Multi-Broker based Market-Driven Service Provisioning in Multi-Domain SD-EONs in Noncooperative Game Scenarios

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Abstract *This work studies multi-broker based market-driven service provisioning in SD-EONs. By leveraging non-cooperative sequential gaming, we design an intelligent bidding strategy for the brokers to compete for provisioning tasks. An OpenFlow based multi-domain SD-EON testbed is then used for experimental demonstrations.*

Introduction

Software-defined networking (SDN) facilitates the programmability of networks. A combination of SDN and elastic optical networking (EON), *i.e.*, software-defined EON (SD-EON), can possibly provide the most adaptive and programmable high-capacity networks with effective resource management and extended service reach[1]. Previously, we showed that the hierarchical control plane architecture that uses a broker to manage SDN controllers can achieve cost-effective multi-domain service provisioning[2]. More recently, we proposed to realize multi-domain provisioning with a multi-broker scenario[3], and highlighted the market incentive-driven interactions between the domain managers and brokers. However, the networking economics behind the multi-broker scheme, *i.e.*, the market-driven service provisioning principles, have not yet been studied.

This paper studies how to assist the brokers in a multi-broker based multi-domain SD-EON to realize market-driven service provisioning. We first model the network operation as a noncooperative sequential game and design a bidding strategy for the brokers to compete for provisioning tasks. Then, we experimentally demonstrate the market-driven framework in an OpenFlow (OF) based multi-domain SD-EON testbed. The results show that the brokers can adjust their pricing strategies intelligently during dynamic network operation for maximizing their utilities.

Network Architecture

Fig. 1(a) shows the network architecture of the multi-broker based multi-domain provisioning framework. In the multi-domain SD-EON, each domain has a centralized OF controller (OF-C), which subscribes to one or more brokers for the broker-service that facilitates multi-domain provisioning[2]. The brokers operate at a higher network control and management (NC&M) level than the OF-Cs and can gather intra-domain information from the OF-Cs, while different brokers can achieve multi-domain provisioning with different strategies.

Market-Driven Multi-Broker Service Model

We model the multi-domain SD-EON as $G = \{G_i(V_i, E_i, BR_i), 1 \leq i \leq N\}$, where N is the number of domains, V_i and E_i are the node and link sets in *Domain* i, respectively, and BR_i is the set of brokers that *Domain* i subscribes to. A multi-domain lightpath request is denoted as $LR(s,d,B,T)$, where s and d ($s \in V_i, d \in V_j, i \neq j$) are the source and destination nodes, B is the bandwidth requirement and T is the service life-time. Upon receiving LR, the OF agent (OF-AG) on s forwards the request information to the OF-C in the source domain (*i.e.*, OF-C-i in *Domain* i), which in turn broadcasts the information to the brokers that it subscribes to. Then, for the market-driven operation, each broker in BR_i calculates a provisioning scheme based on its knowledge on network status, prices the commission that it will charge for the broker-service, and bids for setting up LR for OF-C-i. Finally, OF-C-i decides which broker to use based on their offered commissions.

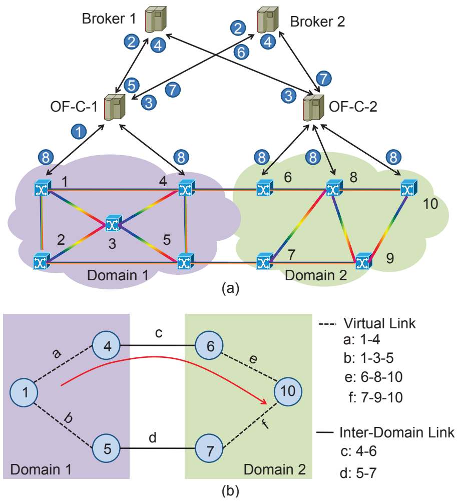

Fig. 1: Multi-broker based market-driven multi-domain provisioning, (a) operation principle and (b) topology virtualization.

