Broker-based Cooperative Game in Multi-Domain SD-EONs: Nash Bargaining for Agreement on Market-Share Partition

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Abstract *We model the cross-domain lightpath provisioning in multi-broker based multi-domain SD-EONs as a cooperative game, propose to obtain Pareto-efficient market-share partition for the brokers with Nash bargaining, and design the system framework to realize the proposal.*

Introduction

Multi-domain software-defined elastic optical networks (SD-EONs) facilitate programmable and application-aware high-capacity optical networking with extended service reach[1]. It is known that with the hierarchical network control and management (NC&M) architecture that places incentive-driven brokers over the domain managers (DMs), we can realize a practical mechanism to operate the multi-domain SD-EONs[2]. Here, the brokers offer cross-domain lightpath provisioning services to the DMs due to profits and they may compete or cooperate with each other in the management plane while DMs select suitable services from these alternative schemes. This forms incentive-driven rational games among the brokers, and in our previous work[3,4], we have considered the non-cooperative game model and designed several bidding strategies for the brokers to maximize their profits. However, the non-cooperative game model might not fully secure the brokers' interests as they reduce their service prices consistently for winning cross-domain provisioning tasks.

A cooperative game model would describe the brokers' behaviors more comprehensively. This means that to maximize their profits, the brokers choose to cooperate based on certain agreement and would only compete when their interests cannot be guaranteed. Hence, this work considers the situation where the brokers are willing to cooperate and can reach an agreement on how to divide the market (*i.e.*, all the pending inter-domain tasks) among them. We use Nash bargaining to obtain Pareto-efficient market-share partition, which means there exists no other solution that brings higher utility to a broker without reducing those of other brokers, and propose a service provisioning framework to facilitate the cooperative game. Simulation results verify the effectiveness of our proposal.

Network Architecture

Fig. 1 shows the proposed system configuration for enabling broker-based Nash bargaining in a multi-domain SD-EON. The optical switches in each domain are controlled by its DM. As a higher-level orchestrator in the management plane, each broker can coordinate the DMs for cross-domain lightpath provisioning based on a global network topology, which is obtained by connecting the intra-domain virtual topologies (ID-VTs) from the DMs. A DM abstracts the virtual links (VLs) in its ID-VT from the related intra-domain path segments, with the scheme defined in its service-level agreements (SLA) with the broker[3]. With the physical topology in Fig. 2(a), if the DM in Domain 1 obtains VLs with the shortest-path routing and balanced-load routing for Broker-1 and Broker-2, respectively, path segments 3-7-9 and 3-7-6-9 will be used to generate VL 3-9 for the two brokers, as shown in Figs. 2(b) and 2(c).

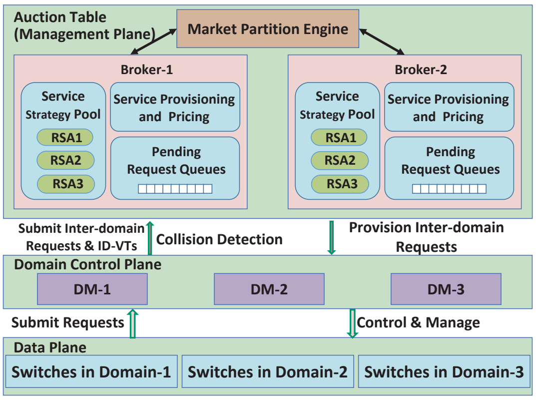


Fig. 1: System configuration for facilitating market-share partition with Nash bargaining in a multi-domain SD-EON.

The brokers store the inter-domain lightpath requests in the pending request queues, and process them in batches synchronously. Each broker gets the provisioning schemes as well as the service costs for the requests with the routing and spectrum assignment (RSA) algorithms in its service strategy pool, and then submits the most cost-efficient scheme to the market partition engine (MPE). MPE calculates the Nash bargaining result based on the brokers' offers to determine their market-shares, and then instructs each broker to handle the requests that it should be responsible for.

