or spaces can remain unchanged under the condition of constant changes. This method considers only the spatial relationship between targets, but does not take into account factors such as the shape and size of the targets. The well-known "network topology" is used to illustrate the connections and communication methods between various nodes in a network. In the modern Internet, there are many different types of devices. Moreover, a logical network arrangement is the key to ensuring that the whole system operates efficiently. In wireless networks, it is closely related to factors such as latency, power, speed, redundancy, etc.

Currently, there are many different network topologies in industry, each with its own advantages and disadvantages. In practice, there are currently almost no such applications for point-to-point network connectivity, except for some that are important or specific [15]. One modern example is the use of Bluetooth instant connection, which can be used to remotely control things such as model aircraft. The easiest way to add more nodes to the network is to use daisy connections. Daisy connections can be divided into two types: linear and circular. In a linear daisy chain, an existing node is connected to another existing node, and connected to another node to another node, and so on. This type of connection makes it easier to add nodes. However, as the number of nodes increases, issues like latency and fault tolerance pose new challenges to network stability and reliability. In the loop network, when one node is connected to another, the third node is added between the two existing nodes to form a loop network. Each of the nodes is precisely connected to the other two. When transmitting data on a single or two-way loop, each node verifies and processes the data; otherwise, it is transmitted again until the destination is reached [16]. Chrysanthemum links can be used to establish a network of connected devices, but there are other better methods for handling most situations.

There are many types of network typologies such as star, ring, bus, tree, grid, honeycomb, and hybrid. Figure 2 depicts several network topologies.

A star topology is a one-core and multi-core star topology. The relationship between multiple nodes and the central node is point-to-point. Due to the centralized control strategy adopted by the central node, the central node is relatively complex and has a high load. This algorithm has smaller network latency and smaller transmission errors. If the center functions normally, the network functions properly. Its shortcomings are that when the central system malfunctions, the entire network encounters problems. Moreover, there is limited ability to share resources and the usage rate of communication lines is relatively low.

A ring network is a closed loop comprising multiple nodes that form a closed ring. Each node in the ring network can send messages and is composed of various nodes of the ring network. The transmission medium is connected in a loop between the end user and another end user. In a loop, data is transferred in one direction between different nodes, and information is transferred from one node to another [17].

The bus topology is used for communication between end users. This architecture significantly eliminates the dependency on the central system. Each end user connects to two neighboring end users, creating a point-to-point link. However, it has always been one-way, so there is a saying for both upstream and downstream users. The advantage of this approach is that the flow of information in the network is constant, with only one path between each node, thereby reducing control over the path; each node in the loop is controlled in a bootstrap manner, making the implementation of control software simpler. However, it has several shortcomings: when the signal source in the ring passes through various nodes in a serial manner, it inevitably affects the transmission speed of the signal source, thereby increasing the response time of the network; the circuit is closed and difficult to expand; and the reliability is poor. Once a node fails, the whole network is paralyzed. Because of its high maintenance requirements, it is hard to determine the fault position of the branch node.

All devices in a mesh topology are connected to a connecting medium. A high-speed public bus connects several nodes to form a bus-like network. The hardware of the network interface board in every node has the function of transmitting and receiving, and the receiver receives the serial message on the bus. This is translated into parallel data, which is then transmitted to a personal computer (PC) workstation. The sender converts the parallel message to the serial message, and then transmits it to the bus. If the destination address of the message sent over the bus matches that of a node, the recipient of the message would receive this information. In a bus-based topology, all nodes are directly connected using cables with the required minimum length due to the limited length of the bus which has a certain carrying capacity. The bus can only be attached to a particular node.

Based on bus topology, the tree topology has evolved into a kind of inverted tree. The top of it is the root of a tree, with branches under it. Each branch can also have a sub-branch. The tree root receives data from various sites and then broadcasts the telephone network system throughout the entire network, which is the tree architecture. The advantages are its simple design and low cost. In this network, there is no loop between two nodes, so all the lines are bidirectional. Because of the convenience of expanding nodes in the network, it is easier to find the path of the link.

