# Large Language Model in SD-WAN Intelligent Operations and Maintenance

Yiyun Zhang

Petroleum Institute, China University of Petroleum-Beijing at Karamay, China,
https://orcid.org/0009-0009-0412-0249

Received: October 15, 2023; Revised: November 30, 2023; Accepted: December 13, 2023; Published: December 19, 2023

**Abstract**

The integration of LLM (Large Language Model) into the intelligent operations and maintenance of SD-WAN (Software-Defined Wide Area Networks) is comprehensively explored. As the scale of the network continues to expand and its complexity increases, traditional operation and maintenance methods can no longer meet efficient and accurate requirements. Therefore, LLM technology was introduced, and the intelligent operation and maintenance of the data center network were realized by leveraging its powerful natural language processing capabilities. The importance and shortcomings of SD-WAN and the application scenarios of LLM in network operation and maintenance are first introduced, followed by an elaboration on how LLM can be used for network configuration, network optimization, network maintenance, and network security risk management. Through specific analysis, the significant effect of LLM in enhancing the efficiency and quality of operation and maintenance has been demonstrated. Finally, the advantages and challenges of employing LLM for intelligent network operation and maintenance are summarized, and future research directions are anticipated.

**Keywords**: LLM, network operation, SD-WAN.

## 1 Introduction

In the era of rapid digital transformation, network infrastructure has become pivotal for businesses globally. SD-WAN(Software-Defined Wide Area Network) emerges as a key player in this landscape, revolutionizing how enterprises manage and optimize their network connectivity across various locations. However, the complexity and dynamic nature of modern networks pose significant challenges in network operation and maintenance. The aim of this paper is to address these challenges by harnessing the capabilities of LLM(Large Language Model).A novel approach that leverages LLM for enhanced network operation and maintenance within the SD-WAN framework is proposed. This approach not only streamlines network processes but also significantly improves efficiency, security, and cost-effectiveness. By integrating LLMs into SD-WAN, the aim is to transform conventional methodologies and pave the way for a more intelligent, adaptive, and robust network management approach.

### 1.1 SD-WAN scenario

SDN-WAN is a specific application of SDN, applied to WAN, and used to connect enterprise networks, including branches, data centers and clouds, to achieve the maximum coverage of the wide area network. In today's digital world, SD-WAN has become an important solution as enterprises continue to demand flexible, efficient and secure networks. By leveraging the benefits of SD-WAN, enterprises can simplify their network architecture, improve application performance, reduce costs, enhance security, expand global coverage, improve user experience, and accelerate automation. The biggest feature of the SD-WAN solution is to use software-defined network technology to transfer network control from hardware devices to software, thereby achieving network flexibility and manageability. In this way, the SD-WAN solution can integrate multiple WAN lines to achieve high availability and high performance of the network.

For highly sensitive network scenarios, such as those with audio or video as the main business, the network requirements are particularly high. Once network interruption or jitter occurs, it may cause huge economic losses to the enterprise. For this scenario, the SD-WAN solution can provide redundant backup of a variety of WAN lines, such as MPLS, PON optical broadband, 4G LTE, 5G, etc., to ensure high availability and stability of the network. At the same time, for high-priority applications, the SD-WAN solution can set optimal network paths to ensure fast access and response to business systems.

For network scenarios with many and dispersed branches, the SD-WAN solution can provide a more flexible network solution. Since branches are widely distributed geographically and do not require high network bandwidth, the SD-WAN solution can replace traditional enterprise lines and use home lines to encrypt the network to access the enterprise's internal systems, thereby saving network costs and reducing the difficulty of operation and maintenance.

In addition to the above two scenarios, other newly built network scenarios can also use SD-WAN solutions to replace traditional network solutions. Compared with traditional solutions, SD-WAN solutions have the advantages of low construction cost, data security and reliability, and low difficulty in operation and maintenance. By using SD-WAN solutions, enterprises can achieve rapid deployment, flexible expansion and efficient management, thereby improving their productivity and competitiveness.

In short, with the continuous advancement of technology and the development of enterprise business, SD-WAN solutions have become an important choice for enterprise network construction. By leveraging software-defined network technology, SD-WAN solutions can provide efficient, flexible, and secure network solutions to meet the needs of different scenarios. In the future, with the further development of SD-WAN technology, it is believed that it will be widely used and promoted in more fields.

