Software Defined Networking (SDN) Enabled Optical as a Service (OaaS) with Dynamic Network Provisioning

Yongli Zhao and Jie Zhang
State Key Laboratory of Information Photonics and Optical Communications
Beijing University of Posts and Telecommunications, Beijing 100876, China

Abstract— Optical network has been deployed widely as one of the most important physical infrastructure because of the advantages of high capacity, long transmission distance, and low energy consumption. Then how to exploit the potentiality of optical networks gets more and more attention, especially in the current data center networks. Optical as a service (OaaS) is proposed and designed to provide the optical network resources directly for the data centers with considering both data center and network resources, which can be implemented with software defined networking (SDN). Under SDN enabled OaaS architecture, a new concept of network provisioning is proposed different from legacy connection (lightpath) provisioning, because the client's requests may include not only one end-to-end connection, but also several end-to-end connections, even a network. Also network with edge resources can be provided for the clients. A virtualization engine is designed in SDN enabled OaaS to efficiently complete the network provisioning. As a generalized optimization strategy in SDN enabled OaaS, the cross stratum optimization (CSO) strategy is described by considering both data center and network resource in the paper. Finally the SDN enabled OaaS testbed is demonstrated.

1. INTRODUCTION

With the advent of big data era, data center has become one of the most important application resources, and is necessary to be connected by high bitrate transport networks. Optical networks will be the inevitable choice because of the advantages of high capacity, long transmission distance, and low energy consumption. Then how to exploit the potentiality of optical networks in the current data center networks become more and more important. Because data centers are geographically distributed in different areas, long-haul transmission networks are necessary to delivery such high volume data center traffic. At the same time, with the exponential growth of burst Internet traffic between data centers, the traditional fixed grid optical networks are moving forward to flexi-grid optical networks because of its high spectrum-efficiency and flexibility [1], especially for the super-wavelength application beyond 100 Gbps. Data center interconnected by flexi-grid optical networks is a promising scenario to allocate spectral resources for applications in a dynamic, tunable and efficient control manner [2, 3], because flexi-grid optical networking is capable of ultra-high capacity, bit-rate transparency, distance adaption and low power density, and represent a potentially disruptive solution for overcoming emerging data center network bottlenecks. Inter-data center networking architecture, algorithm and control plane have been addressed in flexible bandwidth optical networks [4, 5].

On the other hand, in order to achieve the optimization of application and network resource, Cross Stratum Optimization (CSO) is proposed [6], which can enable a joint optimization of application and network resources and take the optical as a service (OaaS) [7]. Meanwhile, as centralized control architecture, the Software Defined Networking (SDN) enabled by OpenFlow protocol, has attracted much attention by supporting programmability of network functionalities and protocols [8, 9]. Extension of OpenFlow protocol is necessary to support CSO procedure for meeting the scalability and flexibility requirements, including resource customization and cooperation in dynamic multi-layer networks [10].

With the development of data center networks, the forms of client's requests are frequently changing. The current client's requests may include not only one end-to-end connection, but also several end-to-end connections, even a network in data center networks. Then, the network with edge resources can be provided for the clients together. Network provisioning will become an important request form relative to legacy lightpath provisioning. The dynamic anycast service [11] considering backup resource is one of the typical requests with network provisioning. In the process of network provisioning, no further detailed network information needs to be provided for the client, except the final virtualized network with edge data center resource. SDN will be the best choice of implementation technology because of its overview over heterogeneous network resources.

While resource virtualization is an effective solution to network provisioning. A lot of studies have focused on the mapping problem for resource virtualization [12]. At the same time, the control plane techniques with dynamic and intelligent virtual network provisioning have been coming into view [14]. The concept of network provisioning is proposed in the paper, which is implemented on the software defined networking (SDN) enabled optical as a service (OaaS) testbed.

