GPT-Enabled Digital Twin Assistant for Multi-task Cooperative Management in Autonomous Optical Network

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Abstract: A GPT-enabled digital twin (DT) assistant is implemented with the capabilities of intention understanding, analysis, reasoning, and complex multi-task collaboration, which integrate DT technologies to enhance the automated operation, monitoring, control, and upgrade of optical networks.

1. Introduction

With the exponential growth of network traffic and continuous expansion of network scale, the operation and maintenance of optical networks have become increasing complex and labor-intensive. By applying the digital twin (DT) technology to optical networks [1], network operators can obtain a comprehensive and systemic perspective of the physical layer to ensure the high-reliability operation and high-efficiency management. However, the implementation of DT in optical networks involves a multitude of tasks [2], such as mirror modeling, state updating, performance analysis, link optimization, feedback controlling, system upgrading, etc. The orchestration and cooperation of these tasks are intricate and heavily reliant on the human intervention, resulting in low efficiency and high costs. Therefore, it is still eager to develop an intelligent multi-task coordination assistant that can assist in orchestrating and executing multiple tasks systematically and automatically for the autonomous optical networks.

Recent advancements in large language models (LLMs) have opened up new opportunities for diverse natural language processing (NLP)-related tasks [3], including intent understanding, content generating, text summarization, language translating, question answering, etc. In particular, GPT (Generative Pre-trained Transformer) developed by OpenAI is currently considered as the most prominent and powerful LLM for artificial general intelligence (AGI). The GPT is a generalist model that can effectively solve multiple general-purpose tasks on a broad scale [4]. Therefore, it has the potential to serve as an DT assistant to implement multi-task cooperative management for autonomous optical networks, so that reliably liberating labor and time while improving the operational efficiency of physical networks. However, it always faces challenges when tackling specific tasks within particular professional domains [5]. In such cases, it is imperative to devise suitable task instructions or formulate specific prompt strategies to elicit its specialized proficiencies.

In this paper, an DT assistant is implemented with the intention understanding, analysis, reasoning, and complex multi-task collaboration capabilities based on GPT-3.5. The extensive knowledge, expert experience, network models and algorithms that meet the real-time operation and monitoring of optical networks are collected, organized, and stored to help solve the operational and maintenance problems. The proposed GPT-enabled DT assistant effectively analyzes the problems by retrieving the above knowledge, intelligently outputs instructions to calculation tools, and coordinates various operational results of the DT system. We take the quality of transmission (QoT) estimation problem as an example to implement the important role of GPT-enabled DT assistant in the automation process. Simultaneously, three scenarios for network analysis, optimization, and upgrade based on QoT estimation results are proposed, further demonstrating the reliable participation of LLM in the development of optical networks towards automation.

2. Principle

The current implementation of DT in large-scale optical networks primarily involves the QoT estimation to predict the power and signal-to-noise (SNR) of optical signals after fiber transmission, which related to the complex calculation on inter-channel nonlinear interference (NLI) in the presence of stimulated Raman scattering (SRS) effects in a wide spectral range [6]. The GPT-enabled assistant is implemented to meet the increasing demand for real-time updates and the dynamic QoT estimation. The basic knowledge of optical communication manuals, protocols, standards, network topology information, and expert experience related to optical network transmission are pre-classified and stored in the knowledge base. The DT optical network datasets, algorithms, models, platforms, systems, tools for network QoT estimation and optimization, necessary data collection and configuration application programming interfaces (APIs) are pre-connected and labeled in the tool base, as illustrated in Fig.1.