## 1.2 Challenges and risks of SD-WAN networks

Although the SD-WAN network has many advantages, it also has some disadvantages, mainly due to its more flexible and controllable network connection characteristics. Since SD-WAN uses a cloud-based network management and control platform, this makes the network management platform a potential attack target. The openness and accessibility of networks increases the risk of cyberattacks. Additionally, as SD-WAN spreads, the potential risks of data breaches and network intrusions also increase, especially when connecting multiple branch offices. The challenge of protecting SD-WAN networks from malicious attacks is something organizations must take seriously.

Secondly, there is the cost issue. Although the SD-WAN network has advantages in improving network connection efficiency and reducing operating costs, its deployment and maintenance costs are still a significant consideration. Enterprises need to invest in specialized equipment and software to support the proper operation of SD-WAN networks. Additionally, due to the strong bandwidth requirements of SD-WAN networks, additional network bandwidth upgrades may be required, increasing overall costs. This requires organizations to carefully weigh the economic costs versus performance improvements when adopting SD-WAN.

In addition, network reliability is also an important issue faced by SD-WAN networks. Although SD-WAN networks provide seamless switching and load balancing functions to ensure network stability and high availability, there are still risks of network delays and failures. Especially when managing complex network topologies, troubleshooting network problems can become more difficult, potentially causing business interruptions and delays in data transmission. Therefore, organizations need to carefully consider how to maximize the reliability of their SD-WAN networks and develop effective response strategies to reduce potential impacts.

Finally, there is the issue of technical complexity. The deployment and configuration of SD-WAN networks are relatively complex and require certain technical knowledge and professional capabilities. This can be a challenge for small businesses or those lacking technical staff. In order to effectively deploy and maintain an SD-WAN network, organizations may need to hire professionals, which increases labor costs for the enterprise. Additionally, as technology continues to evolve, organizations will also need to continually train their employees to keep up with the latest developments in SD-WAN network technology. This investment in technology is part of what organizations need to consider when adopting SD-WAN.

## 1.3 LLM in network operation

With the rapid development of SD-WAN technology, network operation and maintenance are facing increasingly complex challenges. In this context, introducing LLM into network operation and maintenance is a very potential solution, which can improve operation and maintenance efficiency and reduce costs. LLM, with its excellent natural language processing capabilities and complex data analysis advantages, provides network Operation and maintenance provides a new perspective and method, and helps staff better understand and master network operation and maintenance knowledge. Here are some details:

Improve operation and maintenance efficiency: The LLM can automatically analyze network performance data, log files and real-time monitoring data to provide key decision-making suggestions for network operation and maintenance personnel. For example, when a network failure occurs, the LLM can quickly identify the problem and recommend the best solution, which greatly reduces the time of manual troubleshooting and repair. The LLM can monitor the operating status of network equipment in real time. Once anomalies or potential problems are discovered, early warning information is immediately sent to network operation and maintenance personnel to help them discover and solve problems in a timely manner, thereby avoiding potential network failures and downtime.

Reduce costs: Through automated decision support and real-time monitoring and early warning systems, LLMs can significantly reduce the workload and manual intervention required by network operation and maintenance personnel, thereby lowering labor costs. Additionally, LLMs are capable of intelligently scheduling and managing network resources, automatically adjusting resource allocation based on business demands and network traffic, thus enhancing resource utilization and reducing operational costs.

Assist decision-makers to learn new network operation and maintenance knowledge: For new employees or those in need of knowledge updates, LLMs can intelligently recommend relevant network operation and maintenance learning materials, best practices, and technical articles, aiding them in quickly adapting to the work environment and enhancing their skill levels. Furthermore, LLMs are capable of dynamically adjusting the content and difficulty of learning based on the user's progress and feedback, providing a personalized learning experience to assist users in better mastering network operation and maintenance knowledge and skills.

Continuous optimization: By collecting and analyzing a large volume of network operation and maintenance data, LLMs can continuously optimize their decision-making recommendations and learning capabilities, thus enhancing the efficiency and accuracy of network operation and maintenance. Network operation and maintenance personnel, while using LLMs, provide ongoing feedback, which can be utilized to improve the performance of LLMs and enhance the practicality of decision-making recommendations.