Cooperative Game Based on Nash Bargaining

We model an N-domain SD-EON as $G = \{G_n(V_n, E_n)\}$, where V_n and E_n are the node and link sets in *Domain* $n \in [1, N]$. The management plane contains K brokers. A lightpath request is denoted as $r_i(s_i, d_i, B_i, T_i)$, where s_i and d_i are the source and destination nodes, B_i is the bandwidth requirement, and T_i is the holding time. If we assume that the brokers process a batch of M pending requests each time, we have $R = \{r_i, i \in [1, M]\}$ as the set of requests in each Nash bargaining.

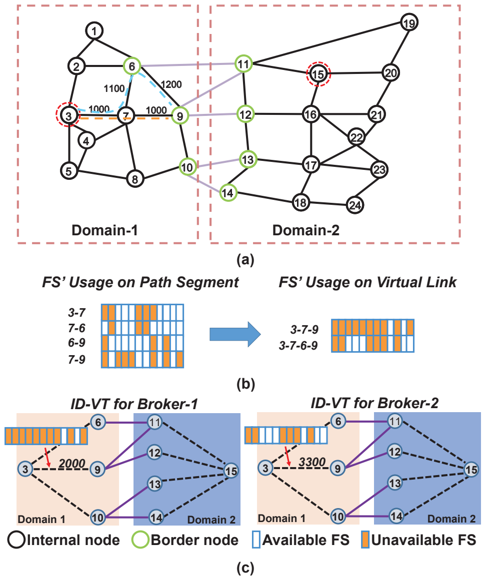


Fig. 2: (a) Network topology, (b) FS utilization on path segments, (c) ID-VTs for brokers.

Similar to our previous work[3,4], we still assume that Broker-k ($k \in [1, K]$) prices its service for request r_i as

$$P_i^k = T_i \cdot (SU_i^k \cdot c_S + RE_i^k \cdot c_R) \cdot (1+\delta_i^k) = C_i^k \cdot (1+\delta_i^k), \quad (1)$$

where SU_i^k and RE_i^k are the spectra in frequency slots (FS') and the number of O/E/O converters allocated to request r_i, respectively, c_S and c_R denote the unit prices of FS and O/E/O converter usages, respectively, δ_i^k is the profit ratio, and C_i^k is the base cost of provisioning r_i. The base cost C_i^k is known after the broker performing RSA for the request, but it needs to determine the profit ratio before submitting its offer to MPE. The optimal profit ratio can be calculated by solving the following optimization.

$$Maximize \quad C_i^k \cdot \delta_i^k \cdot f_{sr}(g_i^k) = C_i^k \cdot \delta_i^k \cdot f_{sr}(\frac{(1+\delta_i^k) \cdot C_i^k}{B_i \cdot T_i}), \quad (2)$$

where $f_{sr}(\cdot)$ is the satisfaction ratio function for the DMs. Basically, the satisfaction ratio is introduced because we want to avoid the case that the brokers become greedy and form a coalition to raise their prices unrestrictedly. More specifically, $f_{sr}(g_i^k)$ returns the probability that the DMs would accept the service offers from a broker, when they find that the expected unit service price is g_i^k. Apparently, $f_{sr}(g_i^k)$ should be a decreasing function and output 0 when g_i^k is abnormally large. Broker-k tries to provision the request with all the RSA algorithms in its service strategy pool, solves the optimization in Eq. (2) each time, and selects the provisioning scheme that brings the maximum profit to submit to MPE. After obtaining the service offers from all the brokers for all the M pending requests, MPE determines the Nash bargaining result by solving[5]

$$\begin{aligned} &\max_{\{R_1, R_2, \ldots, R_K\}} \prod_{k=1}^{K} (S_k - D_k), \\ &s.t. \bigcup_{k=1}^{K} R_k = R \quad \text{and} \quad R_{k_1} \bigcap R_{k_2} = \emptyset, \ \{k_1, k_2 : k_1 \neq k_2\}, \end{aligned} \quad (3)$$

where S_k and D_k denote the profits that Broker-k can obtain in the Nash bargaining and a non-cooperative game, respectively, and R_k is the set of requests that are allocated to Broker-k. Hence, S_k can be got as

$$S_k = \sum_{\{i:\ r_i \in R_k\}} C_i^k \cdot \delta_i^k \cdot f_{sr}(g_i^k), \quad (4)$$

while D_k can be calculated as

$$D_k = \sum_{\{i:\ C_i^k = min\{C_i^1, \ldots, C_i^K\}\}} C_i^k \cdot \delta_{min} \cdot f_{sr}(g_i^k)), \quad (5)$$

