Research on dynamic access strategy of wireless Mesh network for lifting operation monitoring data

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Abstract. Cranes play an indispensable role in the safety management of power construction sites. For the lifting operation, there are many challenges in the process of transmitting the safety monitoring data collected on site to the wireless Mesh network through WIFI. The purpose of this study is to construct a wireless Mesh network dynamic access model suitable for crane hoisting operation monitoring data, and on this basis, the access control strategy of each monitoring data acquisition node is formulated. Through simulation experiments, the proposed dynamic access model and its supporting access strategy can significantly optimize the transmission performance of monitoring data in wireless Mesh networks, and ensure that the efficiency and reliability of data transmission are improved. It provides new ideas and technical support for safety monitoring in power construction sites in this study, and has important practical significance for improving the safety management level of construction sites.

Keywords: crane, lifting operation, Mesh network, access.

1. Introduction

This template in the field of crane engineering application, the safety monitoring data collected from the hoisting operation site is directly transmitted to the visual background terminal through wireless WIFI, thus constructing a wireless Mesh network[1]. In this network architecture, the design of the access mechanism is particularly critical. It needs to be optimized according to specific scenarios and application requirements to ensure the optimization of network performance and effectively guarantee the operational reliability of the system[2]. In view of the urgent need to improve the reliability of the on-site monitoring network for crane hoisting operations, research on dynamic access strategies in wireless Mesh networks has become an academic hot spot in this field[3].

Through in-depth analysis of the structural stress of the crane, Xue Jindon and other scholars determined the key stress monitoring points, and proposed the overall framework of the stress monitoring system based on wireless sensor network (WSN) technology[4]. They selected a suitable wireless sensor network platform to design strain monitoring circuit and related software programs, and then developed a special application software for stress monitoring of gantry cranes, which provides technical support for real-time monitoring of crane operation status[5]. Aiming at the problem of insufficient stability of wireless Mesh network, Zhang Peng and other researchers introduced an improved WIFI access applicable wireless Mesh network model by analyzing the characteristics of nodes, and proposed a set of node access control strategy[6]. This method aims to optimize the network structure, enhance the stability and reliability of data transmission, and thus improve the performance of the entire network.Yang et al.proposed a routing optimization algorithm based on constrained paths[7], which can significantly reduce the probability of network congestion ; Sharopush 's evaluation of the flow model for multiple black hole attacks provides a theoretical basis for the design of security mechanisms in this study[8].

The above method mainly relies on a single factor as the influencing factor of Mesh network access control, which is difficult to fully solve the problems of low resource utilization, serious interference and network performance degradation caused by unreasonable node access in practical applications. Compared with the traditional single-factor access strategy (such as RSSI-based channel selection), the proposed method shows stronger adaptability in complex topologies through joint optimization of multi-dimensional parameters (channel bandwidth, transmission power, interference level). Firstly, we use Time GAN (Generative Adversarial Networks based on time series) to train the Mesh node sample data collected in advance under different access methods and wireless environments, and construct a model that can dynamically expand the sample according to the real-time reporting data. Then, the data of the current wireless environment is input into the trained Time GAN model to generate a variety of access strategies suitable for each Mesh node in the current environment. Finally, the multi-arm slot machine algorithm is used to evaluate these strategies, and the optimal access strategy is selected to improve the performance of the monitoring data wireless Mesh network.

2. Design of Mesh node access policy set

In the crane hoisting operation, multi-source sensing data such as electric field strength, high-resolution Lider 360 ° AI surround view system, lifting posture and grounding state are collected in real time. These data are directly uploaded to the visual background terminal through wireless WIFI, and a wireless Mesh network for real-time monitoring of on-site security risk status is constructed. The design of the access mechanism of the wireless Mesh network is very important. It involves many aspects such as wireless bandwidth resource allocation, access mode selection and physical layer access control. These design factors directly affect the operating efficiency of Mesh nodes when sharing the public resources of wireless channels, and then have a key impact on the performance of the entire network. The factors to be considered in ensuring the reliability design of the wireless Mesh network access mechanism are shown in Table 1.

Table 1. Key design goals of Mesh network access mechanism

Design Objective	Description
Fast Access	The design should ensure that nodes can quickly complete the connection process to minimize waiting time.
Security	Ensure the security of data transmission, preventing unauthorized access and potential security threats.
Fairness	Achieve fairness in resource allocation, ensuring each node receives a reasonable opportunity to access the channel.
Adaptability	The mechanism must be flexible enough to accommodate different types of network topologies and rapidly changing service demands.
Stability and Reliability	Enhance the stability and reliability of data transmission, ensuring continuous and efficient network operation in complex environments.

To this end, based on the WiFi6-based wireless Mesh network interference model, collected sample data that can reflect the interference status of each node in the network. Then, Time GAN is used to train the Mesh backbone network node sample data collected in advance under different access methods and wireless channel environments, so as to generate a model that can dynamically expand the sample according to the real-time data reported by the Mesh node.

