Broker-based Multi-Task Gaming to Facilitate Profit-Driven Network Orchestration in Multi-Domain SD-EONs

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Abstract: We propose a novel network framework to facilitate multi-broker based network orchestration in multi-domain SD-EONs. With the framework, the brokers can compete for a bundle of request-provisioning tasks with an effective bidding strategy to maximize their profits.

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1. Introduction

Software-defined elastic optical networks (SD-EONs) expect to achieve adaptive, programmable, and application-aware high-capacity networking with extended service reach [1]. Meanwhile, considering the geographical span of backbone networks and the heterogeneous technologies of multi-vendor network elements, we must address multi-domain heterogeneous networking scenarios [1]. Recently, market-driven multi-broker management plane has been proposed [2] as a realistic solution to facilitate cross-domain network orchestration while assuring autonomy of each domain and supporting agile service provisioning across multiple domains. In the market place of the Internet, multiple brokers are likely to offer services to SD-EON domains due to market incentives [2]. The brokers may cooperate or compete with each other in the market [2]. In [3], the authors modeled the network operation in a multi-broker based multi-domain SD-EON as a non-cooperative game, and designed a simple bidding strategy for the brokers to compete for provisioning tasks. The drawbacks of their model were two-fold. Firstly, the model asks the brokers to bid for each individual task, which would increase the communication overhead and operational cost significantly. Secondly, it had each broker to use one service provisioning strategy (*i.e.*, the routing and spectrum assignment (RSA) algorithm).

In this work, we propose a new, efficient, and practical network framework for multi-broker based profit-driven network orchestration in multi-domain SD-EONs. We design a gaming scenario to allow the brokers to bid for a bundle of provisioning tasks. Meanwhile, each broker is provided a pool of service provisioning strategies, from which it can choose the most cost-effective one based on the network status. We also design the work-flows for both the brokers and SDN controllers in this framework, and conduct theoretical analysis to obtain an effective bidding strategy for the brokers to compete for provisioning tasks. Simulations results show that with the proposed scheme, the brokers can adapt their service strategies intelligently to maximize the profits.

2. Network Architecture and Operation Principle

Fig. 1(a) shows the proposed network architecture for profit-driven network orchestration in multi-domain SD-EON. In each domain, there is an OpenFlow controller (OF-C) to manage the optical switches for intra-domain service provisioning. Meanwhile, it also subscribes to the brokers on the auction table for multi-domain provisioning. The brokers operate at a higher network control and management (NC&M) level than the OF-Cs [2]. Basically, they can get intra-domain information from the OF-Cs and instruct the OF-Cs to set up multi-domain lightpaths. To provision a multi-domain lightpath, each broker should have a global view of the network, which includes the status of inter-domain links and intra-domain virtual topologies (ID-VTs) from the domain OF-Cs. Each ID-VT consists of some virtual links (VLs), which are abstracted from the related intra-domain path segments. Note that, depending on the service-level agreements among them, the domain OF-Cs can submit different ID-VTs to the broker. For example, in Figs. 2(a) and 2(b), OF-C-1 abstracts the path segment from 2 to 7 in different manners for Broker-1 and Broker-2. Basically, it submits the shortest path segment (2-3-7) to Broker-1, while Broker-2 is provided with the one that has the most available frequency slots (FS') (2-4-5-7). Hence, although the brokers obtain similar ID-VTs to provision the multi-domain request from 2 to 9, the same VL on their ID-VTs can have different properties.

The auction table operates as a discrete-time system, which means that when each provisioning period begins, the brokers bid for provisioning tasks and the domain OF-Cs choose the most cost-effective broker to seal the deals. Then, the winning broker instructs the OF-Cs to provision the multi-domain requests accordingly. To improve the operation efficiency of the system, each broker assigns a queue to store the pending multi-domain requests from each domain (as shown in Fig. 1(a)). Then, in each game, all the brokers bid for the pending requests from one domain, and to maximize its profit, each broker has to choose the most cost-effective service strategy based on its knowledge on the network, *i.e.*, selecting the best RSA scheme from its service strategy pool in Fig. 1(a). Note that, as different brokers