In summary, introducing LLM into network operation and maintenance can significantly improve operation and maintenance efficiency, reduce costs, and help decision-makers learn new network operation and maintenance knowledge. With the continuous evolution and application promotion of technology, it is believed that LLM will play an increasingly important role in the field of network operation and maintenance in the future.

### 1.4 Structure of this article

An innovative approach is proposed to explore the application of LLM in SD-WAN intelligent operation and maintenance, particularly addressing operational cost issues such as security, scalability, and troubleshooting of SD-WAN networks. The approach relies on LLM's advanced natural language processing capabilities to improve the efficiency and accuracy of network management. The application of LLM in network configuration, optimization, maintenance, and security risk management is explored in detail, showcasing their advantages in automated decision support and real-time monitoring and early warning. At the same time, the history and current development of LLM, as well as the latest research progress in the fields of model architecture optimization, training method improvement, and network technology applications, are also reviewed. Through this study, not only is the application potential of LLM in network operation and maintenance highlighted, but guidance is also provided for future technology development and research directions.

## 2 LLM Basics

The development of LLM represents a monumental leap in the field of artificial intelligence and machine learning. Tracing back its origins to the simple yet pioneering neural network models, LLM have evolved through various technological advancements and conceptual shifts. This paper delves into the history and current state of LLM, highlighting their transformative journey from basic neural networks to the sophisticated, multi-modal giants that they are today. The exploration will be conducted on the foundational models that have paved the way for modern Large Language Models (LLMs), the significant breakthroughs that have been achieved in their evolution, and their current applications across various fields, with a particular emphasis on their impactful role in the network domain.

### 2.1 LLM history

The embryonic stage of LLM is the traditional neural network model stage represented by CNN. In 1956, starting from the concept of "artificial intelligence" proposed by computer expert John McCarthy, AI development gradually developed from being based on small-scale expert knowledge to being based on machine learning. In 1980, the prototype of the convolutional neural network, known as CNN, was developed. In 1998, LeNet-5, the basic structure of modern convolutional neural networks, was born. The machine learning method changed from an early model based on shallow machine learning to a model based on deep learning, laying the foundation for in-depth research in natural language generation, computer vision and other fields. It has laid the foundation and has pioneering significance for the subsequent iteration of deep learning frameworks and the development of LLM. Then ushered in the exploration and precipitation period (2006-2019), the new neural network model stage represented by Transformer. In 2013, the natural language processing model Word2Vec was born, and for the first time proposed the "word vector model" that converts words into vectors, so as to Computers understand and process text data better. In 2014, the birth of GAN (Generative Adversarial Network), known as one of the most powerful algorithm models in the 21st century, marked that deep learning has entered a new stage of generative model research. In 2017, Google subversively proposed the Transformer architecture, a neural network structure based on the self-attention mechanism, which laid the foundation for the LLM pre-training algorithm architecture. In 2018, OpenAI and Google released the GPT-1 and BERT LLM respectively, which means that pre-trained LLM have become mainstream in the field of natural language processing. During the exploration period, the new neural network architecture represented by Transformer laid the foundation for the algorithm architecture of LLM and significantly improved the performance of LLM technology.

## 2.2 LLM now

In 2020, OpenAI launched GPT-3, with the model parameter size reaching 175 billion, becoming the largest language model at the time, and achieving huge performance improvements in zero-sample learning tasks. Subsequently, more strategies such as reinforcement learning based on human feedback (RHLF), code pre-training, instruction fine-tuning, etc. began to appear, and were used to further improve reasoning capabilities and task generalization. In November 2022, ChatGPT equipped with GPT3.5 was born, quickly detonating the Internet with its realistic natural language interaction and multi-scenario content generation capabilities. In March 2023, the latest large-scale multi-modal pre-training model released - GPT-4, has multi-modal understanding and multi-type content generation capabilities. During the period of rapid development, the perfect combination of big data, big computing power and big algorithms has greatly improved the pre-training and generation capabilities of LLM as well as the multi-modal and multi-scenario application capabilities. For example, the great success of ChatGPT was achieved with the support of the powerful computing power of Microsoft Azure and massive data such as wiki, and based on the Transformer architecture, adhering to the strategy of fine-tuning the GPT model and reinforcement learning with human feedback (RLHF).

