Data-driven network analytics and network optimisation in SDN-based programmable optical networks

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***Abstract*—5G, IoT and other emerging network applications drive the future optical network to be more flexible and dynamic. Fully awareness of current network status is critical for better network programming in short timescale. In this paper, the centralized network database with network monitoring data and network configuration information enables network analytics application to support the future dynamic and programmable optical network.**

***Index Terms*—component, formatting, style, styling, insert**

I. Introduction

Traditional static optical networks have been evolving continuously to offer more point-to-point link capacities by introducing coherent detection technology, sophisticated digital signal processing algorithms and space division multiplexing technologies [1]. However, the recent emerging network applications, such as big data, Internet of things (IoT) and 5G networks, require not only high-capacity optical links, but a dynamic or even programmable optical network. For example, the future 5G applications with peak network speed up to 10 Gbps will bring dynamic mobile traffic with significant bandwidths [2]. The dynamic and mobile network traffic requires network management in an end-to-end approach with ultra flexible network functions [3]. On the other side, software-defined networks (SDN) have been extended to optical networks to enable programmable, automatic and disaggregated optical networks [4]. The centralized SDN controller enables network programmability in the network controller layer and brings traffic engineering to multi-domain networks [5], [6]. Therefore, it's time to reconsider the architecture of the traditional static optical networks and bring programmability and flexibility for future dynamic optical networks.

In the future optical networks, network dynamics suggest two key points about network flexibility. Firstly, in dynamic optical networks, both the optical hardware and the control software should be flexible, configurable or even programmable. Each individual network function can be configured in a fine granularity to satisfy variable requirements in the dynamic optical networks. Furthermore, the whole optical node can deploy network functions in an on-demand manner [7]. Secondly, the dynamic optical networks also mean network connections will serve in a short timescale, not the same as the set-and-go link setup in the traditional static networks. In dynamic optical networks, network reconfigurations will happen more frequently. Thus, a short configuration/install time is required in the dynamic optical networks. In addition, network planning should consider the short period of the dynamic network services, which may lead to a margin-reduced optical link [8]. The network dynamics will bring many advantages to optical networks. However, it also raises new challenges for network management and network operation.

In this paper, a network-scale centralized network configuration and monitoring database (NCMdB) is implemented over an SDN-enabled optical network. The centralized NCMdB stores both the current and historical network configurations and network performance monitoring information. The NCMdB enables data-driven network analytics applications and support network optimization through the SDN interface in programmable optical networks. The network analytics applications can analyze the data in the NCMdB and offer suggestions for network planning and network optimization through the SDN controller. In this paper, a machine-learning OSNR prediction application that run over the NCMdB has been developed to assist both the network planning and network optimization. The NCMdB-powered network analytics and network optimization forms a new network-management approach for the dynamic optical network and bring new network functions.

II. Control loop for dynamic optical networks

Driven by the dynamic bandwidth requests, dynamic optical networks require a new network-service-deployment mechanism. The network functions/services should be deployed automatically. The time-consuming test and optimization operations need to be eliminated and to be replaced with instant

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network responses for deployment verifications. To achieve this, both the network monitoring device and novel control softwares are required. It's worthy noting that the network responses are not only for the latest-deployed services, but also for the previous deployed network services. The reason is that the latest-deployed network function may affect the current network services. In some extreme cases, the existing network service may fail due to the new network functions. Especially, in the margin-reduced optical network, the failure may happen more frequently and the network replanning, which is totally forbidden in the traditional networks, need to be introduced in the dynamic optical networks.