Remember the Mesh node sample data P{E, W, K}, then you can get the channel environment, access methods, performance indicators, such as the formula (1-3),The workflow of the model is shown in Figure 1.

$$E_i = \sum | P_{wi} - P_{wj} | / P_{wi} \tag{1}$$

$$W = \{Ch, BW, Pow\} \tag{2}$$

$$K = \{TP, Delay\} \tag{3}$$

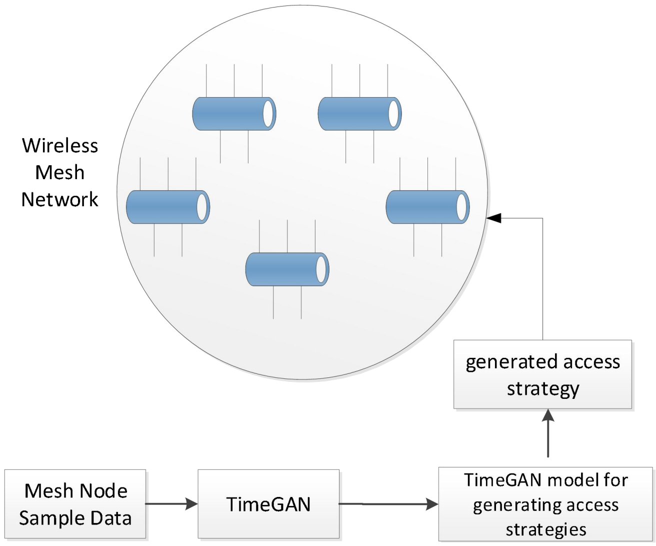

Fig. 1 The workflow of the model

3. Dynamic Access Model for Wireless Mesh Networks Based on the Multi-Armed Bandit Problem

The system is divided into two parts : training stage and application stage. It aims to optimize the access strategy of each node in wireless Mesh network through intelligent algorithm, so as to improve the overall network performance. In the training phase, the data set used to train the Time GAN model is first collected from the wireless Mesh network. Each sample data includes the channel environment, access mode and performance indicators (such as throughput and transmission delay) of Mesh nodes. Then, the Time GAN model is used to train these data to generate a model that can generate an optimal access policy set based on the data reported by Mesh nodes in real time. In the application phase, the interference data monitored by each node in the wireless Mesh network is input to the trained Time GAN model, and the corresponding data of each Mesh node under different access strategies in the current wireless environment can be output. In order to further optimize these access strategies, the multi-arm slot machine reinforcement learning algorithm is used to make decisions on the generated access strategy set.In order to generate the optimal access policy for each Mesh node in its wireless environment, it is necessary to divide the access policy set S according to the respective wireless environment of the Mesh node, and classify the data of the wireless environment E in the collection S close to the wireless environment of the Mesh node as the access policy subset s of the Mesh node. The access policy subset s can reflect the throughput and transmission delay of Mesh nodes under different access strategies. By inputting the data monitored by each Mesh node and its corresponding access policy subset into the multi-arm slot machine, the access policy optimal at the Mesh node can be output.

Before using the multi-arm slot machine to group and decide the access strategy of Mesh node, the access mode of Mesh node is taken as the action of multi-arm slot machine, and the expected performance index of Mesh node is used as rewards, forming the decision space of multi-arm slot machine. Then the reward function is set, with the cumulative regret function and the maximum number of iterations. In each iteration, the action to be executed is first selected according to the decision algorithm, and then the action is executed to update the reward function and the cumulative regret function. After the maximum number of iterations is reached, the decision result is output according to the cumulative regret value of each action, and the minimum cumulative regret action is that the Mesh node can obtain the expected optimal throughput in its wireless environment.

Let the data format of the access policy set be {E, Ch, BW, Pow, TP, Delay}, and take the access scheme of Mesh node (namely, the channel used, channel bandwidth, transmission power, etc.) as the action of the slot machine:

$$A_t = \{Ch_t, BW_t, Pow_t\}, t = 1,2, \dots T \tag{4}$$

Reward the Mesh node with the expected performance indicator of the above action A:

$$R_t = \{TP_t, Delay_t\} \tag{5}$$

The decision space is as follows:

$$Za=\{Ch, BW, Pow, TP, Delay\} \tag{6}$$

Order Q (t) records the average reward, the action is performed n times, the reward is v1,v2...vn, then the average reward is:

$$Q(t) = \frac{1}{n}\sum_{i=1}^{n} v_i \tag{7}$$

By maximizing the average reward, the wireless Mesh network can be solved.Through the above methods, the system can not only generate access strategies suitable for different wireless environments based on real-time monitoring data, but also further optimize these strategies through the multi-armed slot machine algorithm to ensure that each Mesh node can find the optimal access scheme in a complex wireless environment. This not only improves the performance of a single node, but also significantly enhances the stability and efficiency of the entire wireless Mesh network.