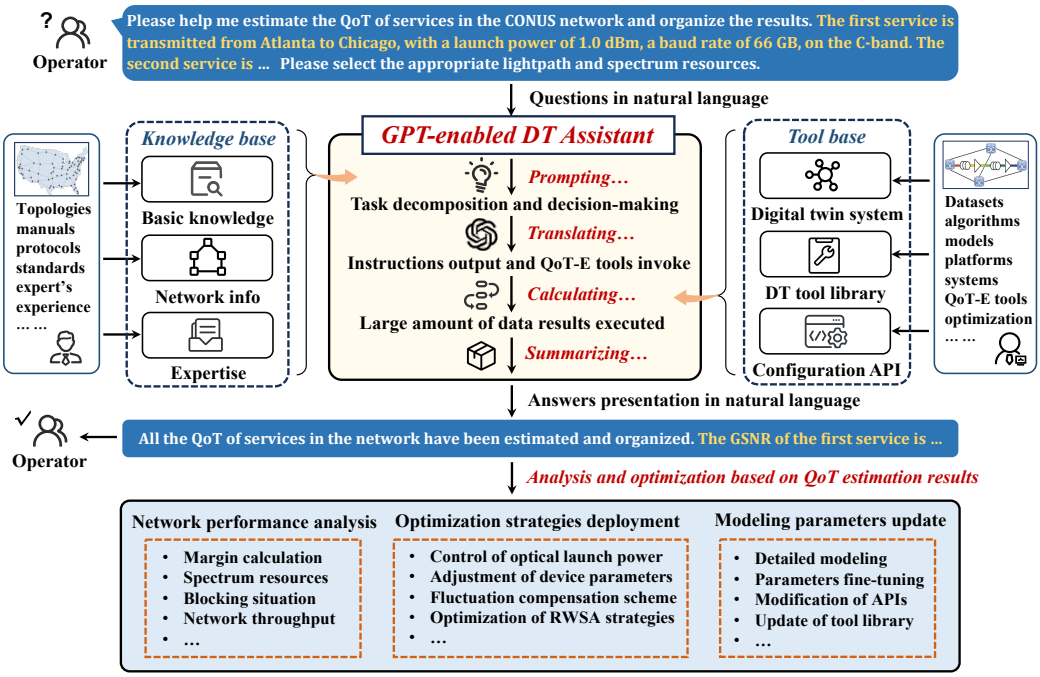

Fig. 1. The GPT-enabled DT assistant supports the network automation operation

When the network operator proposes a specific problem such as QoT estimation but he/she cannot proficient in tools for the optical network operation. The GPT-enabled DT assistant receives the natural language question and executes the following process to solve the problem: 1. Accurately locate the necessary optical network knowledge and problem-solving strategies through correlation search of the knowledge base, and provide it as a prompt to GPT to utilize its understanding and analysis ability. 2. After task decomposition and decision making, GPT transforms this problem into multiple specific sub-tasks and pointed out the tools needed in the DT domain with the computer instructions. 3. The GPT-enabled DT assistant hands over various instructions to the QoT estimation tools to collaborate on specific sub-tasks step-by-step [7]. 4. A large number of program execution results are organized and summarized, and the GPT-enabled DT assistant outputs the final results in natural language as answers presentation.

Utilizing its capabilities in information integration and analytical reasoning, GPT as a high-performance LLM, empowers network operators to evaluate the current transmission performance based on the results of QoT estimation. This assessment encompasses margin calculations, spectrum resource allocation, evaluation of network congestion, and statistics on network throughput. Professional methodologies for addressing these issues are pre-incorporated into knowledge and tool bases. Furthermore, to advance network automation, optimization strategies for real networks can be implemented with the GPT-enabled assistant and its coding capabilities enable fine-tuning of models and parameters in DT systems, promoting further efficiency and customization.

3. Demonstration and Results

To verify the ability of GPT-enabled DT assistant to realize the autonomous operation and maintenance of optical networks, three typical task scenarios were tested: (a) QoT estimation task, (b) network analysis task, (c) optimize and upgrade task, as shown in Fig. 2.

First, the GPT-enabled DT assistant is equipped with prior expertise for QoT estimation (QoT-E) in optical networks, along with APIs connected to both Gaussian noise (GN) model-based and machine learning (ML) model-based QoT-E tools [8]. The complex task of simulating specific services within the CORONET CONUS network at a given time was decomposed into a coordinating process that involves QoT-E and routing wavelength and spectrum allocation (RWSA). By leveraging the GPT's advanced intent understanding and analysis capabilities, honed through prompt-tuning, the DT assistant is proficient in translating the operator's intentions into instructions and efficiently invoking the requisite QoT-E tools, thereby enabling the automation of intricate and repetitive tasks. Subsequently, by invoking the related tools (with the physical model parameters such as connections, fiber loss, dispersion, gain of Erbium-doped optical fiber amplifier (EDFA), and noise figure are set in advance) in the optical network to execute the tasks, the QoT-E results were organized and output. The curves in Fig. 2(a) show the calculated generalized SNR (GSNR) and margin profiles on an optical multiplex section (OMS) in the CONUS network at three times with adding/dropping signals, marked insufficient margin values.

