Geography-based Service Function Path (SFP) Provisioning in Inter-Datacenter Elastic Optical Networks

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ABSTRACT

Inside a service function chain (SFC), traffic flow follows a certain route, namely a service function path (SFP), to travel through each service function (SF) entity. A SFP consists of several end-to-end segments, whose source and destination are named anchor node (AN). SFs are located in multiple datacenters (DCs), and inter-DC light-paths need to be provisioned between separated SFs. In this paper, we introduce geography information of optical nodes and DCs, define special geographic distance between ANs in inter-DC elastic optical networks (EONs). Then following minimal geographic distance principle, we propose a geography-based SFP provisioning solution, which contains two heuristic algorithms, named geography-based shortest path and first-fit algorithm (GSP-FF) and geography-based *k*-shortest paths and first-fit algorithm (GK-FF). These algorithms can compress AN selection procedure extremely in fixed time, which cost little time for the AN selection of resource allocation. And benchmark algorithm use Dijkstra shortest path calculation and first-fit FS selection to allocate IT resources in DCs and FS resources in EONs. Then GSP-FF and GK-FF are proposed to provision SFPs efficiently. In our simulation, we compare our proposed algorithms with benchmark algorithm deeply on blocking probability, running time, average hops, average geographic distance, *et al.* under different traffic load and other simulation environment. We also analyze the trend and reason for the performance difference among these algorithms. According detailed evaluation, simulation proves that the proposed algorithms in this paper could use geographic information efficiently, and achieve lower blocking probability with lower running time compared with the benchmark algorithm.

Keywords: Elastic optical networks, service function chain, service function path

1. INTRODUCTION

Network function virtualization (NFV) [1] enables flexible add/drop operations for network functions. With NFV, data flows may need to be steered through multiple virtual network functions (VNFs) Those functions are usually provided by data-centers (DCs), which are usually distributed and connected by metro/backbone networks. Network function is also known as service function, and a set of such functions is defined as a service function chain (SFC) [2]. Inside a SFC, traffic flow follows a certain route, namely a service function path (SFP), to travel through each SF entity [3]. SFP provisioning, also known as VNF forwarding graph, is a key problem in SFC scenario [1]. A SFP consists of several end-to-end segments from the source to the destination. For the SFC, whose SFs are located in multiple DCs, inter-DC lightpaths need to be provisioned for inter-SF transport. Thus, IT resources supporting SFs in DCs and frequency slots (FSs) in elastic optical networks (EONs) should be allocated jointly to provision SFPs dynamically. SFP provisioning can be divided into two interrelated steps: anchor nodes (ANs) selection and resource allocation. AN has been defined in our previous work [4], which is a selected optical node which connects a DC directly, and the DC could provide enough SFs that the SFC needs. Once an AN is selected, the SFP must go through it. Resource allocation consists of two sub-steps: IT resource allocation in DCs, and spectrum resources allocation in EONs.

There are some related research to solve SFP provisioning problem. Ref. [2] proposed a vertex-centric distributed resource orchestration algorithm to search all available mappings of a SFC in multi-domain networks. Ref. [5] discussed dynamic construction for VNF forwarding graph considering spectrum fragmentation. Ref. [6] discussed SFC Provisioning with mixed-strategy gaming in broker-based EONs. In SFP provisioning, the locations of optical nodes and DCs contains helpful information for AN selection; however, these works did not consider how to use them. In this paper, we introduce geography information of optical nodes and DCs, and proposed a geography-based SFP provisioning solution. Then two geography-based heuristic algorithms are proposed to provision SFPs efficiently.

2. GEOGRAPHY-BASED SFP PROVISIONING

Firstly, we introduce definition of geographic distance (GD) that is different from straight-line distance. Fig. 1 shows an example, where V_s and V_d are source and destination nodes, *c* and *x* is two ANs. GD of *c* to V_s and Vd is *E*, GD of *x* to V_s and V_d is *G*. The minimal one of *E* and *G* is shown in Eqn. (1). If *E* and *G* are all negative or positive, which indicates they are on the same side to V_s, the minimal one is the one closer to V_s. If only one of *E* and *G* are positive, the positive one is the minimal one, because it is closer to V_d along the line between V_s and V_d.

$$MGD(E,G)_{v_s \to v_d} = \begin{cases} \min\{|E|,|G|\}, & E \cdot G \geq 0 \\ \max\{E,G\}, & E \cdot G < 0 \end{cases} \tag{1}$$

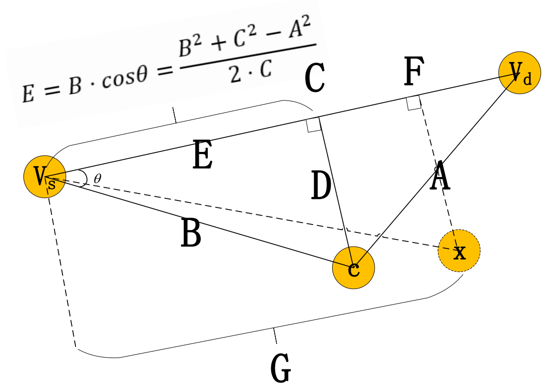


Figure 1. Geographic distance calculation

Optical network topologies have two characteristics: firstly, they are normally sparse graph according to statistical data of backbone optical network topologies globally. Secondly, there is generally no direct connection between any two optical nodes that are far away from each other. Based on these two characteristics, geography location may reflect some valuable information. Firstly, absolute value of GD has an approximate positive correlation with the hops between two nodes. Secondly, AN selection could make SFP close to the destination node by choosing the node satisfying minimal GD.