4. Simulation validation

In order to fully evaluate the effectiveness of the proposed adaptive channel selection algorithm, a detailed simulation test was performed using the MATLAB R2021 a platform in the Windows 11 (64-bit) operating system environment. The experimental design is divided into two main parts : Firstly, multiple sets of experiments are carried out for different distances between nodes to investigate the impact of the algorithm on node throughput and delay in Mesh networks. Secondly, the situation of wireless Mesh network accessing different number of terminal devices is simulated, and the performance of the algorithm under the condition of increasing network load is explored. The research results show that after applying the adaptive channel selection algorithm, the overall throughput of the network is significantly improved and the delay is correspondingly reduced,

whether in short distance or long distance, or in the face of different numbers of access terminals. Especially in high-density user scenarios, the algorithm effectively alleviates the downward trend of network performance before optimization, and improves transmission efficiency and reduces delay by optimizing channel allocation. This not only verifies the ability of the algorithm to improve the performance of wireless Mesh networks, but also lays a foundation for further research in related fields.

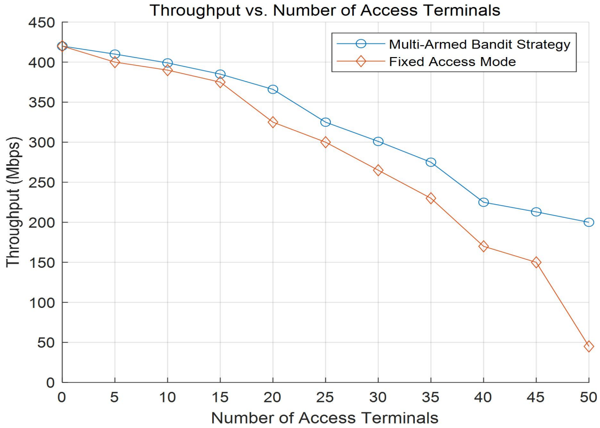

Fig. 2. Analysis of the Impact of Access Terminal Quantity on Throughpu

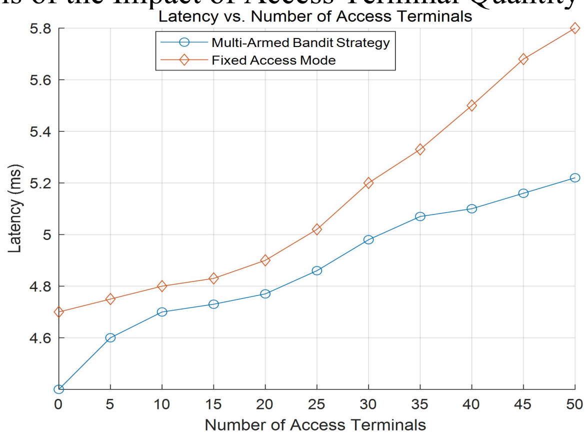

Fig. 3. Analysis of the Impact of Access Terminal Quantity on Latency

The experimental results show that the throughput of the system is improved by about 18 % when the distance between nodes is changed by applying the access strategy selection algorithm, and the impact on the delay is relatively small. Further analysis shows that when a large number of terminal devices are connected to the wireless Mesh network, the optimization effect of the algorithm is more significant : the system throughput is increased by about 25 %, and the delay is reduced by about 8 %.

These results show that the access strategy selection algorithm can effectively improve the overall performance of wireless Mesh networks in different application scenarios. Specifically, in the situation where the distance between nodes changes, although the delay has not been significantly improved, the significant increase in throughput proves the effectiveness of the algorithm in optimizing data transmission efficiency. In the high-density user scenario, not only the throughput has been significantly improved, but also the reduction of delay shows the potential of the algorithm in reducing network delay and improving response speed.

5. Conclusion

Aiming at the problem of Mesh node access in lifting detection system, this paper proposes a wireless Mesh network access mode selection method based on Time GAN and multi-arm slot machine. This method first inputs the real-time monitoring data in the wireless Mesh network into the optimization model generated by the Time GAN model training in advance, and generates an access policy set suitable for the current wireless environment. This process not only improves the communication resource utilization of the wireless Mesh backbone network, but also significantly enhances the overall performance of the system. The simulation results show that the proposed dynamic access model and its corresponding access strategy perform well on multiple key performance indicators. Specifically, this method can effectively improve the network throughput, reduce the transmission delay, and improve the stability and response speed of the system.

In addition, by introducing the multi-arm slot machine reinforcement learning algorithm, the system can automatically select the optimal access strategy in different wireless environments to ensure that each Mesh node can obtain the best performance under its specific conditions. This not only solves the problems of uneven resource allocation and low efficiency in the traditional access mode, but also provides valuable reference and technical support for similar application scenarios in the future. In summary, the wireless Mesh network access mode selection method based on TimeGAN and multi-arm slot machine proposed in this paper provides an innovative and effective solution for the efficient operation of the lifting detection system. This method not only verifies its potential in improving the performance of monitoring data wireless Mesh networks, but also lays a solid foundation for further research and development. Future work will further explore the applicability and optimization potential of this method in a wider range of application scenarios.

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