2. SDN ENABLED OAAS ARCHITECTURE

We propose an OaaS architecture based on SDN as shown in Fig. 1. Two kinds of controllers are included in OaaS, which are network controller (NC) and application controller (AC). The former keeps the resources of multi-layer and multi-domain optical networks, and can provide the virtualized network from the underlying network by virtualization engine introduced in Section 4. While AC maintains the application resources in data centers, takes charge of data center resource scheduling, and triggers the related NC to complete the function of routing and resource allocation. According to the requirement, AC customizes appropriate virtual resources through related NC with extended OpenFlow protocol (OFP). OFP is deployed here as the interface protocol between south and north. Path Computation Element Protocol (PCEP) or OFP can be adopted here as the east and west interfaces in this architecture. For clients, SDN enabled OaaS architecture can be considered as an effective integration solution for resource provisioning, including network and data center resources. Optimal utilization of various resources can be achieved through the cooperation between AC and NC.

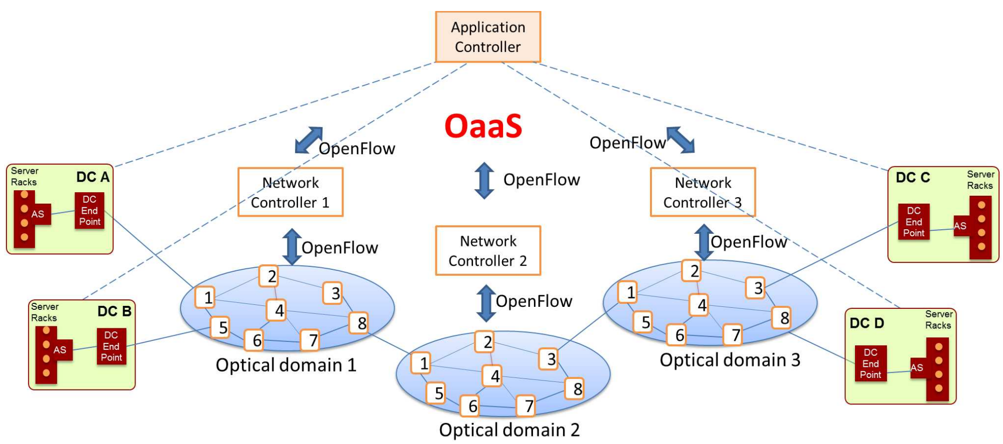

Figure 1: SDN enabled OaaS architecture.

3. NETWORK PROVISIONING

A new form of service request is emerging different from legacy lighpath provisioning, i.e., network provisioning, the meaning of which can be found in Fig. 2. The details are introduced as follows.

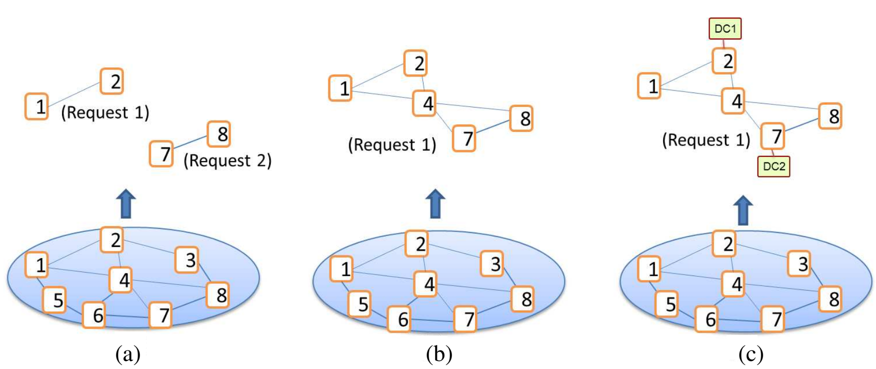

Figure 2: (a) lightpath provisioning, (b) network provisioning, (c) network provisioning with edge resource.

3.1. Lightpath Provisioning

In the traditional optical networks, what the client requests is point-to-point connection or point-to-multi-point connection as shown in Fig. 2(a). Different wavelength resources along different fiber links are provided for the clients. In the process of lightpath provisioning, routing function can choose the most suitable path from the source to the destination by some routing algorithms, such as Dijskra algorithm and KSP algorithm. Of course, some parameters can be used as the weight value, such as the cost, path length, link delay and available resource. Then the wavelength resource is allocated for the request along the route by some wavelength assignment policies, such as First Fit (FF) and Random Fit (RF). Finally, an end-to-end lightpath is setup for the service request.