The market-driven multi-broker service can be modeled as a noncooperative sequential game[4]. Here, the players are the brokers and their targets are to maximize their utilities during the dynamic network operation. We assume that each broker prices its commission for provisioning $LR(s,d,B,T)$ as

$$C = T \cdot (S_u \cdot c_S + R_u \cdot c_R) \cdot (1+\delta) = \mathscr{C} \cdot (1+\delta), \quad (1)$$

where S_u is the total spectrum utilization in terms of the number of assigned frequency slots (FS'), R_u is the number of optical-to-electrical-to-optical (O/E/O) regenerators that need to be allocated, c_S and c_R are the unit prices for FS and regenerator utilization, respectively, and variable δ ($\delta_{\min} \leq \delta \leq \delta_{\max}$) is the pricing ratio with which the broker prices its commission based on the base commission $\mathscr{C}$.

In each game, a broker first analyzes all its competitors' behaviors based on the results of historical games. We denote the probability that *Broker* k will price its commission higher than C^* as $p_k(C^*)$. Then, a *Broker* k_0 needs to predict $p_k(C^*)$ for all the other possible brokers, *i.e.*, $k \in BR_i$, $k \neq k_0$ (assuming *Domain* i is the source domain). Let $C_{k,m}$ be the commission from *Broker* k in the m-th game and $\mathscr{C}_{k_0,m}$ be the base commission of *Broker* k_0 in the m-th game, we define $\hat{C}_{k,M}(m,k_0)$ as the predicted commission from *Broker* k for the current game, which is predicted by *Broker* k_0 based on the m-th game.

$$\hat{C}_{k,M}(m,k_0) = \left(C_{k,M-1} \cdot \frac{\mathscr{C}_{k_0,M}}{\mathscr{C}_{k_0,M-1}}\right) \cdot \left(\frac{C_{k,m}}{C_{k,m-1}} \cdot \frac{\mathscr{C}_{k_0,m-1}}{\mathscr{C}_{k_0,m}}\right), \tag{2}$$

where $1 < m < M$, and we assume that there have been $M-1$ games since the system starts. Then, we define $\Phi_{k,m}$ as the gaming result of *Broker* k in the m-th game, where $\Phi_{k,m} = 1$ if *Broker* k wins the game (*i.e.*, successful bidding), otherwise $\Phi_{k,m} = 0$. Hence, *Broker* k_0 can obtain $p_k(C^*)$ as

$$p_k(C^*) = \frac{\sum\limits_{\{m:\ \Phi_{k,m}=\Phi_{k,M-1}\}} \omega_m \cdot \frac{(\hat{C}_{k,M}(m,k_0)-C^*)+|\hat{C}_{k,M}(m,k_0)-C^*|}{2(\hat{C}_{k,M}(m,k_0)-C^*)}}{\sum\limits_{\{m:\ \Phi_{k,m}=\Phi_{k,M-1}\}} \omega_m}, \tag{3}$$

where ω_m is the weight of the m-th game. Then, for the M-th game, *Broker* k_0 can determine its commission C^* by solving the following optimization

$$Maximize \quad C^* \cdot \prod_{\{k \in BR_i:\ k \neq k_0\}} p_k(C^*). \tag{4}$$

Here, the second term is the probability that *Broker* k_0 will win the M-th game, *i.e.*, all the other possible brokers charge higher commissions than its commission C^*. In all, the optimization in Eq. (4) maximizes the expected utility of *Broker* k_0.

System Implementation

We implement the multi-broker based market-driven multi-domain service provisioning framework in an OF-based multi-domain SD-EON control plane testbed. The OF-Cs are programmed based on the POX platform, while each optical network element is software-emulated, *i.e.*, running Open-vSwitch on high-performance Linux servers[1]. Fig. 1 shows the detailed procedure of the market-driven service provisioning.