In a honeycomb topology, various nodes in a network are interconnected through transmission lines, and each node is connected by at least two nodes. Although grid topology is highly reliable, it has a complicated structure. The implementation cost is high, and the management and maintenance are difficult, so it is not commonly used in local area networks. The advantage of this typology is that it is highly reliable. In an ordinary communication subnet, any two node switches have two or more communication paths [18]. It has good scalability and can construct different forms, use different communication channels, and have different transmission rates. However, its shortcomings are its complex network architecture, high investment, and difficult maintenance.

A hybrid topology is a type of network topology formed by combining two or more network topologies together.

2.3 Topological Structure Optimization Method Based on Electrical Information Data

According to the optimization method of topology structure of electric information data, the steps that are followed are:

(1) Electrical information data is collected, including voltage, current, power, etc.

(2) The load situation of each node is calculated, including current, power, etc.

(3) Based on the load situation, the connection mode of each node has been optimized to achieve network load balance.

(4) All factors are taken into account.

In a network, if a node fails, the remaining data would be redistributed to neighboring nodes. To ensure normal operation of the network and prevent congestion, it is necessary to redistribute a large amount of idle data. Based on this, a series fault model is proposed according to the redistributing principle, and the load and node are given as a function.

The functional relationship between the initial load L_j of node j in the network and its node degree is defined as follows:

$$L_j = \beta k_j^{\alpha} \tag{1}$$

where the initial load strength of the nodes is controlled by α, β, and they can be adjusted. The degree of node k_j represents the number of nodes adjacent to the node, which is the number of edges connected to the program.

In accordance with the priority principle, the load of node i is redistributed to neighboring nodes j. The principle of node load redistribution is as follows:

$$\prod_j = \frac{\beta k_j^{\partial}}{\sum_{n \notin \Gamma_i} \beta k_v^{\alpha}} \tag{2}$$

where Γ_i represents all adjacent nodes on node i.

Based on the principle of load redistribution, the extra load after node i fails ΔL_{ij} Node j received from i is as follows:

$$\Delta L_{ij} = L_{ij} \frac{k_j^{\alpha}}{\sum_{n \in \Gamma_i} k_n^{\alpha}} \tag{3}$$

It can be seen that the additional load ΔL_{ij} received by node j does not depend on the parameter β it selects, so it is not set in the simulation experiment.

Network capacity C_{aj} is an indicator used to show load carrying capacity, which is related to network overhead. Assuming that a node has a capacity proportional to its initial load, it can be described as follows:

$$C_{aj} = TL_j, \; j = 1, 2, \ldots, N \tag{4}$$

where $T \geq 1$ represents the fault-tolerant parameter. If node j receives an additional load exceeding its capacity, that is, $L_j + \Delta L_{ij} > C_{aj}$, the node j would fail. The failure of node j would cause more load redistribution, leading to the failure of other nodes and causing a chain reaction.

The low-voltage substation topology is an important basis for power enterprises to carry out line loss analysis, power flow calculation, and fault diagnosis, and is also a prerequisite for ensuring the safety and effective management of the power grid. However, at present, there are a large number of low voltage platform areas in cities with rapid changes, and there are significant differences in the way that power companies monitor and analyze power grid data. Monitoring and analyzing the operational status of the power network