3.2. Network Provisioning

As a new form of dynamic service request, network provisioning requires a network with multiple nodes and links, just like Virtual Private Network (VPN). Also some network performance parameters may be proposed by the clients with the request, such as the latency, security, and robustness. A network with available resources and meeting the requirement above must be provided dynamically by the operator. No further detailed information about the network is necessary for the clients. But the operator must consider how to provide the network resource, not only meeting the client's requirement, but also considering the cost. Some routing algorithms can be deployed to finish the path computation between more than one node pairs. Then the wavelength resources are allocated for different connections on the network topology. Whether the wavelength continuity constraint is considered or not here depends on the network equipment. Resource mapping between the point-to-point request and physical topology must be considered in the process.

3.3. Network Provisioning with Edge Resource

For some requests, both the network resource and the application resource should be provided. This is a new request form, which we can name network provisioning with edge resource. Then, how to implement this function will be the main focus of the IT and network operator. Generally, the edge resource can be selected first according to some considerations, such as backup and traffic load balancing. And then a networking provisioning request emerges, which can be handled with the method mentioned in Subsection 3.2. Of course, some other methods can be used to meet this kind of request. For example, we can consider both application resource and network resource at the same time, and allocate the resource according to a comprehensive evaluation index, which is the key idea of Cross Stratum Optimization (CSO).

4. VIRTUALIZATION ENGINE EMBEDDED IN OAAS

In order to finish the network provisioning effectively, a virtualization engine is designed under SDN enabled OaaS architecture as shown in Fig. 3. The physical infrastructure in current data center networks consists of facilities in different network domains, e.g., optical transport networks, IP WAN, data centers, etc.. One or more Domain Virtualization Engines (DVE) can be deployed for each domain, and act as special network controllers to slice, partition or aggregate the controlled network or application resources. DVEs could be connected to controllers to provide virtual single-domain topologies, be cascaded recursively, or be aggregated to a high-level one called Infrastructure Virtualization Engine (IVE), which collects resource information of different domains from each DVE or directly from each domain, and can provide VIs to renter's controllers with various kinds of resource forms to meet different demands.

5. CROSS STRATUM OPTIMIZATION STRATEGY IN OAAS

The CSO of application and network resources can be realized under the unified control architecture based on SDN enabled OaaS as depicted in Fig. 4(a) by cross stratum virtualization (CSV) approach. According to the requirement, AC customizes appropriate virtual resources through related NC with extended OFP. In addition, dynamic global load balancing strategy (DGLB) can be implemented based on both application and network resources, while NC can trigger service-aware PCE algorithm (SA-PCE) based on the result of DGLB. NC interacts with each other for the security and virtual network information. OpenFlow enabled routers and optical transport nodes are realized by extending match domain in OFP. The responsibilities and interactions among entities are provided as shown in Fig. 4(b).

When OpenFlow parser (OP) receives a new flow, it will map it into request parameters and forward it to server selection engine (SSE). The certified request is transmitted to application resource virtualization module (ARVM). ARVM provides SSE with the suitable application resource from data center network, while SSE customizes virtual network information from SC through secondary CSV. After completing DGLB, SSE chooses the most optimal server or virtual machine (VM) for users, allocates application resources and determines the location of application. According to the result, AC transmits application requirements to related SCs via OP. When data process (DP) in SCs receives the location of the server/VM and service type, it will translate this profile into connection and service parameters, such as bandwidth, delay and jitter, and forwards this profile to path computation element (PCE). Then extended OpenFlow module (EOM) assigns the wavelength resource in the optical networks.