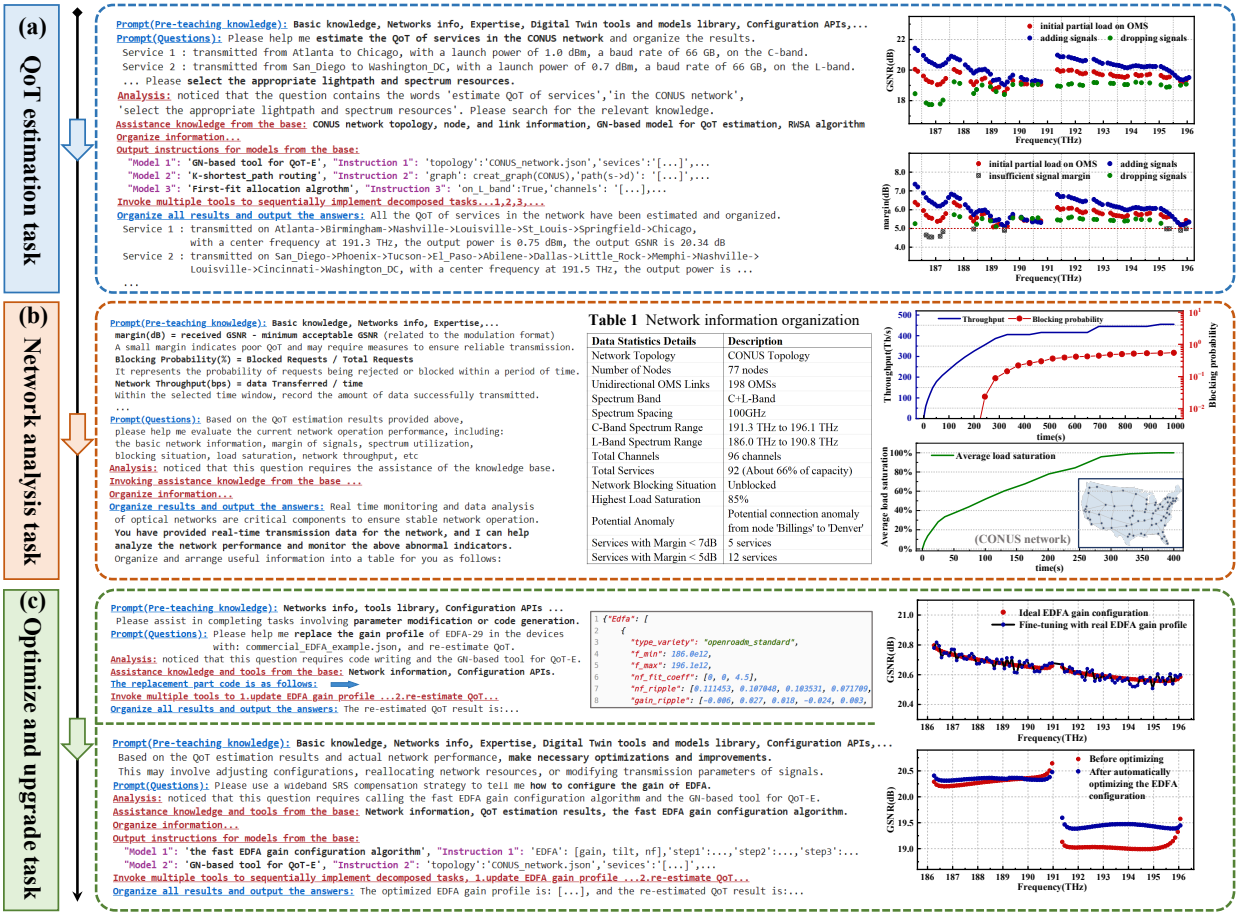

Fig. 2. The GPT-enabled DT assistant automates collaborative works in three typical task scenarios and results presentations: (a) QoT estimation task, figures: GSNR/margin profiles on an OMS estimated three times with adding/dropping, (b) network analysis task, table: network information organization from GPT-enabled assistant, figures: indicator presentations for the running CONUS network, (c) optimize and upgrade task, code: GPT-based debug for EDFA configuration, figures: GSNRs before and after updating configurations

Second, leveraging the results of QoT-E and professional knowledge, the GPT-enabled assistant plays a pivotal role in analyzing the current operational status and various network performance metrics, as illustrated in Fig. 2(b). The network information summaries, performance monitoring, and metric evaluations can all be efficiently accomplished and presented through its systematic inductive reasoning ability, without manual intervention. Third, network optimization and modeling upgrades are essential components to the progression of DT intelligently assisted physical networks. In these tasks, the GPT-enabled assistant demonstrated its prowess in code debugging and coordinating optimization and model configuration as presented in the two examples in Fig. 2(c): fine-tuning models by replacing EDFA gain profiles and employing optimization strategies [9] for the automatic update of EDFA configurations on a full loaded 5-span transmission link in the CONUS network.

In conclusion, a GPT-enabled DT assistant was implemented in optical networks to support the real-time operation, comprehensive analysis, automatic control and upgrade. The results we presented indicating that GPT has reliable performance in reducing labor costs and interventions, and enhance the optical network automation.

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4. References

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