## 2.3 LLM in the network field

Network Configuration: LLM can automatically configure network devices and services, reducing manual configuration errors and time consumption. Using big data analysis and machine learning technology, the big model can intelligently adjust network configurations based on historical data and real-time network conditions. LLM can dynamically optimize resource allocation based on network traffic and application requirements. For example, in data center networks, LLM can monitor traffic patterns in real time and intelligently adjust bandwidth allocation and server load to improve resource utilization efficiency. The role of LLM large prediction model is shown in Figure 1.

Network Optimization: By analyzing network traffic and performance data in real time, LLM can identify and resolve network bottlenecks and improve overall network performance. LLM can predict network failures and performance degradation trends, take maintenance measures in advance, and avoid serious network failures and interruptions.

Cyber Security: LLM can monitor and analyze network traffic in real time and identify potential security threats. By learning from a constantly updated threat database, LLM can quickly respond to emerging cyber attack vectors. LLM can assess security risks in the network and provide customized security policies and solutions. Through in-depth analysis of network security incidents, LLM can help network administrators manage network security risks more effectively.

Network Maintenance: LLM can quickly diagnose network problems and provide solutions, reducing recovery time from network failures. Leveraging advanced diagnostic algorithms and rich historical data, LLM can improve fault diagnosis accuracy. By continuously monitoring network performance indicators, LLM can ensure the stable operation of the network. When performance degradation is detected, the LLM can make timely optimization suggestions.

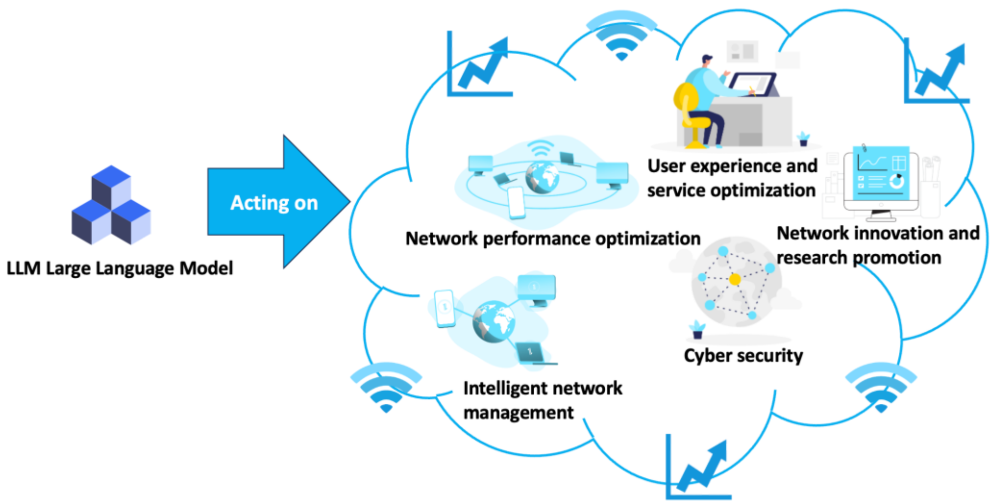


Figure 1. The role of LLM large prediction model in multiple future network fields.

## 3 Application of LLM in SD-WAN operation and maintenance

In the contemporary era of network management, the integration of LLM into SD-WAN operations marks a significant evolution in how networks are managed and optimized. This paper outlines the development of a comprehensive architecture that seamlessly integrates LLM into the SD-WAN framework, revolutionizing traditional network operation and maintenance practices. A symbiotic relationship between LLM and SD-WAN is the focal point of this study, wherein the capabilities of LLM in data analysis, pattern recognition, and natural language processing are utilized to augment the efficiency, reliability, and security of network systems. This integration promises to address the complexities of modern network infrastructures, offering innovative solutions that cater to the dynamic needs of contemporary enterprise networks.

### 3.1 Design overall architecture

Introducing LLM into SD-WAN operations involves building a comprehensive framework that effectively blends the advanced capabilities of LLM with the specific needs of SD-WAN. This overall architecture (Figure 2) can be divided into several key components to ensure that LLM plays its maximum role in improving network efficiency, reliability and security.