- **Step 1:** A multi-domain lightpath request $LR(s,d,B,T)$ arrives and the OF-AG on $s \in V_i$ uses a *PacketIn* message to report it to OF-C-i.
- **Step 2:** OF-C-i broadcasts the information of LR to all the brokers in BR_i using *Inter_Domain_Request* messages, which are designed in this work.
- **Steps 3-4:** Each broker negotiates with the related OF-Cs with *Status_Request* and *Status_Reply* messages, which are also designed in this work, to obtain intra-domain status. Then, each broker has a global view of the network, including the information of inter-domain links and virtualized network status of each domain provided by the OF-Cs. Specifically, the OF-Cs abstract the related intra-domain path segments, *i.e.*, s to egress nodes, ingress nodes to egress nodes, and ingress nodes to d for the source, intermediate and destination domains, respectively, as virtual links. The virtual links represent the segments' information, including the spectrum utilizations and transmission distances. Fig. 1(b) shows the topology virtualization for the multi-domain lightpath request that is from *Node* 1 to *Node* 10 in Fig. 1(a), *e.g.*, OF-C-1 and OF-C-2 abstract path segments 1-3-5 and 6-8-10 as virtual links b and e in Fig. 1(b), respectively.
- **Step 5:** Each broker calculates the provisioning scheme (*i.e.*, the routing and spectrum assignment (RSA) and regenerator allocation) for LR based on the virtual topology that it obtains. Note that in our market-driven service model, an OF-C can provide different intra-domain virtualizations to different brokers based on their service-level agreements (SLAs). Then, the broker prices its commission with Eqs. (1)-(4) and sends the result to OF-C-i using a *Provision_Request* message.
- **Step 6:** OF-C-i compares the commissions from the brokers, selects the broker that offered the lowest commission, and relies on it to provision LR. Then, OF-C-i informs the brokers about its decision with *Provision_Reply* messages.
- **Step 7:** The winner broker sets up the multi-domain lightpath for LR by distributing its provisioning scheme to the related OF-Cs with *Inter_Domain_Reply* messages.
- **Step 8:** Each OF-C that receives the *Inter_Domain_Reply* message sets up the path segment in its own domain by sending *Flow_Mod* messages to the related OF-AGs. Finally, LR is provisioned according to the winner broker's scheme.

Experimental Demonstration

We conduct market-driven service provisioning experiments with our multi-domain SD-EON control plane testbed. Fig. 2 shows the topology of the multi-domain SD-EON that consists of two domains. We implement two brokers in the testbed, and make them use different service provisioning strategies. Specifically, *Broker* 1 uses the fragmentation-aware RSA scheme (FA)[5], while *Broker* 2 incorporates a simple K-shortest-path RSA scheme (KSP). Note that similar to our previous work[1], we make both FA and KSP consider the quality-of-transmission (QoT) and incorporate adaptive modulation-format selection and regenerator allocation accordingly. For KSP, the broker calculates K shortest paths in the virtual topology and selects the one whose base commission (*i.e.*, $\mathscr{C}$ in Eq. (1)) is the lowest.

Fig. 3 shows the message list captured in OF-C-

1 for provisioning a multi-domain lightpath from *Node* 7 to *Node* 21. It can be seen that the system operates exactly as our design. The detailed structures of *Status_Reply* and *Inter_Domain_Reply* messages are depicted in Figs. 4(a) and 4(b), respectively. We observe that OF-C-1 reports the path distances, numbers of hops and spectrum utilizations on three virtual links (*i.e.*, path segments 7-6, 7-9 and 7-8-10) to the broker, while the broker selects the second virtual link. Also, the broker obtains the spectrum assignment as FS-block [125, 132] and the modulation-format as BPSK for both the virtual and inter-domain links.