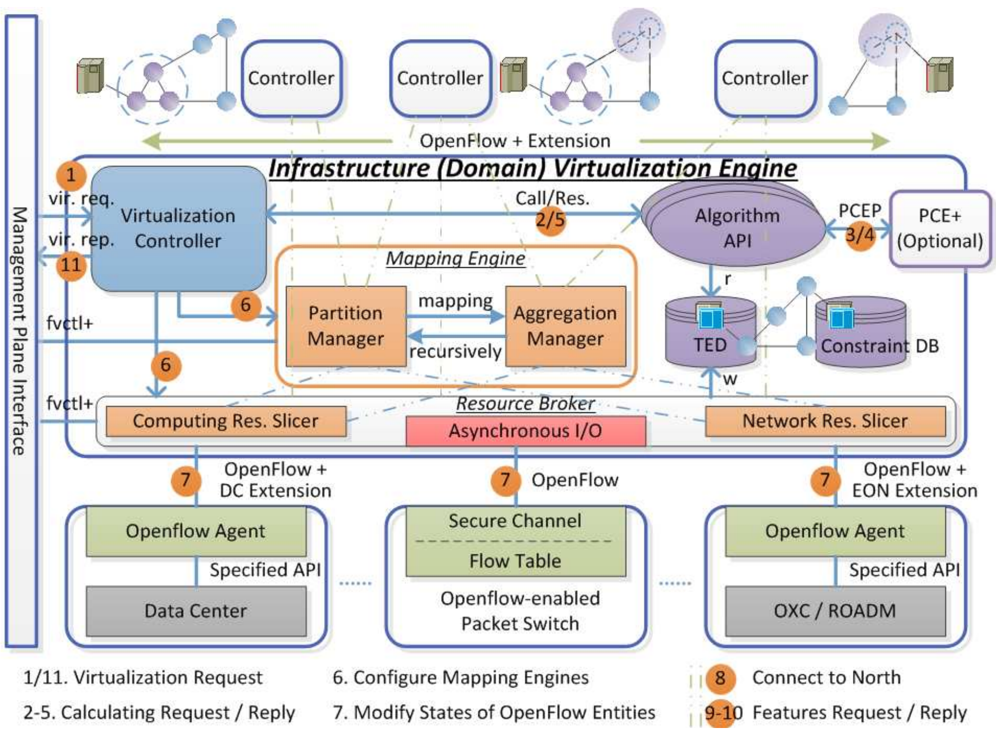

Figure 3: The composition block diagram of virtualization engine.

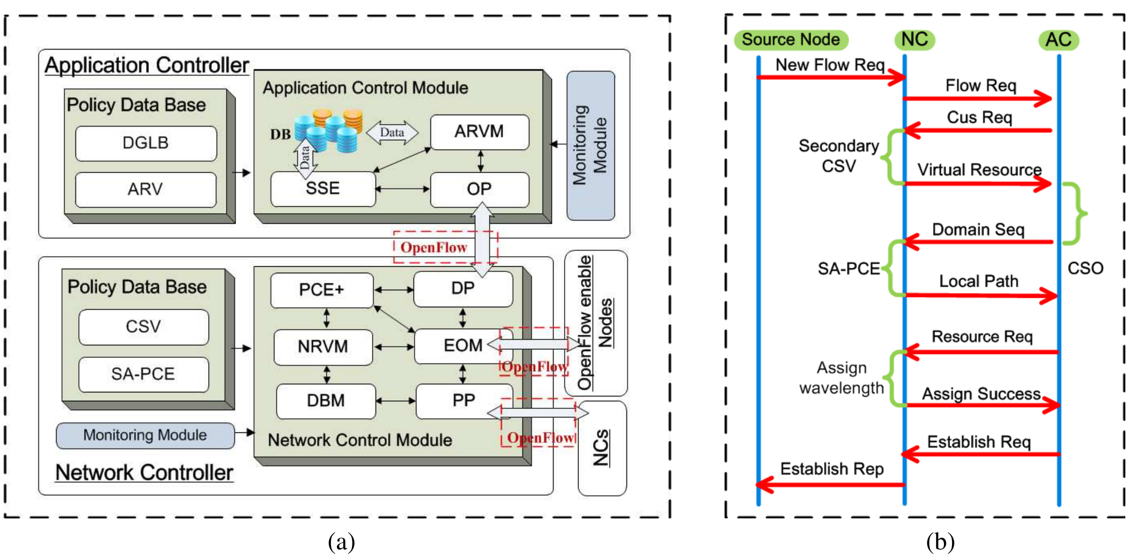

Figure 4: (a) Module diagram, (b) CSO procedure.

