Multi-Broker based Software-Defined Optical Networks

(Invited Paper)

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***Abstract*—This paper investigates the multi-broker based network control and management paradigm for realizing scalable and cost-effective service provisioning in multi-domain software-defined optical networks. Experimental results verify the feasibility of the proposal and demonstrate $\sim 7.6\times$ blocking reduction comparing with the conventional single-broker based solution.**

***Index Terms*—Multi-broker, Multi-domain, Software-defined optical networks.**

I. Introduction

The upcoming era of cloud computing and big data is driving the backbone networks to evolve to multi-domain and multi-technology networks that can support dynamic, high-capacity and quality-of-service guaranteed end-to-end services. By incorporating the advantages from software-defined networking, the recently reported concept of multi-domain software-defined optical networking (SD-ON) [1] has become a promising solution for building the next-generation backbone networks. A variety of service provisioning schemes based on flat/hierarchial control plane arrangements have been studied for multi-domain SD-ON [2], [3]. However, these existing works suffer from the drawbacks of either low resource efficiency or poor scalability and survivability.

In this paper, we investigate the multi-broker based network control and management (NC&M) paradigm for multi-domain SD-ONs. We first elaborate on the system architecture and operation principle of our proposal. A multi-domain SD-ON control plane testbed is then implemented and experiments performed on it verify the feasibility of the multi-broker based framework and show remarkable improvement in network throughput can be achieved comparing with the existing solution.

II. Network Architecture

Fig. 1 shows the system architecture of the proposed multi-broker based multi-domain SD-ONs, which adopts a three-layer NC&M hierarchy. Each domain manager (DM) in the domain manager plane owns and operates the data plane equipment (*e.g.*, transponders and switches) in its domain through an SDN controller. DMs perform intra-domain service provisioning privately, whereas for inter-domain services, collaborations among different DMs for cross-domain resource configurations are required. We introduce a broker plane that lies on top of domain manager plane to undertake such coordination tasks.

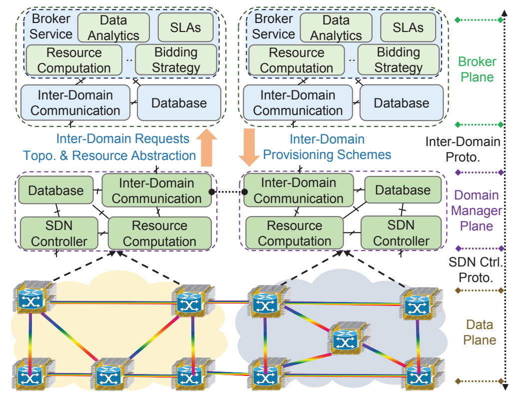

Fig. 1. System block diagram of multi-broker based multi-domain SD-ONs.

Specifically, we enable multiple brokers residing in the broker plane, each of which interacts with DMs using certain inter-domain communication protocol to collect domain topology and resource abstractions and calculate inter-domain service schemes with them. Each DM can subscribe to multiple brokers for inter-domain services and submit different intra-domain information to them based on the signed service level agreements (SLAs). Here, the brokers generally are managed by third-party entities and participate in the multi-domain service provisioning due to market-driven incentives (*e.g.*, reputation, revenue gain *etc*.). Note that, DMs can also bypass brokers to accomplish the inter-domain service provisioning in a peer-to-peer manner [3] for the consideration of enhanced domain autonomy.

III. Operation Principle

We elaborate on the operation principle of the proposed framework performing inter-domain lightpath provisioning. We consider a multi-domain flex-grid optical network denoted as $G = \{G_n(V_n, E_n)\}$ with V_n and E_n representing the node and link sets in domain G_n. Θ_n consists of the brokers that the DM of domain G_n (*i.e.*, DM-n) subscribes to. Upon receiving an inter-domain lightpath request $\mathcal{R}(s, d, B, T)$ from $s \in G_i$ to $d \in G_j, i \neq j$, where B (Gb/s) is the bandwidth requirement and T is the service duration, DM-i broadcasts the request to all the brokers in Θ_i. Then, each broker communicates with related DMs for collecting the information (*i.e.*, spectrum utilization and physical length *etc.*) regarding intra-domain

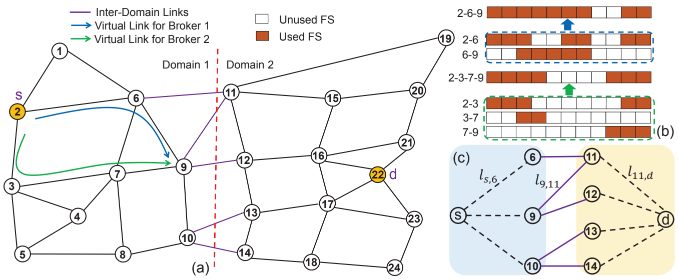

Fig. 2. (a) Two-domain SD-ON topology, (b) spectrum utilizations on different links and paths and (c) virtual topology constructed for $\mathcal{R}\,(s=2, d=22)$.