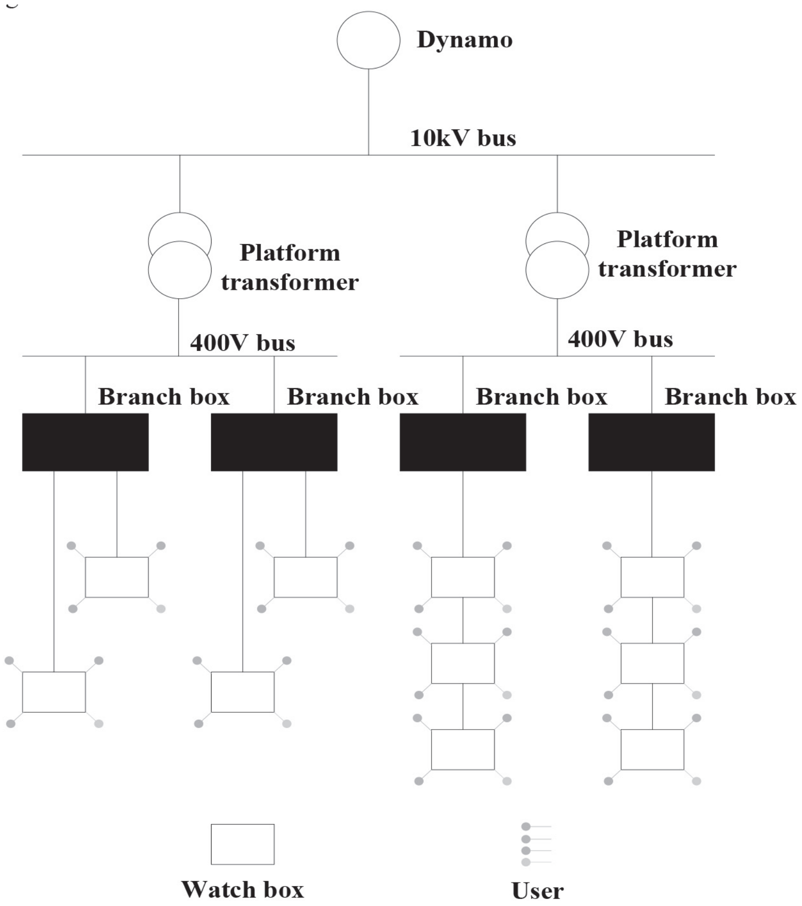

Figure 3 Power supply model under low voltage.

requires manual work, which not only wastes manpower and material resources, but also affects work efficiency. The power supply under low voltage is shown in Figure 3.

Figure 3 is a schematic diagram of the power topology in a typical area. There are two ways to connect the meter boxes inside the building: parallel connection under the branch box and series connection under the branch box. The black line transmits three-phase electric power to the meter box, and then leads a single-phase line from the meter box to provide power for users.

3. SIMULATION EXPERIMENTS AND PERFORMANCE EVALUATION OF WIRELESS NETWORK TOPOLOGY STRUCTURE

3.1 Preparation for Simulation Experiments of Network Topology Structure

To validate the optimization method of topology structure, a new FW-PSO algorithm, which combines FW and PSO, is proposed. On this basis, the optimization method of electrical information in a database based on network topology is proposed.

Guided by historical optimal values and current global optimal values, the PSO algorithm can quickly obtain good optimization results and has fast convergence. With the feasible direction method algorithm, operations such as burst and mutation are performed on the feasible direction method, enabling it to achieve global optimization in the search space. The PSO algorithm consists of the following steps:

In the first step, when the PSO algorithm has reached the maximum iteration count, the n particles with the best adaptability are retained, and the gronum-n particles with the worst adaptability are eliminated. Here, gronum-n is the size of the population.

Next, the remaining n particles are subjected to explosion, mutation, selection, and so on to obtain the gronum-n particles.

The third step involves combining the remaining n particles with the gronum-n particles obtained from the fireworks algorithm to form a new particle swarm, and perform subsequent iteration gen_{max}.

Simulation experiments are carried out to test the reliability and efficiency of FW-PSO optimization algorithm in network topology. The simulation parameters are given in Table 1. Specifically: (1) based on the characteristic of sensor network, the topology model is built, and the node matrix is constructed; (2) based on the setting of simulation parameters, the preliminary optimization and application of the FW-PSO algorithm are carried out, and (3) following the specific steps in the fuzzy PSO algorithm, the algorithm is optimized and the optimal solution is obtained.

Table 1 Simulation parameter settings.