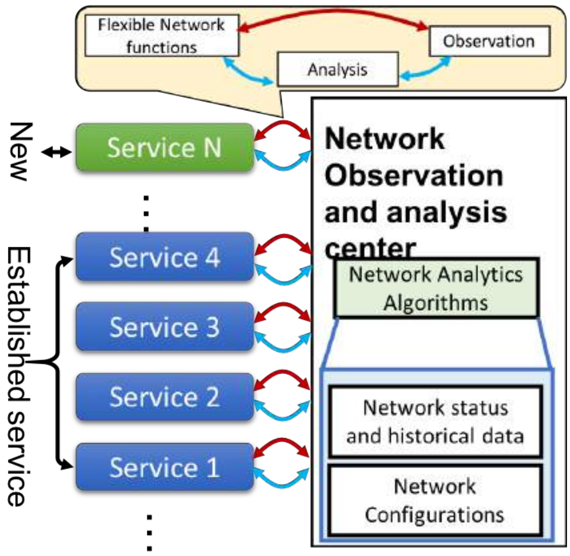

Fig. 1. Network control loop for dynamic optical networks.

Figure 1 shows the proposed network control loop in dynamic optical networks. For each service, deployment, observation and optimization will form a continuous operation circle. As shown in the inset of Fig. 1, a closed service operation loop will be established for each service. Firstly, the flexible network service or function is deployed according to the traffic request. Then, the network observation and analysis center will allocate the monitoring and related network analytics resources for the deployed services. The established operation circle provides instant responses the new deployed services to confirm the successful deployment. Then, the circle will continuously monitor the service. The network observation and analysis center will provide the monitoring functions to the deployed services. The monitoring functions are implemented with both network performance monitoring and the network analytics algorithms. In most case, the monitoring data are shared among several services. Thus, the monitoring data are uploaded to the cloud and processed jointly under different perspectives. As introduced first in [9], Fig. 2 presents the implementation of the proposed network observation and analysis center. Several key technologies are introduced as follows:

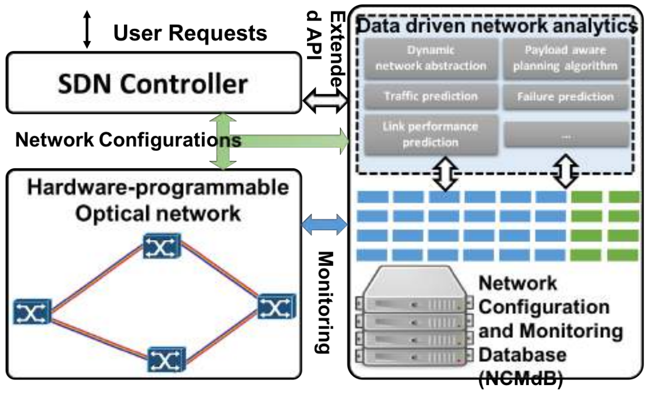

Fig. 2. Implementation of centralized network observation and analysis center.

A. Programmable node architecture and hitless reconfigurable network functions

Dynamic optical networks require flexible network configurations for the diverse network requests. In addition, network function reconfiguration are required for possible network replanning. Thus, network functions should be flexible and can be reconfigurable without any data loss, i.e., hitless operation. Part of the network reconfigurability can be achieved in the network control software with network function virtualization technologies (NFV) [10]. In this part, we mainly focus on the flexibility offered by the hardware implementation.

Regarding optical node functions, architecture-on-demand (AoD) based optical node architecture has been introduced to optical network by modularizing key network functions and deploying network function programmability [7], [11]. For the first time, the AoD concept is used to provide an SDM/WDM ROADM solution for future multi-core fiber based multi-dimensional optical networks [12].

For optical network functions, bandwidth variable transmitter (BVT) is one of the key enabling technologies for elastic optical networks. From the perspective of the optical hardware, BVTs require the hitless reconfigurations in operation baud rate and spectral efficiency. BVT with variable baud rates can be configured to accommodate variable spectrum slots in elastic optical networks. In [13], BVT is used to tolerate the filtering effect of the legacy wavelength selective switching (WSS) device in a fixed-grid and flex-grid coexisted network. Possible hitless operation of the BVT can be achieved for the elastic interface in flex-grid optical networks [14]. On the other side, BVTs with variable spectral efficiencies could deliver variable transmission capacities based on the link distance. In [15], real-time modulation-adaptable transmitter is reported to offer quick switching between QPSK and 16QAM signal formats. An spectral-efficiency adaptable transmitter with a fine-granularity is implemented based probabilistic shaping for network planning [16].

