Service Function-Oriented Topology Aggregation in Multi-Domain Inter-DC Elastic Optical Networks

Boyuan Yan, Yongli Zhao, Xiaosong Yu, Wei Wang, and Jie Zhang
State Key Laboratory of Information Photonics and Optical Communications, Beijing Univ. of Posts & Telecom, 10086, China
Email: {yanboyuan, yonglizhao, xiaosongyu, weiw, lgr24}@bupt.edu.cn

Abstract: A service function-oriented topology aggregation is proposed, based on which a routing and resource assignment algorithm is designed for service function chain construction in multi-domain optical networks. Simulation results show it can achieve high efficiency.
OCIS codes: (060.4251) Networks, assignment and routing algorithms; (060.4258) Networks, network topology.

1. Introduction

Nowadays, some traffic flows of different applications need to be handled through multiple service functions (e.g., firewall, data encryption, data decryption) to satisfy different service requirements. Service functions (SFs), also known as network functions (NFs), are generally implemented by traditional middle-boxes or network function virtualization (NFV) [1], and deployed in data centers (DCs). DCs are placed at different places, and connected to optical nodes in metro/backbone networks. A set of SFs required by specific traffic flow in fixed order or flexible order, is called SF chain (SFC). And a SF path (SFP) is a certain route to steer traffic to form a SFC [2]. In inter-DC elastic optical networks (IDC-EONs), the provisioning of a SFP depends on SF allocation in DCs, and frequency slot (FS) allocation in EONs. In a SFP, the selected optical node connecting a DC is called anchor node (AN), and the DC provides enough specific SFs for the SFP. ANs split a SFP into multiple segments, FS allocation on each segment should follow the continuity constraint and the contiguity constraint [3] in EONs.

SFP calculation is a challenging task to satisfy service requirements [4], especially when the SFP crosses multi-domains. In large multi-domain networks, internal topology of each domain needs to be aggregated to show necessary and non-confidential information to other domains, or specific machine (e.g. multi-domain controller in multi-layer software-defined networks). Then cross-domain resource allocation could be supported. The process to aggregate network is called topology aggregation. Traditional topology aggregation only contains the cost of routing across the domain [5], but no SFs information. In this paper, we present a SF-oriented topology aggregation mechanism. Then a seriatim optimal anchor selection (SOAS) algorithm is proposed to calculate available cross-domain SFPs for multi-domain IDC-EONs.

2. SF-oriented topology aggregation mechanism

Examples of SF-oriented topology aggregation for multi-domain IDC-EONs is shown in Fig. 1. Fig. 1(a) shows a three-domain network, and Fig. 1(b) shows its aggregated topology. The number upon specific node indicates the SF supported by this node. Two SFCs in a fixed order supported by this network are SFC1 and SFC2. There are three types of adjacent relationship for every two SFs, i.e., $SF1 \rightarrow SF2$, $SF2 \rightarrow SF3$, and $SF3 \rightarrow SF2$.

SF-oriented topology aggregation consists of node aggregation and link aggregation. For node aggregation, there

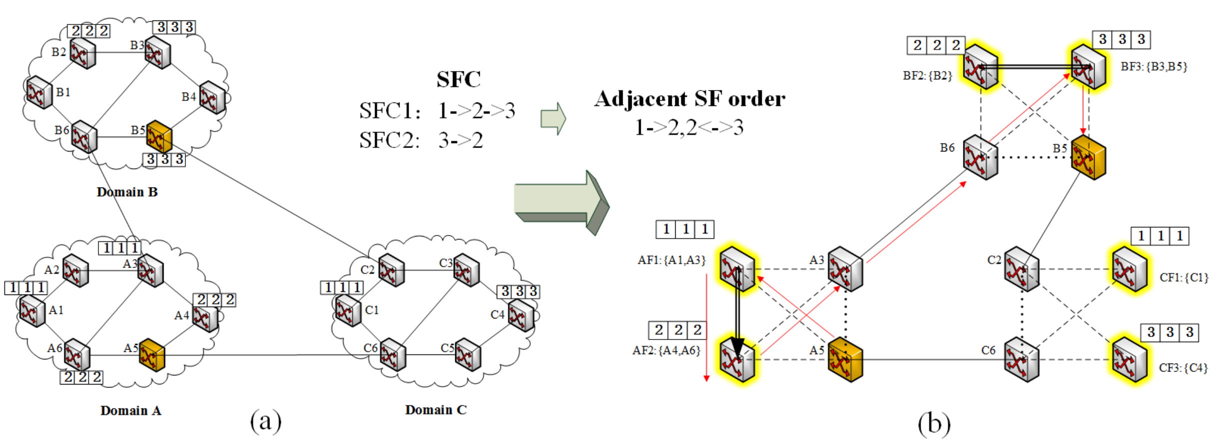

Fig. 1 Topology aggregation demonstration: (a) multi-domain network, (b) aggregated network

are two kinds of aggregated nodes, i.e., border nodes (BNs) and virtual SF-enabled nodes (VSNs). BNs indicate domain border and inter-domain connectivity, and virtual SF-enabled nodes (VSNs) summarize specific SF resource on all nodes. For example, in Fig. 1, BNs of domain **A** are A3 to domain **B**, and A5 to domain **C**. Domain **A** contains SF1 on A1 and A3, SF2 on A4 and A5. So, these two SFs on four nodes are aggregated as two VSNs: AF1 is mapped to physical A1 and A3 that support SF1, and AF2 is mapped to physical A4 and A5 that support SF2.

