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# Learning-based network path planning for traffic engineering

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## HIGHLIGHTS

- A sequential model learns implicit paths from historical traffic experiences.
- Attention mechanism captures correlations between source paths and target paths.
- Beam search guarantees path connectivity by holding candidate paths.
- A high testing accuracy implies the superiority of our proposal.

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## ABSTRACT

Recent advances in traffic engineering offer a series of techniques to address the network problems due to the explosive growth of Internet traffic. In traffic engineering, dynamic path planning is essential for prevalent applications, e.g., load balancing, traffic monitoring and firewall. Application-specific methods can indeed improve the network performance but can hardly be extended to general scenarios. Meanwhile, massive data generated in the current Internet has not been fully exploited, which may convey much valuable knowledge and information to facilitate traffic engineering. In this paper, we propose a learning-based network path planning method under forwarding constraints for finer-grained and effective traffic engineering. We form the path planning problem as the problem of inferring a sequence of nodes in a network path and adapt a sequence-to-sequence model to learn implicit forwarding paths based on empirical network traffic data. To boost the model performance, attention mechanism and beam search are adapted to capture the essential sequential features of the nodes in a path and guarantee the path connectivity. To validate the effectiveness of the derived model, we implement it in Mininet emulator environment and leverage the traffic data generated by both a real-world GEANT network topology and a grid network topology to train and evaluate the model. Experiment results exhibit a high testing accuracy and imply the superiority of our proposal.



## 1. Introduction

Traffic Engineering (TE) is crucial for enhancing the utility and performance of networks in the era of big data [1,2]. It has been a hot topic in recent research trend [1–5], due to the increasing demands on dynamic network maintenance, management and Quality-of-Service (QoS) guarantee [2].

Path planning is one of the most important aspects of TE, providing selected routing and forwarding paths between nodes to offer high-performance networks [6,7]. Due to diversified services and advanced networking techniques like network virtualization, network dynamics have become a normal phenomenon, resulting in an increasing demand for path planning under various requirements and/or conditions [7–10]. For instance, forwarding path is restricted to go through one or several given nodes for e.g. traffic monitoring.

The emerging Software Defined Networking (SDN) paradigm [11,12] has gained its popularity and drawn considerable attentions for smooth and rapid development of new TE algorithms, due to its capability of decoupling the control plane from the data plane. This decoupling releases computing resources in commodity switches to simplify switch functions and pull the forwarding decision making and computing into a high level controller, which is able to take global information into consideration.

With the increment of various emerging applications, massive data has been produced from the Internet [13,14]. The hidden information behind the data implies important knowledge [15] for efficient TE [3]. Data-driven applications take as input the massive data to help adapt learning algorithms into distinctive circumstances. Successes in [16,17] clarify the importance of leveraging useful data generated from the network. Their large-scale

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data analysis enables promising applications, such as semantic interpretation and user experience improvement.

We intend to extend data-driven learning promoted by deep learning methods to the path planning problem. Deep learning has been massively developed and rapidly deployed by a variety of applications [18], which makes the utmost data be fully perceived by the application. Though deep learning methods have succeeded in many fields, challenges still exist when being introduced into network applications [3]. For example, dynamics in networking needs human-like behavior for model to fit. To solve this problem, the authors in [4,5] incorporated reinforcement learning to flexibly make decisions in a dynamic network environment, but they focus on coarse flow split ratio control for communication transferring.

To make a further progress, in this paper we aim to have finer-grained network-level path planning driven by empirical traffic data. To achieve this purpose, we treat the network path as a sequential data, since a path with a set of forwarding hops explicitly express its serializability. One notable sequence analysis technique comes from Natural Language Processing (NLP), where sentences or phrases are intrinsically serialized. Inspired by sentences analysis in NLP, we merge neural networks and build a sequence-to-sequence (seq2seq) model [19] to capture inner characteristics of sequence-like traffic forwarding and routing path. Abundant traffic information from the network can provide a natural way for model training. We will extract sequential features from empirical traffic data and apply them into path discovery.