virtual links (VLs). Here, VLs refer to the path segments from the source node to domain border nodes, from domain border nodes to the destination node and among domain border nodes for source, destination and intermediate domains, respectively. Note that, brokers may receive different VLs depending on the actual SLAs they have with the DMs. For example, DM-1 in Fig. 2(a) calculates the shortest path, *i.e.*, 2−6−9, as VL s−9 for broker-1, while abstracting path 2−3−7−9 with the largest amount of available spectrum (as shown in Fig. 2(b)) for broker-2. With the obtained VLs, each broker can construct a virtual topology as depicted in Fig. 2(c) and calculate a routing, modulation and spectrum assignment solution for the request. Each broker should also analyze the other brokers' behaviors and offer an appealing service price for attracting the DM to use its service scheme. Finally, DM-i selects a broker according to certain rules (*e.g.*, lowest price, best quality-of-service *etc.*) as the winner, which in turn coordinates corresponding DMs to accomplish the end-to-end lightpath configuration. Overall, the aforementioned activities in fact form an incentive-driven market, where brokers compete for multi-domain provisioning tasks, while DMs pursue better services and improved network throughput.

IV. Experimental Results

We build a multi-domain SD-ON control plane testbed based on the two-domain topology in Fig. 2(a) and implement two brokers in the broker plane, each of which receives VLs calculated based on the shortest path or load-balanced routing respectively, provides service schemes with the least resource costs and bids for the service prices using the strategy developed in [4]. The data plane of the SD-ON is assumed to use the flex-grid spectrum allocation scheme, with the capacity of each frequency slot (FS) being 12.5 GHz and each link accommodating 358 FS's. Every domain border node is equipped with 50 optical-electrical-optical converters. The bandwidth demand of each inter-domain lightpath request is randomly selected from $[25, 250]$ Gb/s.

Fig. 3(a) shows the list of control messages captured on DM-1 for provisioning an inter-domain lightpath request from *Node* 2 to 20. We can observe that the system works correctly according to our design and the total control plane latency for setting up the lightpath is 42 msec. We show the details of the *Status_Reply* and *Inter_Domain_Reply* messages used

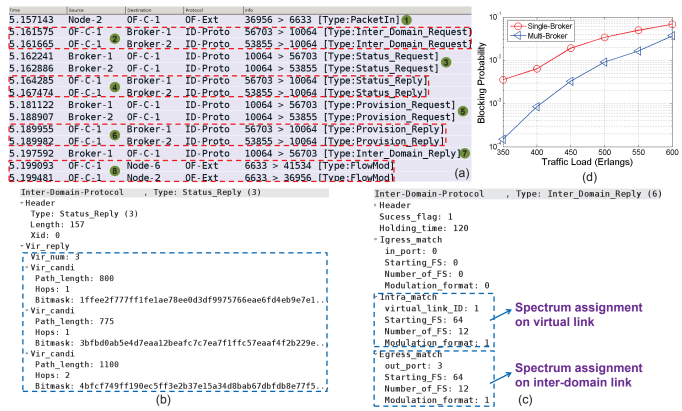

Fig. 3. (a) Capture of the message list for provisioning $\mathcal{R}\,(s=2, d=20)$, (b) *Status_Reply* (from broker-1 to DM-1) and (c) *Inter_Domain_Reply* (from broker-1 to DM-1) messages used in the experiment, (d) results on blocking probability of inter-domain lightpath requests [4].

in the above procedures in Figs. 3(b) and (c) respectively. Specifically, the *Status_Reply* message indicates that DM-1 reports three VLs (*i.e.*, 2−6, 2−6−9 and 2−3−5−8−10) to broker-1, while the service scheme carried by the *Inter_Domain_Reply* message from broker-1 suggests using the first VL and allocating FS-block $[64, 75]$ on both the VL and inter-domain link with BPSK as the modulation format. Results on request blocking probability from the dynamic service provisioning experiments are plotted in Fig. 3(d), which show the remarkable advantage of the proposed multi-broker based scheme comparing with the conventional single-broker based solution, *i.e.*, $\sim 9\times$ blocking reduction is achieved.

V. Conclusion

This paper investigated the multi-broker based NC&M framework for multi-domain SD-ONs. Experimental assessments verified the feasibility of the proposal and demonstrated $\sim 7.6\times$ blocking reduction comparing with the existing single-broker based scheme.

Acknowledgments

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