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Analysis of Intelligent Operation and Maintenance Technology Strategy of Communication Networks Based on Large Language Models

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Abstract. With the continuous improvement of communication network scale and business complexity, the traditional operation and maintenance methods relying on manual experience and rules face certain limitations in multi-source information processing and complex fault analysis. The ability of large language model in natural language understanding, knowledge association and cross-task processing provides a new research path for intelligent operation and maintenance of communication networks. This paper takes the application of large language model in intelligent operation and maintenance of communication network as the research topic, adopts the method of literature review and comparative analysis, combs the basic system of intelligent operation and maintenance of communication network, and summarizes relevant research and typical applications from four aspects: intelligent question answering, fault diagnosis, network optimization and network security. It is found that the large language model can enhance the interaction ability between the operation and maintenance personnel and the network system, and improve the knowledge association and auxiliary decision-making ability in complex network tasks. However, there are still some limitations in real-time performance, computing cost, domain knowledge adaptation, output reliability and data security. According to the research, the big language model is more suitable as the capabilities of traditional intelligent operation and maintenance system at the present stage. By cooperating with the professional model, knowledge base and automatic operation and maintenance technology, it is expected to further promote the development of intelligent operation and maintenance of communication network to the direction of intelligence and automation.

Keywords: big language model, communication network, intelligent operation and maintenance, fault diagnosis, network optimization

1. Introduction

As the scale of 5G and subsequent communication networks continues to expand, network equipment, service types, and operation and maintenance data continue to increase. Traditional operation and maintenance methods that rely on manual experience and fixed rules face certain limitations in complex fault analysis and multi-source information processing.

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In recent years, the intelligent operation and maintenance of communication network has gradually developed from single automatic monitoring to data-driven and intelligent decision-making. By integrating logs, alarms, performance indicators and network knowledge, the efficiency of network state perception and fault handling has been improved [1-3]. Therefore, how to further improve the ability of intelligent operation and maintenance system to understand and process complex network information has become a problem worthy of attention in the field of communication network operation and maintenance.

Existing research has explored cross-disciplinary network operation and maintenance, time series data analysis, data-aware fusion, and knowledge graph [1-4]. Related research can use network operation data to achieve anomaly detection, fault prediction and knowledge association, which provides a more mature data and technical basis for intelligent operation and maintenance. However, traditional methods usually build models for specific tasks, and there are still some limitations in the face of complex natural language interaction, multi-source information association and cross-task operation and maintenance requirements. At the same time, the large language model provides a new technical path for network operation and maintenance with strong natural language understanding, knowledge association and task reasoning ability [5-7].

Based on this, this paper focuses on the application of large language model in intelligent operation and maintenance of communication network. Firstly, the basic system of intelligent operation and maintenance of communication network is sorted out, and the role of large language model in intelligent operation and maintenance system is analyzed. Then, the existing research is summarized from four aspects : intelligent question answering, fault diagnosis, network optimization and network security, and the application characteristics of related technologies are analyzed. On this basis, the main limitations of the existing research are further summarized, and the possible future development directions are summarized. This paper aims to sort out the development status of the integration of large language model and intelligent operation and maintenance of communication network, and provide reference for the research and practical application of related technologies.

2. Communication network intelligent operation and maintenance technology framework

Intelligent operation and maintenance of communication network is a process of network state perception, fault analysis, operation and maintenance decision-making and task execution by using data analysis, artificial intelligence and automation technology. With the expansion of the network scale, the operation and maintenance data gradually presents the characteristics of multi-source, heterogeneous and dynamic changes. Therefore, the existing research pays more attention to the collection, fusion and analysis of different types of network data [1-3]. For example, related research uses time series data, log information, knowledge graph and other technologies to carry out network state analysis and fault prediction, providing data and knowledge basis for intelligent operation and maintenance [2, 4, 8].

From the perspective of the overall process, the intelligent operation and maintenance of communication network can be summarized as a closed-loop system of 'data acquisition-state perception-intelligent analysis-decision execution-feedback optimization'. The system first obtains log, alarm, performance index and configuration information from network equipment and business platform, and forms network status information through data processing and association. Then, the network operation status is analyzed by means of anomaly detection, fault prediction and knowledge graph, and the corresponding operation and maintenance decisions are formed according to the analysis results. Finally, the execution is completed through automatic arrangement or manual

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confirmation, and the execution results are fed back to the system to form a continuously optimized operation and maintenance closed loop [8-10].