B. Network configuration and monitoring database (NCMdB)

In dynamic optical networks, network status becomes critical to plan, deploy, and configure network functions. Understanding the current network status could lead to an intelligent network planning. After the deployment of network functions or services, instant network responses will confirm the success of functions deployments. Then, the deployed network functions or services requires continuous network performance monitoring, which also rely on the awareness of the network status. In addition, network analytics applications would require the history network status. Therefore, the network status data is at the heart of the dynamic optical networks. On the other side, the centralized network controller in SDN makes the collecting of network configurations possible and easier. So, a well-structured network configuration and monitoring database is one of the key technologies to implement the closed network control loop in dynamic optical networks.

In [16], we built a network-scale NCMdB, which collects all the network configurations from the centralized SDN controller, network performance monitoring data from all the optical performance monitoring devices, and device operation information from the used electrical devices. Any event that will change the network status will trigger a new record to store the new data in the NCMdB. The NCMdB stores the raw data from all the optical performance monitors through dedicated links. All the physical parameters can be monitored and stored in the database. The monitoring data are linked to the network configurations. In principle, the NCMdB could record all the operation information of the current networks and the previous network status.

The NCMdB collects all the raw monitoring data to a centralized network space. Therefore, the monitoring data can be processed by different applications, i.e., network analytics applications. As shown in Fig. 2, network analytics applications can be developed over the NCMdB.

A parallel database schema is used to manage the data. In our design, the MongoDB, which has a hierarchical document-based data model design using JavaScript Object Notation (JSON) as the file format, is used to store all the collected information. The MongoDB based solution is able to support the complex data structures recorded throughout the experiments. Furthermore, the MongoDB based NCMDB could easily provide network interfaces for other applications.

C. SDN enabled network analytics application

On top of the NCMdB, multiple network analytics application can be developed.The NCMdB that includes monitoring and configuration data from all the network devices and links enables end-to-end connection analysis. Variable network analytics applications can access the monitoring and configuration data simultaneously. As shown in Fig. 2, a myriad of network analytics applications can run on top of the NCMdB to offer new network functions.

In SDN-enabled networks, the SDN controller can talk to the NCMdB rather than the real network monitoring device to access the monitoring data. The network analytics application can access more data with more computing resources, therefore can offer more information than the monitoring data. In addition, the network analytics applications could offer extra network functions. To facilitate the communications with the SDN controller, the developed network analytics applications should also support SDN protocol. Then, the SDN controller can use the network analytics applications more efficiently.

In the SDN controller, extra SDN plug-ins for the network analytics application should be developed to inform the extra network functions offered by the network analytics applications.

In [16], a machine-learning (ML) based OSNR predictor is developed based on a multilayer perceptron (MLP) artificial neural network (ANN) trained using various link and signal parameters extracted from the NCMdB. A supervised learning method i.e. Levenberg-Marquardt (LM) backpropagation (BP) is used for the offline training of ANN. During the training process, vectors p comprising of different link/signal parameters (such as launched power, EDFAs' gains, EDFAs' input and output powers, EDFAs' noise figures (NF) etc.) are applied at the input of ANN while the known OSNR values o at a given node corresponding to these parameters are used as targets. All the link parameters are retrieved from the NCMDB. After training, the OSNR predictor can predict the OSNR penalty of the unestablished optical path.

III. USE CASES

In this section, SDN-based network planning with ML-based OSRN prediction was demonstrated successfully over a field-trail testbed. The experimental demonstration is reported in [16]. The field-trial testbed consists of parts of the national dark fiber infrastructure service (NDFIS) from Bristol to Froxfield. Several extra nodes are located in our lab.

Figure 3 shows the workflow of the experimental demonstration. User requests are emulated and submitted to the SDN controller. Each user requests from the SDN controller to connect a source to a destination at a specific bandwidth. The SDN controller leverages the path computation application to determine a suitable path for the user request. If a path is successfully found, the SDN controller then finds a set of available wavelengths for the transmission. The SDN controller afterwards queries the trained ML application to predict the link performance for all the available wavelengths. Based on the predictions, the controller calculates the possible available link bandwidth and the optical modulation to use for the available wavelengths. In case the predicted bandwidth is lower than the one requested from the user, then the algorithm terminates, and the user request is not accommodated. If not, then the first available wavelength that meets the user bandwidth requirement, across the selected path that connect the user-selected endpoints, is chosen for the transmission. Following that, the SDN controller configures the optical switches appropriately using the OpenFlow protocol.