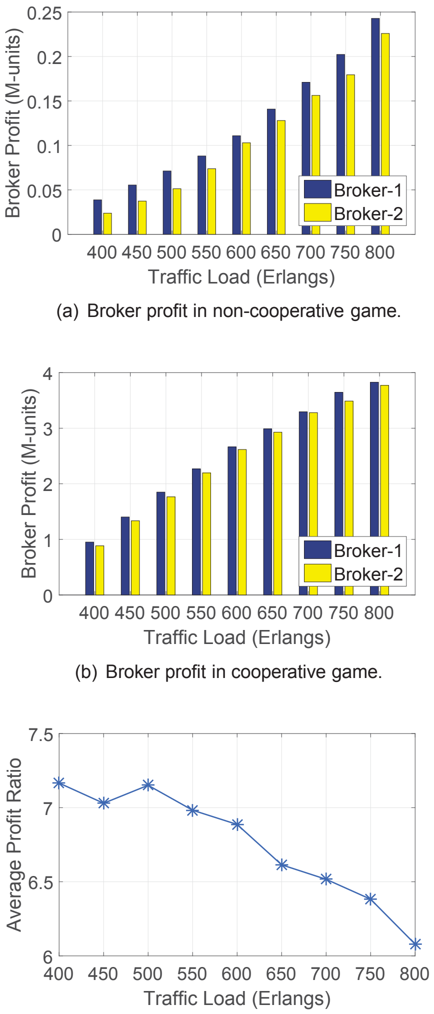
where $\{i:\ C_i^k = min\{C_i^1, \ldots, C_i^K\}\}$ means that in the non-cooperative game, Broker-k only wins a provisioning task when it offers the lowest price among all the brokers, and δ_{min} is the lower-bound of the profit ratio. The reason why we use δ_{min} here is that in the non-cooperative game, each broker has to offer the lowest-possible service price to maximize its probability of winning a bid and thus δ_{min} can be a good approximation of the actual profit ratio. Note that, Eqs. (3)-(5) reveal two basic facts about Nash bargaining: 1) the final market-share of a broker would decrease with its profit, which is because other brokers will only agree on a bargaining outcome when the broker is willing to trade its market-share for profit, and 2) each broker would only join the Nash bargaining when its profit would be higher than that it could get in the non-cooperative game.

Considering that for each request, the base costs from the brokers are comparable, we can solve the Nash bargaining approximately by making $(S_k - D_k)$ equal for all the brokers. Hence, we propose *Algorithm* 1 for MPE to allocate requests to the brokers.

Algorithm 1 Request Allocation for Approximating Nash Bargaining Result

```
for each request r_i do
    if r_i can only be provisioned by Broker-k then
        insert r_i into R_k;
    end if
end for
while there are still unallocated request(s) do
    k* = argmin_{k∈[1,K]} (S_k − D_k);
    find r_i to bring the maximum profit to Broker-k*;
    insert r_i into R_{k*};
end while
```

After receiving the bargaining result from MPE, each broker sends the service price of each request that it is responsible for to the concerning DM. Once the DM accepts the offer, the broker can instruct the related DMs to set up the inter-domain lightpath. Note that, since the brokers calculate the provisioning schemes independently based on the network without any of the requests, there may be resource collisions during the actual process of request provisioning. Hence, we introduce a round-robin scheme to handle resource collisions. We consider an example with 2 brokers. After Broker-1 provisioning all the requests in its market-share, Broker-2 needs to detect the resource collisions with the help of DMs and re-calculate provisioning



(a) Broker profit in non-cooperative game.

(b) Broker profit in cooperative game.

(c) Average profit ratio in Nash bargaining.

Fig. 3: Simulation results on broker profit and profit ratio.

schemes for the collision requests based on updated ID-VTs. Then, in the next provision period, Broker-2 provisions the requests in its market-share first.