Parameter simulation	Parameter value
Number of network nodes (Gronum)	200
Network edge number (W)	186
Acceleration factorc 1, c_2	1.54245
Minimum inertia weight (W_{min})	0.6
Maximum inertia weight (W_{max})	0.7
Optimal number of particles n retained by PSO algorithm	60
Explosion number regulator A	7
Explosion number regulator M	6
Explosion number regulator a	0.8
Explosion number regulator b	0.5
Machine accuracy (ε)	$2.2435 * 10^{-18}$
Variation spark number	10
Total iterations (Genmax)	200
Number of PSO iterations (Maxgen)	300

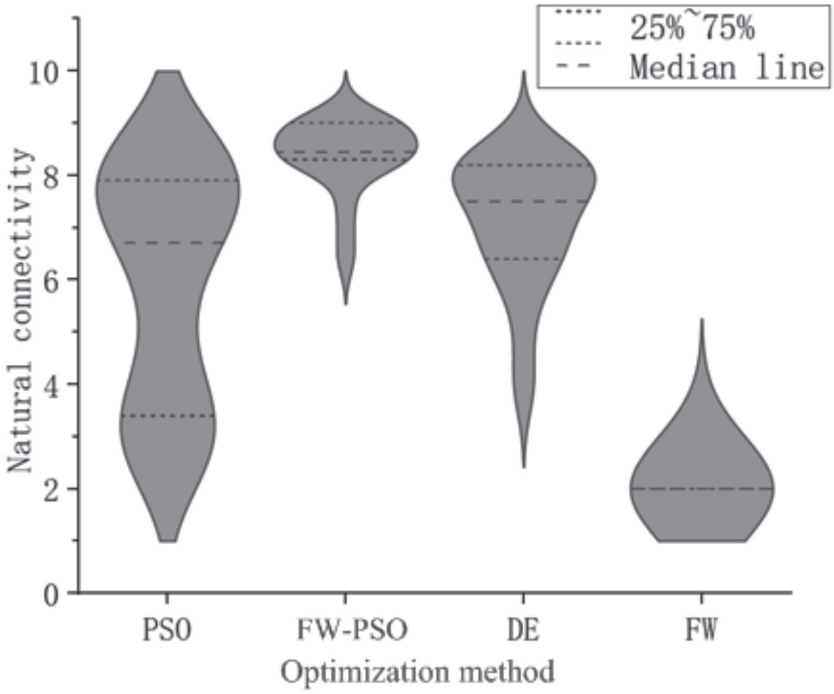

Figure 4 Performance comparison of various optimization algorithms.

3.2 Performance Evaluation of Network Topology Structure

Applying the simulation parameters shown in Table 1, the FW-PSO algorithm, which is a topological structure with the highest natural connectivity, was obtained. The experimental results are shown in Figure 4.

Figure 4 shows that the FW-PSO algorithm performs the best at a 75% confidence interval, and it is also evident that the algorithm performs the best at the median. Based on these results, various algorithms should continue to be studied and analyzed. The natural connectivity values of each algorithm under the iteration of 50, 100, 150, 200, 250, and 300 are shown in Table 2.

Table 2 compares the changes in natural connectivity with the growth of evolutionary algebra in different optimization algorithms. that the table shows that as the number of iterations increases and the topology structure becomes more optimized, the natural connectivity also increases. The optimal natural connectivity of the FW-PSO algorithm is 9. In order to obtain a clearer performance comparison, PSO and FW were analyzed again. The results are shown in Figure 5.

Figure 5 shows that the optimal value for FW is 8.5, and that a curve intersects the two near the 130th iteration. In the iterative optimization stage, the PSO algorithm has greater optimization ability compared to FW. However, in the later stage, the FW algorithm has greater advantages. Hence, it is evident that after the topology optimization of the network, the robustness of this method is greatly improved. This method produced a higher rate of convergence and better optimization effect.

Table 2 Natural connectivity of each algorithm.

Number of iterations	PSO	FW-PSO	DE	FW
50	2.6	6.3	3.8	2
100	3.1	8.2	6.3	2
150	6	8.4	7	2
200	7.3	8.6	7.8	2
250	8	9	8.2	2
300	8.5	9	8.2	2