In the demonstration, the ML algorithm predicts the link performance and return the OSNR at the receiver side around 21 dB and the suggested spectral efficiency is 3.9987. The

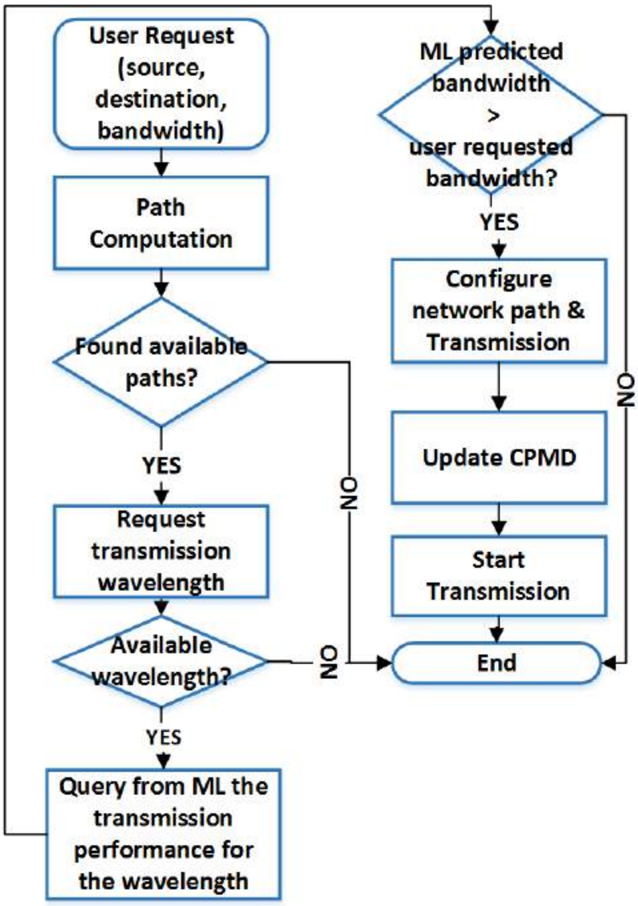

Fig. 3. Workflow of the experimental demonstration.

probabilistic shaping-based transmitter can offer optical signals with spectral efficiencies of 2.8, 3.2, 3.6 and 4 bits per polarization. Based on the QoT prediction, the transmitter is configured with SE at 3.6. Thus, network link can be setup based on the QoT prediction. The recovered constellations after 336.4-km fiber transmission is shown in Fig. 4.

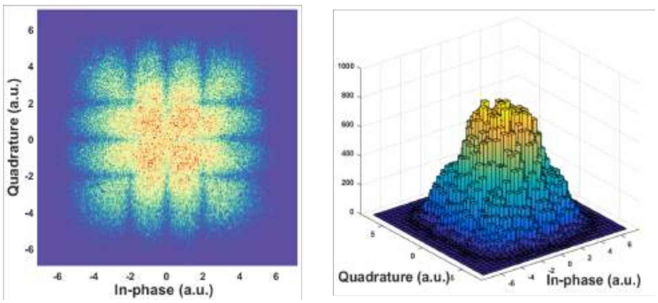

Fig. 4. (a) Recovered constellation diagram with entropies 3.6 after 336.4-km transmission; (b) The received constellation distribution.

IV. Conclusion

In this paper, novel network operation loop is introduced for the dynamic network services. The network-scale NCMdB that stores network monitoring and configuration information provides novel network functions through network analytics application. In this paper, we reported an machine-learning based QoT predictor, which help the SDN controller to plan the network efficiently. The introduced NCMdB and the network analytics applications open new possibilities for future dyanmic optical networks.

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