The addition of the large language model further enhances the ability of natural language understanding, knowledge retrieval and task reasoning in this system. It does not completely replace the traditional operation and maintenance algorithm, but can be used as an intelligent capability layer connecting operation and maintenance personnel, network knowledge and professional models. It obtains professional information through RAG, knowledge graph and domain adaptation, and assists in completing complex operation and maintenance tasks [5-7]. Therefore, this paper will focus on the specific application of large language model in four directions: intelligent question answering, fault diagnosis, network optimization and network security in figure 1.

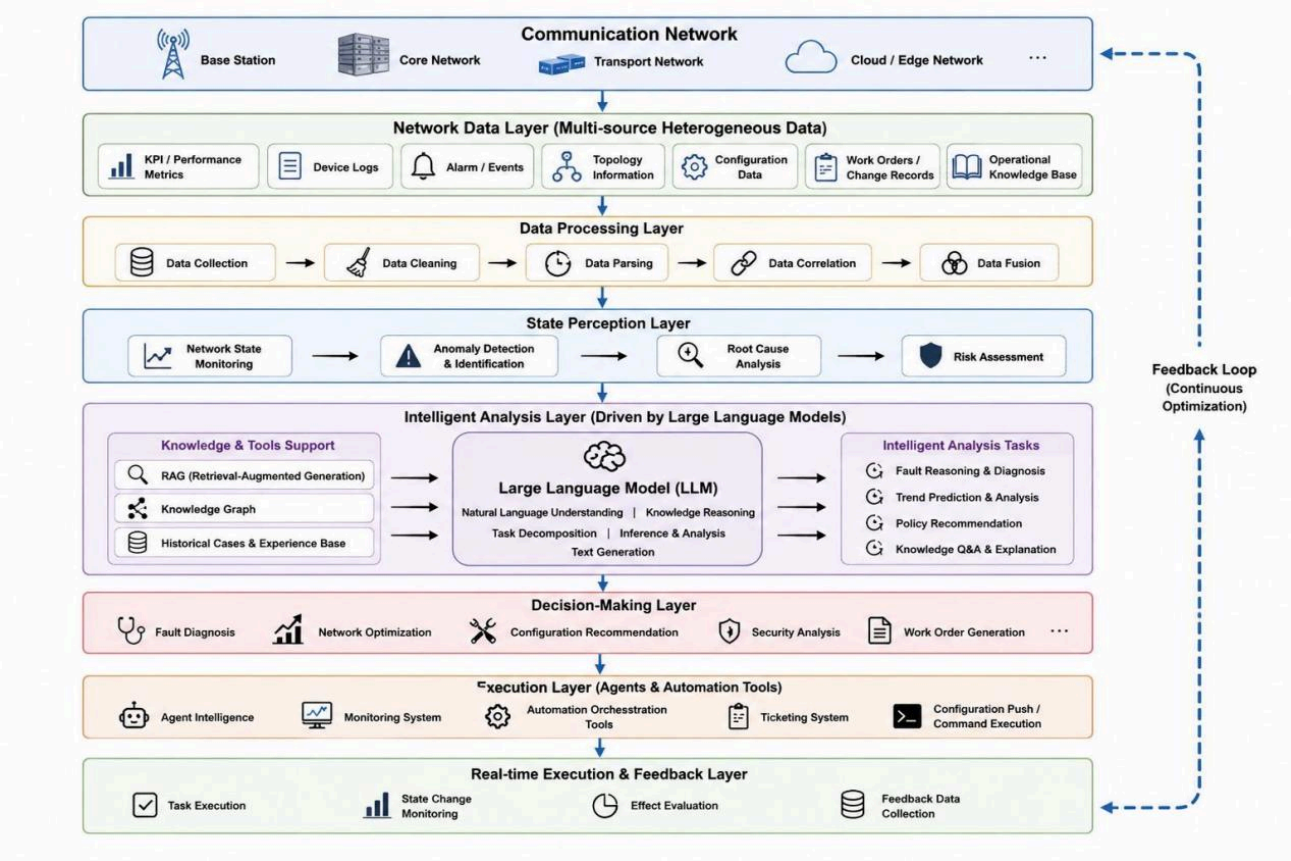

Figure 1. LLM-powered intelligent operations architecture for communication networks (picture credit: original)

3. Application of three language models in intelligent operation and maintenance of communication network

The big language model can transform the problems of operation and maintenance personnel into specific network management tasks through natural language understanding. Combining RAG, knowledge graph and network real-time data, the model can obtain task-related information. Operation and maintenance personnel can thus query device status, historical faults, configuration documents and operation and maintenance specifications through natural language. Compared with the traditional network management mode relying on fixed interface and command line, its

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advantage is to reduce the interaction threshold between operation and maintenance personnel and complex network system.