6. NETWORK PROVISIONING ON SDN ENABLED OAAS TESTBED

The OaaS architecture has been evaluated on the testbed [13]. Four OpenFlow-enabled Flexi-Grid optical nodes are equipped with OTN equipment, each of which comprises flex ROADM and ODU cards. DCs and the other nodes are realized on an array of virtual machines created by VMware software running on IBM X3650 servers. Since each virtual machine has the operation system and its own independent IP address, CPU and memory resource, it can be considered as a real node. The virtual OS technology makes it easy to set up experiment topology based on the backbone of US which comprises 14 nodes and 21 links. For OpenFlow-based SDN control plane, the NC is assigned to support the proposed architecture and deployed in three servers for spectrum control, physical layer parameter adjustment, PCE computation and resource abstraction, while the database server are responsible for maintaining traffic engineering database, management information base, connection status and the configuration of the database and transport resources.

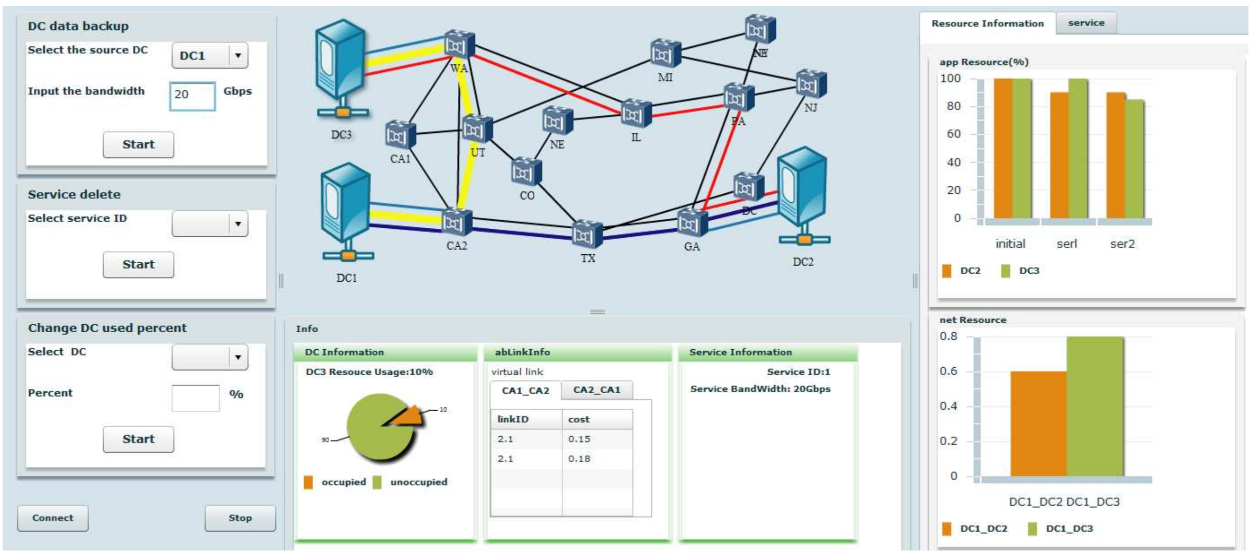

Figure 5: Application graphical user interface (GUI) of testbed.

We have designed and verified experimentally network provisioning in SDN over Flexi-Grid optical networks for Anycast service with backup consideration. The experimental results are shown in Fig. 5. The destination DC is determined by AC with CSO strategy based on various application utilizations among DCs and current network resource. The lightpath for the network provisioning is setup from source to destination node. Additionally, the spectrum bandwidth and corresponding modulation format can be tunable according to different lightpath distances. Fig. 5 verifies the status and destination node choice of data center and various bandwidths of lightpaths in application interface of SDN. The average mean time of network provisioning including three or four paths is about 200 ms, including the time of path computation, resource allocation, and lightpath establishment. The extended flow table modification message for network provisioning setup can be captured with some software tools like Wireshark.

7. CONCLUSIONS

SDN enabled OaaS architecture has been designed as an effective solution for data center networking, which can make full use of network resource and data center resource by considering them together through CSO strategy. Network provisioning is proposed compared with lightpath provisioning. As a new dynamic request form, network provisioning can provide the client with a complete network, which has enough bandwidth resource, required good performance, even enough edge resources. A virtualization engine is designed in this architecture to implement network provisioning with partition manager or aggregation manager. The cross stratum optimization (CSO) strategy is introduced in this architecture to optimize the utilization of network resource and data center resource, which is also implemented in SDN enabled OaaS Testbed as described.

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