Dynamic Controller Deployment for Mixed-Grid Optical Networks

(Invited)

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***Abstract*—Co-existing fixed-grid and flex-grid (i.e., mixed-grid) optical networks introduce new challenges for network orchestration. Such mixed-grid networks are often controlled by hierarchical distributed architecture comprising of Optical Network Controllers and Software-Defined Network Controllers. Optimal deployment of these controllers is very important for efficient management of mixed-grid optical networks.**

Keywords—SDN controllers; optical network controllers; virtual network functions; cost savings.

I. Introduction

With increasing volume and heterogeneity of Internet traffic demand, spectrum of existing ITU-based fixed-grid networks is being exhausted. This situation is being addressed by introducing flex-grid technologies such as with Bandwidth-Variable Optical Cross Connects (BV-OXC), Liquid Crystal (LCoS) based Wavelength-Selective Switches (WSS), Sliceable Bandwidth-Variable Transponders (SBVT), etc. Flex-grid networks offer higher modulation format, higher capacity, variable spectrum granularities, tunable bit rates, and reconfigurability through software. However, since green-field deployment of flex-grid technologies may not be practical (due to the high cost of technology and usability), we envision brown-field networks [1] where both fixed-grid and flex-grid technologies would co-exist (i.e., mixed-grid) with seamless interoperability. To manage and operate such new mixed-grid infrastructures, appropriate deployment of controllers inside the network is an important research problem.

Traditionally, Generalized Multiprotocol Label Switching (GMPLS) technologies are used to maintain a distributed control architecture in optical networks. But the distributed nature of GMPLS might not achieve optimal network resources allocation. To overcome the limitations of GMPLS, the concept of Path Computation Element (PCE) was introduced. PCE is a controller entity responsible for computing a network path based on network state and network graph. Separation of control plane and data plane, an abstraction provided by Software-Defined Networks (SDN), offers easier and realistic solution for network operators [2]. Recently, SDN over existing (PCE-GMPLS-based) optical control plane has enabled integrated control plane with multiple network domains, multiple vendors, and multiple transport technologies. Similar technology comprising SDN controllers and optical network controllers (PCE-GMPLS-based) can enable control plane for mixed-grid optical networks.

Network Function Virtualization (NFV) [3] enables network operators to efficiently deploy, update, monitor, and manage dynamic network services. Prior studies [4] have explored scenarios where SDN controllers and Optical Network (ON) controllers are deployed and used as virtualized instances. Virtualized controller placement has many benefits. First, deploying SDN and ON controllers in traditional hardware boxes manually can take several days compared to few minutes in case of virtual instances (hosted in virtual machines, docker containers, etc.) in the cloud or NFV Infrastructure Point of Presence (NFVI-PoPs). Second, virtualized controllers can be easily recovered from failures or disasters. Typically, snapshots of virtual SDN or ON controllers are collected frequently and such instances can be easily moved from one location to another and redeployed [5]. Third, migration of virtual controllers allows dynamic deployment closer to active users.

In addition, Ref. [4] discussed virtual controllers for tenants, which allows the tenants to control the leased networks. With recent trend towards *pay-as-you-go* models for network leasers, tenants (e.g.., mobile virtual network operators, enterprise customers such as Netflix) would be interested to use controller instances as needed. Dynamic methods are required to deploy more controller instances under high load (i.e., more active users) and to turn-off unnecessary controller instances during low load (i.e., less active users). Although dynamic deployment of NFV instances have been explored in prior studies [6], dynamic deployment of controller instances has not been explored much. Our study explores this important research problem in a mixed-grid optical network scenario. Important questions such as, 'how many controllers are needed?', 'which are optimal locations to place them?', etc. need to be answered.

The rest of this study is organized as follows. Section II discusses control-plane architecture and components of mixed-grid optical network. Section III describes how virtualization can exploit spatio-temporal variation of load. Section IV concludes the study.

II. Control Plane for Mixed-grid Optical Network

Control plane for optical networks consists of hierarchical distributed architecture comprising traditional PCE-GMPLS-based ON controllers and SDN controllers. Fig. 1 shows such an example of hierarchical control plane for mixed-grid optical networks. At the higher control level, SDN controllers are connected with 'management interfaces' (such as Transport Network Orchestrator (TNO), Operations Support Systems (OSS), Network Management System (NMS)), etc. using 'north-bound interfaces'. This allows for abstraction of the details of the complex heterogeneous multi-domain, multitenant optical network. On the other hand, 'south-bound interfaces' of the SDN controllers need enough details to manage and configure the optical network via ON Controllers. 'SDN Domain Controllers' are responsible for different autonomous domains and manages the underlying ON via appropriate ON controllers. Fig. 1 a) assumes mixed-grid is directly controlled by cooperating 'Fixed-grid ON Controller' and 'Flex-grid ON Controller'. With a different approach, Fig. 1 b) assumes a scenario where 'Fixed-grid ON Controller' and 'Flex-grid ON Controller' are controlled by a higher level 'Mixed-grid ON Controller'. In addition to these controllers, tenants usually have their own 'Tenant SDN Controllers', which communicate with 'SDN Domain Controllers' and 'ON Controllers' to manage the tenant network.