Abane et al. proposed an adaptive AI assistant for network management, which combines the large language model with RAG and knowledge graph, so that the model can obtain relevant network knowledge and answer operation and maintenance problems according to the specific network environment [6]. The research shows that the big language model can be used as the natural language interaction entrance between the operation and maintenance personnel and the network knowledge. At the same time, it also shows that the application of the big model in the network field needs to combine external knowledge and real-time network data to reduce the impact of the lack of knowledge of the general model.

3.1. Fault diagnosis

Fault diagnosis mainly uses logs, alarms, performance indicators, network topology and other information to identify anomalies and analyze the causes of faults. The big language model can analyze the operation and maintenance information from different sources through natural language understanding and context correlation ability, and combine the knowledge base to assist fault location and cause explanation. Liu et al.incorporated network diagnosis into the large language model network task system, and pointed out that LLM can participate in the network diagnosis process through task decomposition, knowledge acquisition and reasoning [7]. At the same time, existing communication network research shows that logs and knowledge graphs can provide an important basis for fault prediction and fault correlation [4, 8]. Therefore, LLM is more suitable for combining with traditional fault detection models and network knowledge bases. The professional model provides fault evidence, and the large language model is responsible for information association and diagnostic interpretation. However, the current research on the direct application of LLM to real communication network fault diagnosis is still relatively limited, and its reliability and interpretability still need to be further verified.

3.2. Network optimization

Network optimization involves tasks such as resource allocation, traffic scheduling and service quality assurance. Traditional methods usually need to establish a dedicated model for different network tasks, and the big language model can obtain cross-task processing capabilities through domain adaptation. Wu et al.proposed NetLLM to adapt the large language model to network prediction and optimization tasks, and conducted experiments on multiple tasks such as viewport prediction, HTTP adaptive video streaming, and cluster task scheduling [11]. The research shows that the adapted large language model can achieve competitive task performance, and its core advantage is to use the unified model to serve different network tasks, thereby reducing the cost of repeating the design model for a single task. However, due to the obvious difference between network data and natural language, special data coding and model adaptation methods are still needed in practical applications.

4. The comparison and limitations of existing research

From the existing research, there are obvious differences between the big language model and the traditional intelligent operation and maintenance method in technical characteristics and applicable scenarios. Traditional machine learning and deep learning methods usually design models for

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specific tasks such as fault prediction, anomaly detection or network optimization. They have good stability on specific data sets and tasks, but often need feature design and model training for different tasks. The big language model has strong natural language understanding and cross-task processing capabilities, which can associate the natural language intentions of operation and maintenance personnel with network data and domain knowledge, and assist in complex tasks such as configuration, diagnosis and optimization [5, 7].

However, from the perspective of different application directions, the practical application maturity of the current large language model is not consistent. Intelligent question answering mainly uses the natural language understanding and knowledge retrieval ability of the model, and the technology is relatively mature ; Network optimization research has begun to explore the use of basic models to achieve cross-task adaptation, but it still needs to be specifically designed for network data [6, 12]. Fault diagnosis has higher requirements for data accuracy, real-time performance and result reliability. Existing research focuses more on experimental environments and specific data sets. Therefore, the current large language model is more suitable as an auxiliary capability for traditional intelligent operation and maintenance systems, rather than completely replacing existing professional models and automation systems.

The primary problem faced by existing research is the lack of output reliability. The large language model has the possibility of generating error information and fictional results. In the network operation and maintenance scenario, if the error results are further transformed into configuration commands or fault handling operations, it may cause network anomalies or even business interruptions [5]. Therefore, the current research generally tends to limit the model output through RAG, knowledge graph, manual review or other verification mechanisms, rather than directly allowing the model to perform key network operations autonomously. Hong et al.'s review also pointed out that illusion and output verification are still important obstacles for LLM to enter the actual network management.