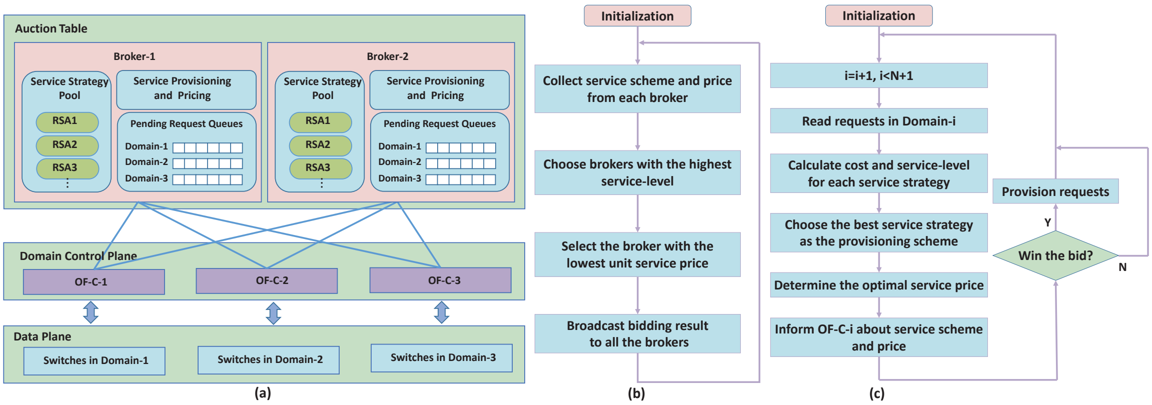

Fig. 1. (a) Network architecture, (b) Work-flow of OF-Cs, (c) Work-flow of brokers.

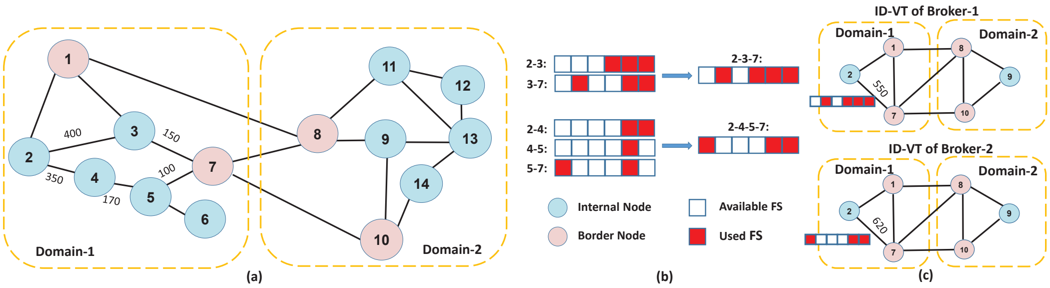

Fig. 2. (a) Network topology, (b) FS usages on intra-domain links, (c) ID-VTs for brokers to serve a multi-domain request.

may have different ID-VTs from the domain OF-Cs, the provisioning results from them can be different even with the same RSA scheme. The details on how to choose the right service strategy will be discussed in the next section.

3. Broker-based Multi-Task Gaming

We assume that the multi-domain SD-EON includes N domains and the OF-C of Domain-n is denoted as OF-C-n. A pending multi-domain request is $r_i(s_i, d_i, B_i, T_i)$, where i is its unique index, s_i and d_i are the source and destination nodes, B_i is the bandwidth requirement, and T_i is the holding time. Since each game is for the pending requests from the same domain, the games for the requests from different domains form independent game sequences. Hence, without loss of generality, we will just consider the game sequence for the requests from one domain in the following theoretical analysis. We use $R_m = \{r_1, r_2, r_3, \cdots\}$ to represent the pending request set for the m-th game.

Considering the fact that certain requests might not be provisioned due to insufficient network resources, we design an evaluation method to help the OF-Cs to select the winning broker quickly. A ranking system is first introduced:

$$l_m^k = \left\lfloor L \cdot \frac{\sum\limits_{r_i \in R_m^k} B_i \cdot T_i}{\sum\limits_{r_i \in R_m} B_i \cdot T_i} \right\rfloor = \left\lfloor L \cdot \frac{Q_m^k}{Q_m} \right\rfloor, \tag{1}$$

where l_m^k is an integer to represent the service-level provided by Broker-k in the m-th game, L is the highest/best service-level, and R_m^k is the set of requests that can be provisioned by Broker-k in the m-th game. Here, we use the product of the required bandwidth and holding time of a request to represent the network resources that it consumes. Hence, Q_m^k is the total provisioned resources by Broker-k in the m-th game, while Q_m is the total required resources in the m-th game. Apparently, if an OF-C tries to get as many pending requests served as possible, it should choose the broker whose service-level is the highest. However, there could be a tie among the brokers in terms of the service-level. In such a case, the OF-C tries to minimize the unit service price, which is $g_m^k = \frac{P_m^k}{Q_m^k}$, where P_m^k is the service price of Broker-k in the m-th game. Fig. 1(b) shows the work-flow for an OF-C to determine the winning broker.