Simulation Demonstration

We perform simulations for two brokers with the 2-domain topology in Fig. 2(a) to evaluate the proposed system framework. The simulation parameters are the same as those in our previous work[4], and we use the non-cooperative game scenario in it as the benchmark. The DMs provide Broker-1 and Broker-2 with the ID-VTs that are calculated using the shortest-path routing and balanced-load routing, respectively. Each broker is equipped with three well-known RSA algorithms in its service strategy pool, *i.e.*, the fragmentation-aware (FA), shortest-path and first-fit (SP-FF) and load-balancing (KSP-LB) schemes. 10 inter-domain requests are processed in each provision period.

Figs. 3(a) and 3(b) plot the average profit of brokers in the non-cooperative and cooperative games, respectively. The results show two promising effects of the proposed Nash bargaining scheme. Firstly, both brokers become significantly more profitable in the cooperative game, *i.e.*, their profits are 15$\sim$20 times higher than those in the non-cooperative game. Secondly, the profits are distributed more evenly between the two brokers with Nash bargaining. Specifically, the ratio between the profits obtained by Broker-1 and Broker-2 is within $[1.0749, 1.6284]$ in the non-cooperative game, while the ratio becomes within $[1.0047, 1.0759]$ in the cooperative game. The brokers not only become more profitable but also have the profits distributed in a fairer way through Nash bargaining. Hence, our proposed system framework provides sufficient incentive to motivate the brokers to work cooperatively.

Fig. 3(c) shows that the average profit ratio in Nash bargaining decreases with the traffic load. This is because the base cost (*i.e.*, C_i^k in Eq. (2)) increases when the traffic load increases, and thus the brokers would decrease their profit ratios to maintain satisfaction ratios of DMs. Thus, the system framework enables the brokers to adjust their service prices intelligently while the DMs' interests are also protected well. Tab. 1 summarizes the average winning rate of each RSA scheme in the brokers' service strategy pools, which indicates that the winning rate of SP-FF is the highest. This is because SP-FF performs the best on finding low-cost provisioning schemes. Finally, we compare the request blocking probability in non-cooperative and cooperative games with Tab. 2, which suggests that the blocking probability in cooperative game is much lower than that in non-cooperative game because network resources are conserved when the DMs refuse the provisioning services with unreasonable prices.

RSA Schemes	SP-FF	FA	KSP-LB
Average Winning Rate	0.53	0.27	0.20

Tab. 1: Winning rate of RSA Schemes.

Traffic Load (Erlangs)	450	500	550	600
Non-cooperative	0	0.0001	0.0004	0.0011
Nash Bargaining	0	0	0	0.0002
Traffic Load (Erlangs)	650	700	750	800
Non-cooperative	0.0028	0.0047	0.0079	0.0133
Nash Bargaining	0.0005	0.0008	0.0010	0.0018

Tab. 2: Request blocking probability in non-cooperative and cooperative games.

Conclusions

We proposed to realize cross-domain lightpath provisioning in multi-broker based multi-domain SD-EONs with Nash bargaining based cooperative games, and designed the system framework to realize the proposal.

References

[1] Z. Zhu et al., "Demonstration of Cooperative Resource Allocation in an OpenFlow-Controlled Multidomain and Multinational SD-EON Testbed," J. Lightwave Technol., Vol. **33**, no. 8, p. 1508 (2015).
[2] S. J. B. Yoo, "Multi-domain Cognitive Optical Software Defined Networks with Market-Driven Brokers," Proc. ECOC'14, We.2.6.3, Cannes (2014).
[3] X. Chen et al., "Multi-Broker based Market-Driven Service Provisioning in Multi-Domain SD-EONs in Noncooperative Game Scenarios," Proc. ECOC'15, We.3.5.6, Valencia (2015).
[4] L. Sun et al., "Broker-based Multi-Task Gaming to Facilitate Profit-Driven Network Orchestration in Multi-Domain SD-EONs," Proc. OFC'16, Th3K.1, Anaheim (2016).
[5] Z. Han et al., "Game Theory in Wireless and Communication Networks," Cambridge University Press, 2012.