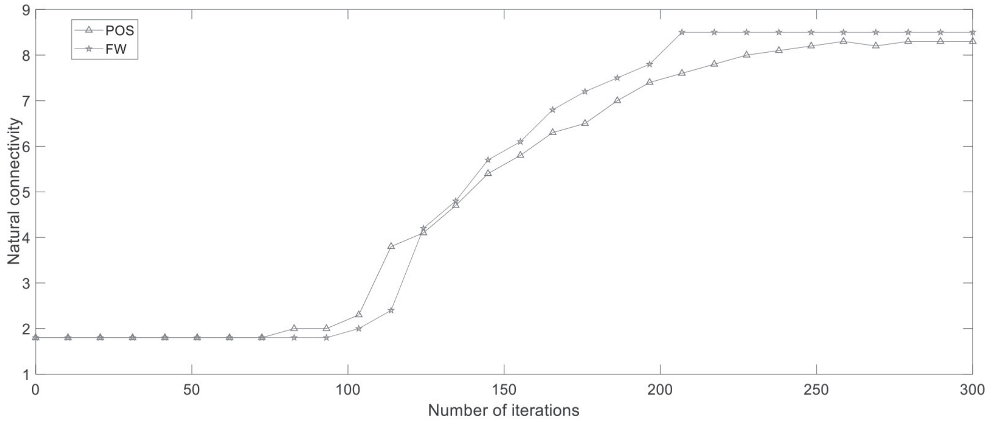

Figure 5 Comparison of PSO and FW algorithm performance.

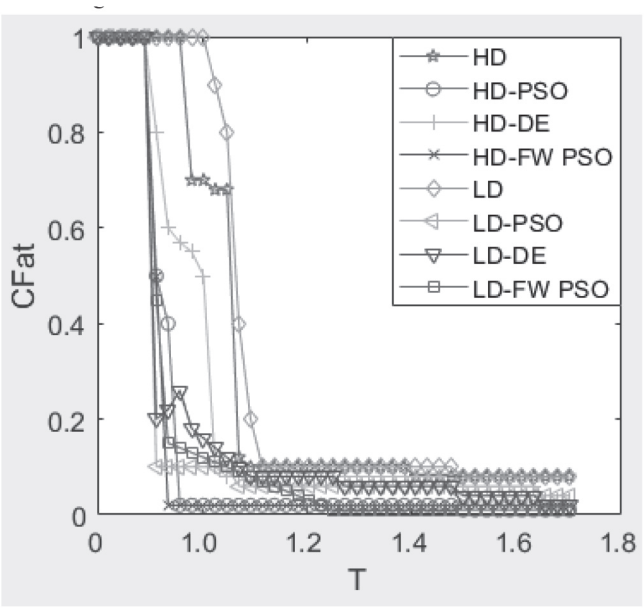

Figure 6 Destructive analysis results under $\alpha < 1$.

3.3 Survivability Evaluation of Wireless Network Topology Structure

By studying the dynamic and static survivability of the optimized network structure, the survivability of the optimized network structure is explored. Firstly, two attack methods, HD attack and LD attack, were selected to determine the network's resistance to cascading failures before and after optimization, known as dynamic survivability. On this basis, this study also analyzed the survivability performance of the network when encountering random attacks. In order to avoid random factors, 41 repetitive experiments were carried out and their mean values were measured. Under the conditions of $\alpha < 1$, $\alpha = 1$, and $\alpha > 1$, an analysis was conducted to determine the invulnerability of the wireless network topology. The results of the invulnerability analysis of the wireless network topology under $\alpha < 1$ are shown in Figure 6.

Figure 6 shows that when $\alpha < 1$, the key threshold before optimization during HD attacks is 1.54. The network optimized by PSO algorithm, DE algorithm, and FW-PSO