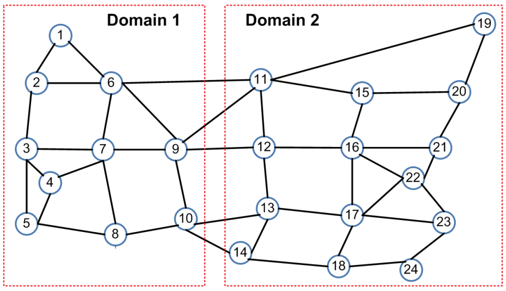

Fig. 2: Topology of the multi-domain SD-EON testbed.

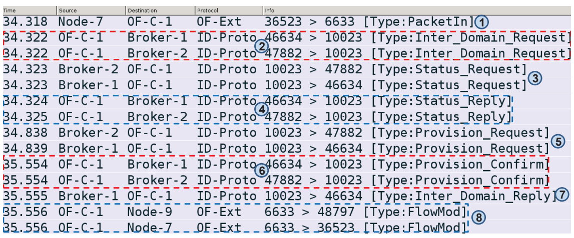

Fig. 3: Messages for provisioning a multi-domain lightpath.

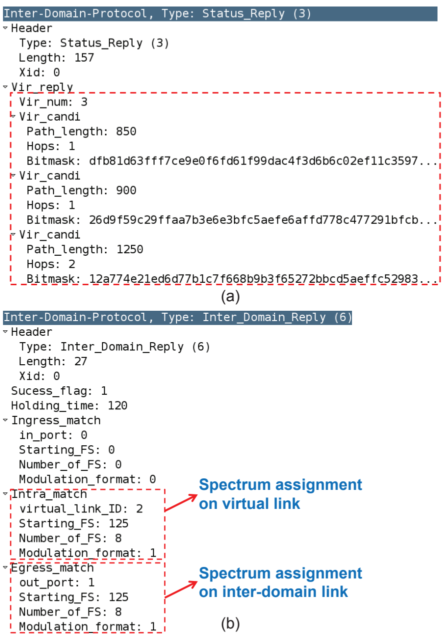

Fig. 4: Wireshark captures for (a) *Status_Reply* and (b) *Inter_Domain_Reply* messages.

We then perform experiments on dynamic network operation to show the effectiveness of the proposed framework. The multi-domain lightpath requests are generated dynamically by each OF-AG according to the Poisson traffic model. The destination nodes are randomly chosen and the bandwidth requirements are uniformly distributed within [25, 250] Gb/s. c_S and c_R are set as 1 and 5 cost units, respectively, and δ ranges within [0.1, 0.5]. Fig. 5 shows the evolutions of the commissions from the brokers when the traffic load is 450 Erlangs, and we can see that the brokers adjust their pricing strategies adaptively. For instance, the broker using KSP decreases its pricing ratio δ from 0.3 to 0.2 after having lost the sixth game, and then wins the seventh game. Fig. 6 shows the results on brokers' total utilities, which indicate that the broker using KSP always acquires a higher utility. This is because it tries to minimize the cost of provisioning schemes and hence becomes advantageous in the market-drive games.

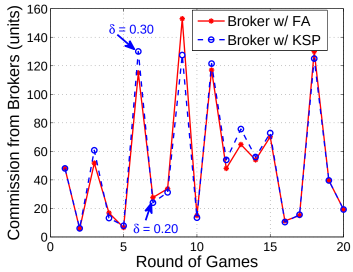

Fig. 5: Evolutions of the brokers' commissions (450 Erlangs).

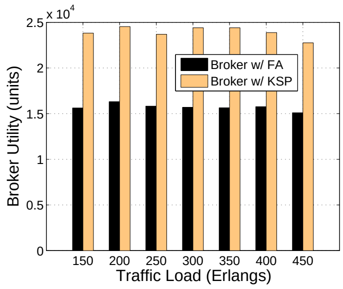

Fig. 6: Results on brokers' utilities.

Conclusions

We modeled the multi-broker based market-driven service provisioning in multi-domain SD-EONs as a non-cooperative sequential game and designed bidding strategy for the brokers to compete for provisioning tasks. We implemented the design and demonstrated it experimentally in a multi-domain SD-EON testbed.

References

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