For link aggregation, there are three kind of aggregated links, i.e., link between every two BNs (LB), link between each BN and each VSN (LBV), and link between VSNs extracted from adjacent SF orders (LV). LBs contain routing information across this domain directly without accessing any DC. LBVs contain routing information between each BN and each VSN in the same domain, to provide full connection access to SFs for the traffic coming from other domains. And LVs contain necessary routing information between VSNs according to adjacent SF orders, to steer traffic from one VSN to another in the same domain. As Fig. 1 shows, link between A3 and A5 is a LB marked as $L_{A3\leftrightarrow A5}$. $L_{A3\leftrightarrow AF1}$, $L_{A3\leftrightarrow AF2}$, $L_{A5\leftrightarrow AF1}$, and $L_{A5\leftrightarrow AF2}$ are LBVs, and $L_{AF1\rightarrow AF2}$ is a directed LBV extracted from adjacent SF order $SF1\rightarrow SF2$. $L_{BF2\leftrightarrow BF3}$ is a bi-directional LBV extracted from adjacent SF order $SF2\leftrightarrow SF3$ in domain **B**. However, there is no LBV in domain **C** because SF1 and SF3 have no adjacent SF order.

There is one-to-many mapping relationship between VSNs on aggregated topology and SF-enabled nodes on physical topology as mentioned above. So, aggregated link attributes of LBVs and LVs contain multiple routing information from different sources to different destinations, whose data format should be different from physical link attributes. And then, the virtual SFP on aggregated topology maybe mapped to multiple physical SFPs. For example, there is a SFC1 request from A5 to B5. If the aggregated route is $A5\rightarrow AF1\rightarrow AF2\rightarrow A3\rightarrow B6\rightarrow BF3\rightarrow B5$ as red one-way arrows in Fig. 1(b) shows, then this route could be mapped to 8 physical loose routes as Fig. 2 shows. Physical loose route only contains designed BNs and ANs from source to destination, but this route doesn't specify strict path. Concrete routing and resource allocation need to be calculated inside the domains that loose route passed.

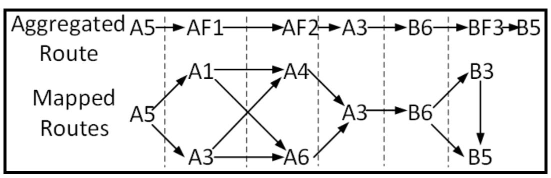

Fig. 2 Mapped physical loose routes

3. SOAS and Global SOAS

The cross-domain SFP calculation is similar with single-domain SFP calculation. For example, they both need execute AN selection, and calculate available resource allocation for a segment. So, cross-domain SFP algorithm could be proposed based on single-domain SFP algorithm. As Fig. 3 shows, we present a basic algorithm called global seriatim optimal anchor selection (GSOAS) algorithm for single-domain SFP algorithm, and based on it, we present seriatim optimal anchor selection (SOAS) algorithm for cross-domain SFP algorithm. In GSOAS, we search all alternative ANs for each segment, and choose the one by the rule of minimal hop count. And in SOAS, firstly, we select the best VSN as virtual AN following minimal hop count for each segment, and build an aggregated SFP on aggregated topology. Then we select the optimal SFP mapped from aggregated SFP with minimal hop count.

GSOAS Algorithm	**SOAS Algorithm**
1: Cross-domain SFC request arrives. **2**: **For** each segment of SFC in order **do** **3**: Search all alternative ANs from multiple domains as targets of each segment, and choose the one with minimal hop count. **4**: **End For** **5**: Build a SFP from selected segments above, and execute it.	**1**: Cross-domain SFC request arrives. **2**: Update aggregated topology. **3**: **For** each segment of SFC in order **do** **4**: Search all alternative VSNs from all domains as target of each segment, and choose the one with minimal hop count. **5**: **End For** **6**: Build an aggregated SFP from selected segments above. **7**: **For** each link of aggregated SFP in order **do** **8**: Map this aggregated link to multiple segments of physical topology, and choose the one with minimal hop count. **9**: **End For** **10**: Build a physical SFP and execute it.
(a)	(b)

Fig. 3 Algorithm description of (a) GSOAS, (b) SOAS

GSOAS contains one sub-algorithm, i.e., physical routing and resource allocation (PRRA) algorithm, which is used to allocate FS and SF resource for each segment. If the segment is cross-domain, this segment should be divided into smaller segments by border nodes. And SOAS contains three sub-algorithms, i.e., aggregating link (AL) algorithm, aggregated routing and resource allocation (ARRA) algorithm, and PRRA algorithm. AL is used to build aggregated link matrixes on each domain, ARRA is used to calculate routes between aggregated nodes on aggregated topology. Implementations of sub-algorithms would influence the performance of GSOAS and SOAS.