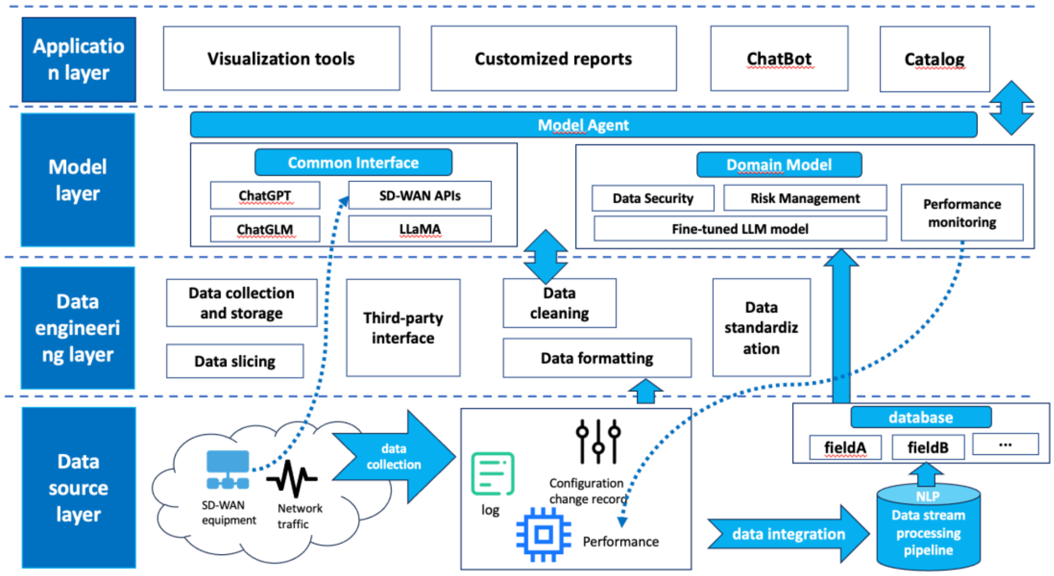


Figure 2. LLM's SD-WAN operation and maintenance architecture diagram

## 3.2 Application Analysis

The potential role of LLM in SD-WAN operations can be analyzed from multiple aspects. Since the core strengths of LLMs lie in advanced data analysis, pattern recognition, natural language processing, and decision support, their application in SD-WAN environments can bring significant improvements and optimizations. This task covers many aspects, including but not limited to network configuration, network optimization, network maintenance, and network security risk management. Here are detailed instructions on these aspects:

LLM network configuration: Network configuration is the basic work of LLM operation and maintenance, which mainly includes the configuration and management of infrastructure such as network devices, servers, and storage devices. Network configuration for LLM operation and maintenance needs to take into account the storage and computing requirements of the model, as well as the speed and stability of data transmission. During the configuration process, it is necessary to consider parameters such as the network device model, specifications, interface type, and transmission rate, as well as the server's processor, memory, storage space and other parameters. LLM can automate the configuration of network devices and services, including routers, switches, firewalls, and more. It intelligently configures network parameters based on network traffic and application requirements to improve configuration efficiency. At the same time, the LLM can dynamically allocate network resources, such as bandwidth and routing priority, according to network conditions and business needs, ensuring the performance and reliability of key applications. By integrating multiple network technologies and protocols, the LLM can provide a unified network management interface and simplify the network configuration and management process.

LLM network optimization: Network optimization plays a vital role in the operational maintenance of LLM, aiming to enhance network performance and stability. Within this scope, LLM contribute significantly by monitoring network performance in real time, such as latency and bandwidth usage, thereby promptly identifying and resolving performance bottlenecks. These models are capable of intelligently adjusting traffic distribution and priority, optimizing network resource utilization to reduce congestion and delay. Furthermore, leveraging historical data and pattern recognition, LLM can predict and prevent potential network failures, enabling proactive measures to be taken.