The main contributions of this paper can be summarized as follows:

- This paper proposes a learning-based data-driven model for network planning under constrained conditions, which can be used in SDN controllers to perform finer-grained TE. The model is derived based on the seq2seq processing model with empirical knowledge from historical traffic data. With the derived model, we can have a sequence of nodes as input and predict a sequence of nodes as target path.
- In order to infer a reasonable order of nodes in the target path, attention mechanism is adapted to calculate the correlations between input sequence and target sequence.
- To further ensure the connectivity of the output target path from the derived model, we apply beam search to extensively search candidate sequences. Beam search is able to help the prediction of target paths move out of local optima and explore global optimal solutions. The model can check the order of nodes in terms of the connectivity of a path and only output the available ones.
- To validate the effectiveness of the derived model, we implement it in a typical SDN emulator environment, i.e., Mininet, and leverage the traffic data generated by both a real-world GEANT network topology and a grid network topology to train and evaluate the model. Experiment results exhibit a high testing accuracy and imply the superiority of our proposal.

The remainder of the paper is organized as follows. In Section 2, related work is described. Section 3 introduces preliminary work. A detailed description of our proposed model is presented in Section 4. Experiment results and analysis are conducted in Section 5. Finally, we conclude this study in Section 6.

## 2. Related work

Path planning has been widely studied in wireless networks [8–10] for producing optimal forwarding paths under constraints. Especially, it is crucial for energy-sensitive applications in e.g. wireless sensor networks to meet resource constraints. Most of existing algorithms have been designed at application-level.

Although application-level designs can surely improve network performance, they are not optimized based on general networking scenarios but are based on limited application situations, e.g., leveraging two classic layered approaches in [8]. In contrast, the network-level approaches are finer-grained and can be generalized to different network architectures.

In [20], the authors studied and proposed dynamic routing algorithms for online unicast and multicast requests. The authors considered switch bandwidth, link capacity and bandwidth demand together to maximize accumulated bandwidth of admitted requests. They separated the problem into two issues, link resource cost regression and link capacity maximization without the knowledge of previous request arrivals.

Encoding path is essential for forwarding table state maintained in a switch [21]. To relieve the pressure on the maintenance of switch tables, the authors in [21] proposed a path encoding algorithm to handle variable length interface labels that can shorten any network paths.

A dynamic routing framework based on SDN controller was described in [22], which is to provide the solution for achieving the maximum throughput and minimum cost. The authors used an LSTM model to predict traffic matrix, based on which the routing rules are generated by traffic routing units.

Very recently, in [5], the authors aimed to schedule conventional dynamic traffic and Internet of Things (IoT) with flexible time. They proposed to integrate the reinforcement learning into the decision of IoT traffic transmission. They firstly identified the inefficiency for IoT transmission, and then built a learning model to formulate IoT traffic scheduling issue and determine a controlled split ratio for it. The reward function was given by weighted sum of three types of traffic volumes.

In [4], Chinchali et al. gave a clear definition of the targeted Traffic Engineering (TE) problem, and successfully built a model-free reinforcement learning for a general dynamic routing framework. Two key methods were included, an actor–critic model with experience replay training and a TE-aware exploration, which absorbs the trade-off policy of exploration and exploitation in reinforcement learning. In addition, they utilized the network utility, formulated in [23], of throughput and delay as the reward. Their empirical experiments showed promising results of reinforcement learning for applying in TE problems.

In spite of the successful integration of deep learning, as aforementioned, they only focused on high level flow-oriented split ratio optimization [5], and assumed $K$ available candidate solutions prior to dynamic decisions [4]. In contrast, in this paper we will consider a finer-grained traffic learning and achieve network-level path planning.

## 3. Preliminaries

The seq2seq model [19] is an expanded and specific encoder–decoder model in neural networks for handling sequence data, including sequence data learning, transferring and translation. It now prevails in neural machine translation, text summarization and speech recognition in Natural Language Processing (NLP), image captioning and other sequence data applications. In this section, we give an overview of the formulation and the details of the seq2seq model. To facilitate the understanding, the basis of neural networks and the encoder–decoder structure are introduced in Sections 3.1 and 3.2, respectively, followed by the seq2seq model in Section 3.3.

### 3.1. Basis of neural networks

This study concentrates on building a prototype neural network model to extract and restore hidden optimal paths between network nodes based on empirical forwarding trace data. In this section, we introduce fundamental concepts of prevalent neural network models as background knowledge.