4. Simulation results

To evaluate the performance of proposed SF-oriented topology aggregation, a simulation is performed on multi-domain inter-DC EONs with various domains and 20 optical nodes per domain. The multi-domain topologies are randomly generated by BRITE [6]. We compare SOAS with GSOAS. For the sake of simplification, PRRA in GSOAS and all three sub-algorithms in SOAS calculate paths by using Dijkstra algorithm and allocate FS resource by using First-Fit algorithm. We assume that total number of SFs is 6, 20% nodes can support only one SF, the type of SF is generated randomly. Each optical link can provide 384 available FSs. Arrival and leave of SFC requests follow Poisson process, source and destination of SFC requests are generated randomly.

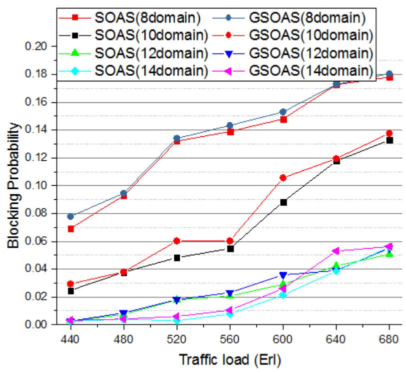

Fig. 4 Blocking Probability

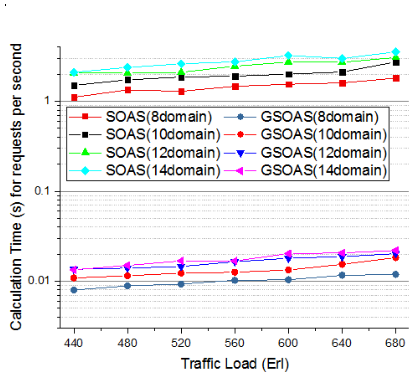

Fig. 5 Running Time for SFCs per time unit

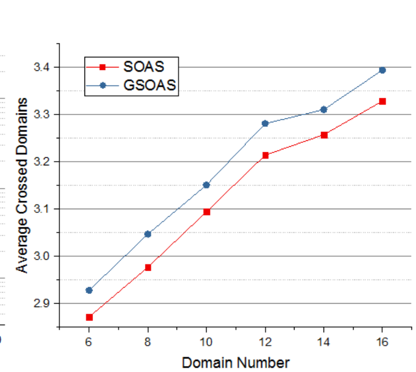

Fig. 6 Average Crossed Domains

Fig. 4 shows blocking probability for different traffic load with different domains. As we know, for an aggregated topology, some link information may be lost. Then, there will be less available routes. Hence the blocking probability based on aggregated topology becomes higher. The performance of SOAS and GSOAS are similar when assigning a SFP, because SF-oriented topology aggregation doesn't lose much link information. And in Fig. 5, the curves of SOAS show calculation time shared by each single domain, including time of topology aggregation and time of executing PRRA in its own domain. The curves of GSOAS show the time for calculating SFPs on multi-domain networks. Calculation time of SOAS are tens of the time of GSOAS on the whole, because the necessary process of information aggregation to build aggregated topology costs much time. Part of aggregated information are useless for current SFC request, but these information are hard to be identified. Fig. 6 shows the comparison for average crossed domains per SFP with different domain number under 560 *Erlang*. The number of crossed domains of SOAS is slightly less than that of GSOAS with different total domain numbers. Because when we use Dijkstra algorithm on aggregated topology, the VSN in the same domain is accessed early than the VSN outside the domain. For example, when we calculate the first AN selection for SFC1 in Fig. 1(b), the route from source A5 to AF1 is calculated before the route from A5 to CF1, because the hops on aggregated topology in the same domain is generally less than the hops in other domains. According to the analysis mentioned above, the SF-oriented topology aggregation can achieve cross-domain SFP calculation with higher resource utilization at the cost of calculation time.

5. Conclusion

We proposed a SF-oriented topology aggregation mechanism, based on which SOAS algorithm is proposed to support SFP calculation in multi-domain IDC-EONs. Simulation results show that the proposed algorithm can achieve cross-domain SFP calculation with higher resource utilization at the cost of calculation time (This work has been partially supported by National Science and Technology Major Project (2017ZX03001016), and National Natural Science Foundation of China (grant no.61571058 and 61601052)).

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