We model the bidding among the brokers as a noncooperative pricing game [3], which means that each broker does not know others' service strategies and prices. Broker-k prices its service as follows in the m-th game:

$$P_m^k = (1+\eta_m^k) \cdot \sum_{r_i \in R_m^k} T_i \cdot (F_i \cdot c_s + E_i \cdot c_r) = (1+\eta_m^k) \cdot c_m^k, \tag{2}$$

where η_m^k is the profit ratio, F_i is the total spectra allocated for r_i, E_i is the number of required optical-to-electrical-to-optical (O/E/O) converters, c_s and c_r are the unit prices of optical spectrum and O/E/O converter, respectively, and

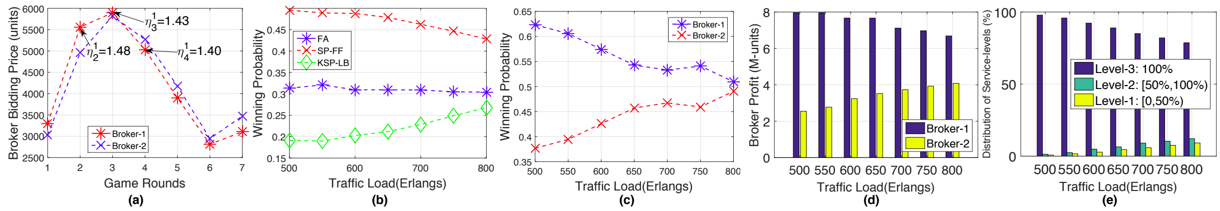

Fig. 3. Results on (a) evolution of each broker's bidding price, (b) winning probability of each service strategy, (c) winning probability of each broker, (d) profit of each broker, (e) distribution of service-levels to requests.

c_m^k is the base service price of Broker-k in the m-th game. Apparently, c_m^k is known when R_m^k is determined. Then, in its practice for the game, Broker-k first tries to use different RSA schemes to serve the requests in R_m, and obtains R_m^k and c_m^k for each RSA scheme. As it knows the evaluation method of the OF-Cs, it will choose the RSA scheme that provides the highest service-level with R_m^k and charges the least unit base service price $q_m^k = \frac{c_m^k}{Q_m^k}$. At this moment, Broker-k determines the RSA scheme to use, and it only needs to figure out η_m^k to maximize its profit. Basically, Broker-k can calculate η_m^k by solving the following optimization problem:

$$\textit{Maximize} \quad \eta_m^k \cdot c_m^k \cdot \prod_{i \neq k} \left[\sum_{l=0}^{l_m^k - 1} \hat{p}_m^i(l) + h \cdot \hat{p}_m^i(l_m^k) \cdot \sum_{l=0}^{\frac{\bar{g_m} - g_m^k}{h} - 1} \hat{f}_m^i\left(g_m^k + \frac{2l+1}{2} \cdot h\right) \right], \tag{3}$$

where h is the Parzen window width, c_m^k, l_m^k, and g_m^k are known, $\hat{p}_m^i(l)$ is the estimated probability that Broker-i achieves service-level l in the m-th game, $\hat{f}_m^i(x)$ is the estimated probability density of the unit service price from Broker-i (*i.e.*, g_m^i), and $\bar{g_m}$ is the upper-bound of a broker's unit service price. We estimate $\hat{p}_m^i(l)$ based on the bidding history and leverage the Parzen window estimation method [4] to obtain $\hat{f}_m^i(x)$. The detailed derivations are omitted here due to the page limit. Fig. 1(c) shows the work-flow for a broker to select the RSA scheme and determine its service price.

4. Simulation Results

We design simulations to evaluate the performance of the proposed scheme. The topology of the multi-domain SD-EON is as that in Fig. 2(a), where there are two domain OF-Cs and two brokers. For the ID-VT abstraction, OF-Cs submit the shortest path segments to Broker-1, while Broker-2 is provided with the one that has the most available FS', as explained in Figs. 2(b) and 2(c). We assume that each broker is equipped with three well-known RSA schemes in its service strategy pool, *i.e.*, the fragmentation-aware (FA), shortest-path and first-fit (SP-FF), and K-shortest-path and load-balancing (KSP-LB) schemes [1]. The dynamic multi-domain requests are generated with the Poisson traffic model. Fig. 3(a) shows the evolution of the bidding prices from the brokers, and we can see that each broker adjusts its service price intelligently according to the bidding history. For instance, after losing for three rounds, Broker-1 decreases its profit ratio to win the 4-th game. Fig. 3(b) plots the winning probability of each RSA scheme at different traffic loads. When the traffic load is low, SP-FF achieves the lowest resource consumption and hence it provides the highest winning probability, but as the traffic load increases, this advantage decreases significantly. KSP-BL can use the resources more rationally and thus its winning probability increases with the traffic load. Meanwhile, compared with those of SP-FF and KSP-BL, the winning probability of FA is the stablest one. Fig. 3(c) shows the winning probability of each broker, which indicates that the bidding performance of Broker-1 decreases with the traffic load while that of Broker-2 has the opposite trend. This is due to the ID-VT abstraction schemes that they are provided with. Fig. 3(d) plots the profit of each broker, which exhibits a similar trend. Fig. 3(e) shows the distribution of the service-levels from the winning service schemes, which indicates that most of the multi-domain requests have been served successfully. Hence, the interests of the OF-Cs have also been taken care of in our proposed framework.

5. Conclusion

We investigated market-driven multi-broker based network orchestration in multi-domain SD-EONs, proposed a new network framework, and demonstrated an effective bidding strategy for the brokers to maximize their profits.

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