The second is the problem of real-time and computational cost. Some tasks in the communication network need to respond quickly, while the large language model usually has high computing and storage requirements, and the inference delay may also limit its application in real-time network control and edge environment [5]. Therefore, the large language model is more suitable for high-level intention understanding, information analysis and auxiliary decision-making, and for the underlying network control tasks with strict delay requirements, it still needs to rely on traditional algorithms and dedicated models. Relevant research also points out that there are still obvious contradictions between model size, inference delay and computing resources.

Finally, security, privacy, and collaboration with existing network systems still need to be further addressed. The network operation and maintenance process contains sensitive data such as device configuration, network topology, logs, and business information. If it is directly input into an external large model, the risk of data leakage may occur. At the same time, the big language model cannot independently replace the existing network management platform, professional algorithms and automated orchestration systems. Therefore, a more reasonable technical route at this stage is to let the large language model undertake tasks such as natural language understanding, knowledge association and complex reasoning, and then complete professional calculation and actual execution by traditional algorithms and network orchestration systems, thus forming a complementary collaborative operation and maintenance mode [5].

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5. The development trend

In view of the problems of reliability, real-time, domain adaptation and security of large language models in the intelligent operation and maintenance of communication networks, future research will pay more attention to the combination of model capabilities and the actual needs of communication networks, and promote the development of large language models from experimental applications to controllable, reliable and practical deployable intelligent operation and maintenance capabilities.

First of all, model lightweight and real-time will become an important direction. Aiming at the problems of large-scale parameters and high inference cost of large-language models, in the future, model deployment costs can be reduced by methods such as model compression, knowledge distillation and efficient fine-tuning of parameters, and models of different scales can be adopted according to different operation and maintenance tasks. For high-level tasks such as fault analysis and operation and maintenance question answering, a large language model with strong ability can be used, while for network monitoring and edge tasks with high real-time requirements, a lightweight model can be used to achieve a balance between model ability and response efficiency [5].

Secondly, knowledge enhancement in the field of communication will further become an important basis for the application of large language models. The general large language model still has limited understanding of professional knowledge such as communication protocols, device configuration, and network topology. Therefore, it is necessary to further combine RAG, knowledge graph, and domain fine-tuning techniques in the future to enable the model to invoke reliable network knowledge and real-time operating data [5, 7]. By combining the language reasoning ability of the model itself with external professional knowledge, the possibility of error information generated by the model can be reduced, and the accuracy of fault analysis and operation and maintenance decision can be improved.

Finally, trusted and secure automated operation and maintenance will become the key to the further application of the large language model. In order to solve the problems of model illusion, wrong decision-making and sensitive network data leakage, it is necessary to establish model output verification, permission control and manual audit mechanism in the future. After the operation and maintenance strategy is generated by the large language model, it is verified by the rule system, knowledge base or simulation environment, and then it is decided whether to implement it [5]. With the continuous improvement of model reliability and security mechanisms, the large language model is expected to be further developed from the current auxiliary analysis tool to an intelligent capability layer that can participate in network operation and maintenance decision-making and automated execution.

6. Conclusion

With the increasing scale and complexity of communication networks, intelligent operation and maintenance has become an important technical means to improve network operation efficiency and ensure network stability. This paper reviews the application of large language model in intelligent operation and maintenance of communication network. Based on the analysis of the basic system of intelligent operation and maintenance of communication network, this paper focuses on the application of large language model in intelligent question answering, fault diagnosis, network optimization and network security.

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Existing research shows that large language models can further expand the application scope of traditional intelligent operation and maintenance systems and reduce the interaction cost between operation and maintenance personnel and complex network systems by virtue of natural language understanding, knowledge association and cross-task processing capabilities. At present, the large language model is still limited by factors such as model illusion, real-time performance, computational cost, insufficient domain knowledge, and data security. Large-scale deployment in real communication networks still needs further verification.

In the future, with the development of model lightweight, domain knowledge enhancement and trusted security mechanism, the further integration of large language model with traditional artificial intelligence and automated operation and maintenance technology will provide new possibilities for the development of intelligent operation and maintenance of communication network to be more intelligent and automated.

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