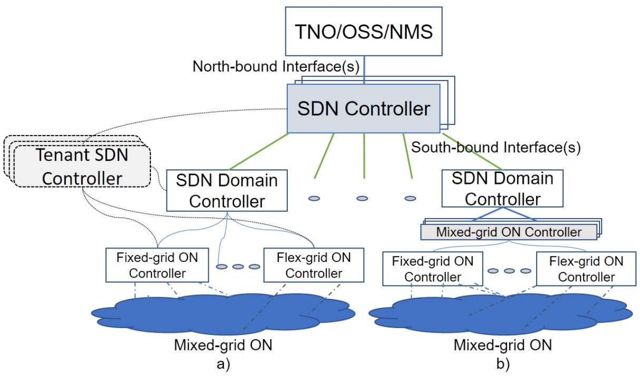

Fig. 1. Control plane architecture for SDN-enabled mixed-grid optical network.

III. Dynamic Deployment of Virtualized Controllers

Recently, NFVI-PoPs are introduced to host such services along with cloud datacenters. Both are possible candidates for hosting virtualized instances of network controllers. Virtualized controllers are faster to deploy, and they provide faster recovery from disasters/failures, compared to hardware-based controllers. Virtualized controllers can be placed in optimal NFVI-PoPs considering latency requirements, cost of deployment, etc. Fig. 2 shows such a scenario over a mixed-grid optical network.

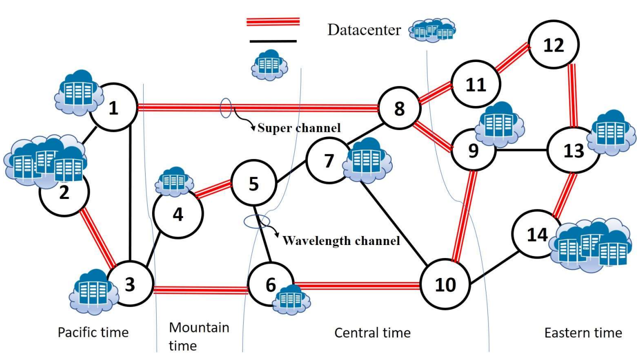

Fig. 2. Example NFVI-PoPs over mixed-grid optical network.

In addition, virtualization of controllers and increasing number of NFVI-PoPs allow us to deploy controllers according to spatio-temporal variation of load. We observe that some of the controllers inside a network may be statically deployed. For example, central SDN controller of a certain part of the network will remain deployed and active irrespective of load. On the other hand, other network controllers (e.g., 'Tenant SDN Controller'), can benefit from dynamic deployment over time. For example, a tenant can benefit from more 'Tenant SDN Controllers' to handle incoming flows when the network experiences high user traffic. On contrary, during lower load, turning off some controller instances will result in lower leasing cost for the tenant (in a *pay-as-you-go* model). Also, from a network operator's perspective, this dynamic deployment will save operational cost.

Fig. 2 shows nation-wide NSFNet topology with 4 US time zones. Load distribution in such a network varies over time and space. For example, for a Netflix-like tenant, 8 PM on the east coast will have much higher number of users, compared to west coast (5 PM Pacific time). At the same time, regions in mountain time may never see as much load due to lower population in those areas. Dynamic controller placement methods should consider such spatio-temporal variation [7] of network load.

Variation of load can occur from other sources such as: special events (National Basketball Association (NBA) games, US presidential debates), disasters, failures, online sales events [8] (e.g., Christmas sales on Amazon, Walmart), etc. Dynamic deployment methods should consider these scenarios as well for the placement of controllers.

IV. Conclusion

Co-existing flex-grid and fixed-grid optical networks introduce new challenges for network management. Flexible features of flex-grid networks can be exploited for the dynamic placement of controllers enabled by virtualization of controllers. Future studies should explore different dynamic load scenarios for controller deployment in mixed-grid optical networks.

Acknowledgement

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