LLM network maintenance: Network maintenance is one of the core tasks of LLM operation and maintenance, and is mainly responsible for troubleshooting and repairing network faults. In LLM operation and maintenance, network troubleshooting needs to take into account many aspects such as the running status of the model, the status of network equipment, and the status of the server. Once a failure occurs, it is necessary to locate the problem in time, analyze the cause, and take corresponding repair measures. In addition, in order to prevent the occurrence of failures, network equipment needs to be inspected and maintained regularly to ensure the normal operation of the equipment. LLM can quickly and accurately diagnose network problems, such as equipment failures, configuration errors, etc., and provide solutions. When a fault is detected, the LLM can automatically perform recovery operations, such as route redirection, configuration rollback, etc., to minimize business interruption. At the same time, the LLM continuously monitors network equipment to ensure stable network operation, and updates maintenance logs and records in a timely manner.

LLM cybersecurity risk management: In large-model operation and maintenance, network security risk management is a key component to ensure the stability and reliability of the entire system. It involves identifying, assessing, mitigating, and monitoring security threats and vulnerabilities that may arise in the network. First, the LLM performs an in-depth analysis of the network to identify potential security threats and vulnerabilities, such as unauthorized access, malware intrusion, or data leakage. Then, based on this information, the LLM will deploy corresponding security measures, including but not limited to firewalls, intrusion detection systems (IDS), and data encryption technologies. In addition, LLM can implement fine-grained access control to ensure that only authorized users can access sensitive resources and data.

Generally speaking, the application of LLM operation and maintenance in the network field can greatly improve the efficiency, stability and security of the network, while also reducing the complexity and error rate of manual operations. With the continuous development of technology, the application scope and capabilities of LLM operation and maintenance will be further expanded, bringing more innovations and improvements to network management in different scenarios as shown in Figure 3.

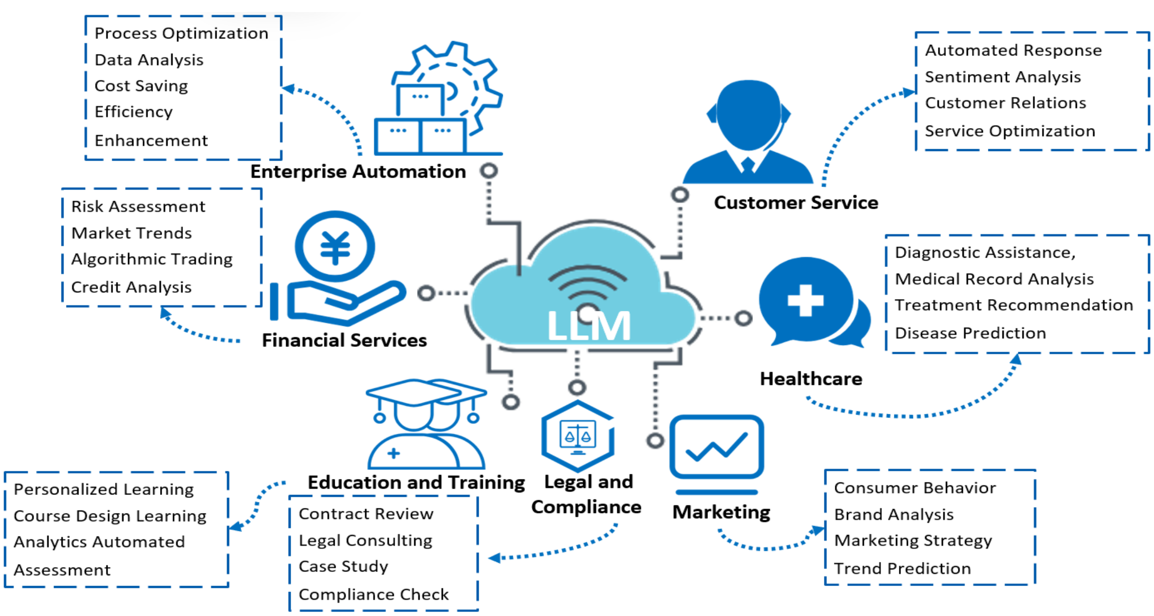


Figure 3. Different application scenarios of LLM large prediction model

# 4 Related work

In the rapidly evolving landscape of technology, significant strides have been made in two distinct yet increasingly interconnected fields: LLM and SD-WAN. Recent advancements and emerging trends in both Large Language Models (LLMs) and Software-Defined Wide Area Networks (SD-WAN) are intended to be illuminated. In the realm of LLM, the continuous enhancement of model architectures, the refinement of training methodologies, and the expansion of applications into diverse sectors are delved into. Concurrently, in the field of SD-WAN, the focus shifts to the optimization of network protocols, the reinforcement of security and reliability measures, and the adoption of intelligent management systems.