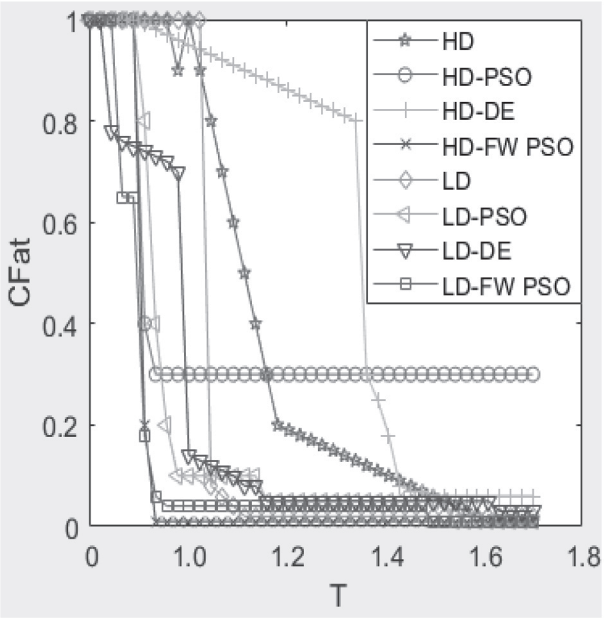

Figure 7 Destructive analysis results at $\alpha = 1$.

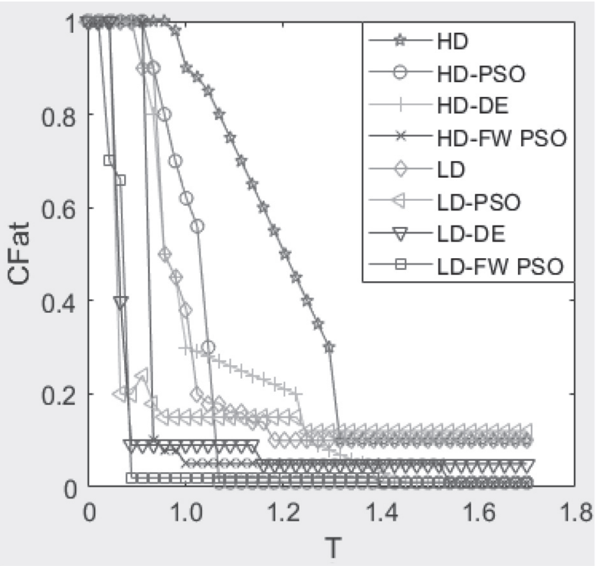

Figure 8 Results of destructive analysis under $\alpha > 1$.

algorithm are 1.14, 1.22, and 1.12, respectively. Under LD attacks, the critical threshold before optimization is1.62. In the network after using PSO algorithm, DE algorithm, and FW-PSO algorithm, the results are 1.24, 1.26, and 1.24, respectively. The results of the invulnerability analysis of the wireless network topology under $\alpha = 1$ are shown in Figure 7.

Figure 7 shows that when $\alpha = 1$, under HD attack, the key threshold before optimization is 1.72. After PSO algorithm, the network optimized by DE algorithm, DE algorithm, and FW-PSO algorithm is 1.12, 1.62, and 1.12, respectively. Before the LD attack, the critical threshold is 1.28, and the networks optimized by PSO algorithm, DE algorithm, and FW-PSO algorithm are1.16, 1.26, and 1.12, respectively. The results of the invulnerability analysis of the wireless network topology under $\alpha > 1$ are shown in Figure 8.

Figure 8 shows that when $\alpha > 1$, the key threshold before optimization during HD attacks is 1.46, and the network optimized by PSO algorithm, DE algorithm, and FW-PSO algorithm is 1.24, 1.4, and 1.12, respectively; the key threshold before optimization during LD attacks is 1.34, and the network optimized by PSO algorithm, DE algorithm, and FW-PSO algorithm is 1,1.08 and 1.08, respectively. Obviously, regardless of the value taken, the FW-PSO algorithm, which was optimized in this paper, significantly improved its survivability under HD or LD attacks.

4. CONCLUSIONS

This study verified the effectiveness of topology optimization methods based on electrical information data, and provided a better understanding of the basic content of the sources and methods used for the collection of electrical data, wireless network topology analysis, and topology optimization methods based on electrical information data under wireless network topology optimization and performance evaluation schemes. This paper also explained the topological structure optimization method applied to electrical data, and then analyzed the FW-PSO algorithm combined with the FW and PSO in this regard. During the analysis process, the optimization performances of each algorithm were compared. It was found that the FW-PSO algorithm can significantly improve the performance of the network. However, this study had one major shortcoming: the number of parameters set for optimization was not large enough for optimization analysis, resulting in incomplete analysis results. It is hoped that performance requirements can be addressed in future research.

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