## 4.1 Field of LLM

Model architecture optimization: In order to further improve the performance of LLM, the model architecture is continuously explored and improved. For example, methods such as hierarchical attention mechanism and attention mechanism enhancement are used to improve the attention and expression capabilities of the model.

Improvement of model training methods: In order to improve the training efficiency and accuracy of LLM, the model training methods are continuously improved. For example, adaptive learning rate, knowledge distillation and other technologies are used to improve the training effect of the model.

Model application expansion: With the wide application of LLM in various fields, the application of LLM in other fields is constantly being explored. For example, in the medical field, LLM can be used for medical image analysis, disease prediction, etc.; in the financial field, LLM can be used for risk assessment, stock prediction, etc.

## 4.2 Field of SD-WAN

Network protocol optimization: In order to improve the performance and stability of SD-WAN, network protocols are continuously optimized. For example, high-performance routing protocols, low-latency transmission protocols and other technologies are used to improve SD-WAN network performance.

Enhanced security and reliability: The security and reliability of SD-WAN are the focus of user concerns. Therefore, new technologies and methods are constantly being explored and adopted to improve the security and reliability of SD-WAN. For example, technologies such as encryption technology and access control policies are used to protect the security and privacy of SD-WAN; technologies such as redundant backup and fault tolerance are used to improve the reliability of SD-WAN.

Intelligent management: In order to facilitate users to manage and maintain SD-WAN, new intelligent management technologies are constantly explored and adopted. For example, artificial intelligence technology, machine learning and other technologies are used to realize automated management and maintenance of SD-WAN.

In short, in the field of LLM and SD-WAN, recent work has mainly focused on model architecture optimization, training method improvement, application expansion, network protocol optimization, security and reliability enhancement, and intelligent management. These efforts aim to improve the performance and stability of LLM and SD-WAN to provide users with better services.

# 5 Conclusion

A comprehensive exploration of the application of LLM in the intelligent operation and maintenance of SD-WAN is undertaken, and an innovative method for applying the advanced natural language processing capabilities of LLM to network operation and maintenance is proposed. All aspects, including network configuration, optimization, maintenance, and security risk management. This method not only significantly improves the efficiency and automation level of network operation and maintenance, but also reduces operating costs and enhances the stability and security of the entire network. Through this method, the problems of low efficiency, high cost and insufficient security risk management in traditional network operation and maintenance are solved, and more efficient and secure network management solutions are provided for enterprises and organizations. In addition, the results of this research not only have practical application value, but also provide new ideas and directions for the development of future network technology.

It is expected that the application of LLM will not be limited solely to the field of network operation and maintenance, but will also expand to a wider range of network technology applications, including network design optimization, intelligent customer service, and AI-based network security threat detection. With the advancement of technology, LLM has the potential to become an important driving force for the development of network technology and promote the construction of a more intelligent, efficient and secure network environment. Future research may focus on improving the adaptability and accuracy of LLM so that it can better respond to changing network environments and needs, thus laying the foundation for more intelligent global network connection and management.

# References


[1] Song, F., Ma, Y., You, I. & Zhang, H. (2023). Smart Collaborative Evolvement for Virtual Group Creation in Customized Industrial IoT. IEEE Transactions on Network Science and Engineering, 10(5), 2514-2524. https://doi.org 10.1109/TNSE.2022.3203790.

[2] Xue, K., Yang, J., Xia, Q., Wei, D. S., Li, J., Sun, Q., & Lu, J. (2021). CSEVP: a collaborative, secure, and efficient content validation protection framework for information centric networking. IEEE Transactions on Network and Service Management, 19(2), 1761-1775. https://doi.org/10.1109/TNSM.2021.3136547

[3] Song, F., Ai, Z., Zhou, Y., You, I., Choo, R., & Zhang, H. (2020) Smart Collaborative Automation for Receive Buffer Control in Multipath Industrial Networks. IEEE Transactions on Industrial Informatics, 16(2),1385-1394, https://doi: 10.1109/TII.2019.2950109.

[4] Kapetanidou, I. A., Malagaris, S., & Tsaoussidis, V. (2022, June). Avoiding notorious content sources: A content-poisoning attack mitigation approach. In 2022 IEEE Symposium on Computers and Communications (ISCC) (pp. 1-6). IEEE. https://doi.org/10.1109/ISCC55528.2022.9912936

[5] Qureshi, A. M., Anjum, N., Rais, R. N. B., Ur-Rehman, M., & Qayyum, A. (2021). Detection of malicious consumer interest packet with dynamic threshold values. PeerJ Computer Science, 7, e435. https://doi.org/10.7717/peerj-cs.435

[6] Srinivasan, S., & Mazumdar, A. P. (2019, July). Mitigating content poisoning in content centric network: A lightweight approach. In 2019 10th International Conference on Computing, Communication and Networking Technologies (ICCCNT) (pp. 1-6). IEEE. https://doi.org/10.1109/ICCCNT45670.2019.8944392

[7] Song, F., Zhu, M., Zhou, Y., You, I., & Zhang, H. (2020) Smart Collaborative Tracking for Ubiquitous Power IoT in Edge-Cloud Interplay Domain. IEEE Internet of Things Journal, 7(7), 6046-6055. https://doi: 10.1109/JIOT.2019.2958097.

[8] Song, Z., & Kar, P. (2020, December). Name-signature lookup system: A security enhancement to named data networking. In 2020 IEEE 19th International Conference on Trust, Security and Privacy in Computing and Communications (TrustCom) (pp. 1444-1448). IEEE. https://doi.org/10.1109/TrustCom50675.2020.00194

[9] Xue, K., He, P., Yang, J., Xia, Q., & Wei, D. S. (2022). Scd2: secure content delivery and deduplication

with multiple content providers in information centric networking. IEEE/ACM Transactions on Networking, 30(4), 1849-1864. https://doi.org/10.1109/TNET.2022.3155110

[10] Song, F., Ai, Z., Zhang, H., You, I., & Li, S. (2021). Smart Collaborative Balancing for Dependable Network Components in Cyber-Physical Systems. IEEE Transactions on Industrial Informatics, 17(10), 6916-6924. https://doi: 10.1109/TII.2020.3029766.

[11] Kang, H., Zhu, Y., Tao, Y., & Yang, J. (2018, August). An in-network collaborative verification mechanism for defending content poisoning in named data networking. In 2018 1st IEEE International Conference on Hot Information-Centric Networking (HotICN) (pp. 46-50). IEEE. https://doi.org/10.1109/HOTICN.2018.8606003

[12] Song, F., Ma, Y., Yuan, Z., You, I., Pau, G. & Zhang, H. (2023) Exploring Reliable Decentralized Networks with Smart Collaborative Theory. IEEE Communications Magazine, 61(8),44-50, https://doi: 10.1109/MCOM.003.2200443.

[13] Yue, P., Li, R., & Pang, B. (2021, September). The random content poisoning attack in NDN. In 2021 IEEE Intl Conf on Parallel & Distributed Processing with Applications, Big Data & Cloud Computing, Sustainable Computing & Communications, Social Computing & Networking (ISPA/BDCloud/SocialCom/SustainCom) (pp. 853-860). IEEE. https://doi.org/10.1109/ISPA-BDCloud-SocialCom-SustainCom52081.2021.00121

[14] Kapetanidou, I. A., Sarros, C. A., & Tsaoussidis, V. (2019). Reputation-based trust approaches in named data networking. Future Internet, 11(11), 241. https://doi.org/10.3390/fi11110241

[15] Sultan, N. H., Varadharajan, V., Camtepe, S., & Nepal, S. (2020). An accountable access control scheme for hierarchical content in named data networks with revocation. In Computer Security–ESORICS 2020: 25th European Symposium on Research in Computer Security, ESORICS 2020, Guildford, UK, September 14–18, 2020, Proceedings, Part I 25 (pp. 569-590). Springer International Publishing. https://doi.org/10.1007/978-3-030-58951-6_28