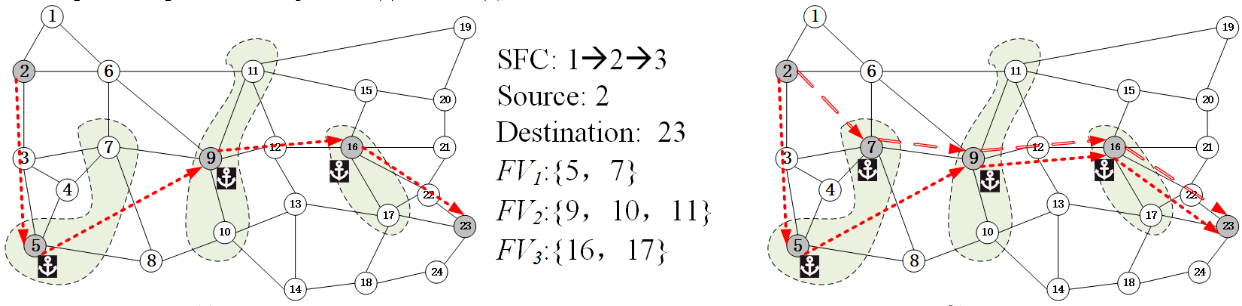
Based on geographic information, this paper proposes two algorithms. 1) geography-based shortest path and first-fit (GSP-FF) and 2) geography-based *k*-shortest paths and first-fit (GK-FF). These two algorithms are described in Fig. 2. Fig. 3 illustrates an example of these two algorithms on USNET with 24-node and 43-link. In Fig. 3, a SFC requires SF 1→2→3 from node 2 to node 23, FV_i is set of available nodes that can support enough IT resource for the *i*-th SF in a SFC.

At **Step 1-5** of GSP-FF, each loop confirms an AN of SFC in order. Firstly, we get GDs of each one of next alternative AN set FV_i, to previous AN and destination, then choose the one as next AN following Eqn. (1). In the first loop, previous AN is the source, and in the last loop, next alternative AN set only contains the destination. Secondly, Dijkstra and First-Fit algorithm for segment from previous AN to next AN is executed. As Fig. 3(a) shows, Node 5 is selected as the next AN during the first AN selection, because its GD to node 2 and node 23 is the minimal of FV_i. Then nodes 9 and 16 are selected as the second and the third AN in the same manner.

At **Step 1-5** of GK-FF, we hold *k* incomplete alternative SFPs, add a segment to them, and update them in each **For** loop. In *i*-th loop, SFV_{i-1} contains the previous ANs that are extracted from all *k* incomplete alternative SFPs. Firstly, we get GDs of each one of next alternative AN set FV_i, to each one of SFV_{i-1} and destination node. For each of SFV_{i-1}, we choose the *k* nodes of FV_i following Eqn. (1) to build *k* segments. Then there are k^2 combinations for the next segment choices at most. Secondly, we select *k* alternative SFPs by the rule of minimal hop count from these combinations, and extract SFV_i

Geography-based Shortest Path and First-Fit (GSP-FF)	Geography-based K-shortest paths and First-Fit (GK-FF)
1: **For** each available AN set FV_i in order **do** **2**: Get GDs of each element of FV_i to previous selected AN and destination. **3**: Select the minimal one as next AN following Eqn. (1). **4**: Execute Dijkstra algorithm and First-Fit algorithm to calculate an available allocation for current segment. If fails, this SFC request is blocked. **5**: **End For** **6**: Make up a SFP according to **For** loop above, and do execution.	**1**: **For** each available AN set FV_i in order **do** **2**: Get GDs of each element of FV_i to each element of previous selected AN set SFV_{i-1} and destination. **3**: Select the minimal *k* as next alternative AN set for each of SFV_{i-1} following Eqn. (1). **4**: Execute Dijkstra algorithm and First-Fit algorithm to calculate k^2 available allocations from *k* elements of SFV_{i-1} to its *k* next alternative AN for current segment. Then select the better *k* by the rule of minimal hop count. If all k^2 decisions fail, this SFC request is blocked. **5**: **End For** **6**: Make up *k* SFPs according to **For** loop above, select the best one following the same rule in **Step 3**, and do execution.
(a)	(b)

Figure. 2. Algorithms description for (a) GSP-FF (b) GK-FF



(a) (b)

Figure. 3. Demonstration of (a) GSP-FF and (b) GK-FF (*k*=2)

from these *k* incomplete SFPs. After **For** loop, we get *k* complete alternative SFPs, then select the one with minimal hop count as final SFP. As Fig. 3(b) shows, SFV_0 only contains source node. When *k*=2, the first *k* incomplete SFPs are 2→5 and 2→7 according to FV_1. So SFV_1 is {5, 7}. And in the second loop, the *k* next alternative nodes for node 5 are {9, 10}, the *k* next alternative nodes for node 7 are {9, 11} following Eqn. (1). So, there are k^2 candidate incomplete SFPs: {2→5→9, 2→7→9, 2→5→10, 2→7→11}. Then choose the first two as *k* incomplete SFPs, so SFV_2 is {9}. And the rest can be done in the same manner. Finally, we get *k* complete SFPs marked by dashed unfilled arrow. In GK-FF, *k* is just the maximum value for extracting subset from alternative AN set for each segment according to Eqn. (1), size of the subset is normally less than *k*.

3. SIMULATION RESULTS

To evaluate the performance of two proposed algorithms, simulation work has been performed on the 75-node and 99-link topology of continental United States [7]. We compare the proposed two algorithms with two benchmark algorithms, which are random shortest path first-fit (RSP-FF) algorithm and greedy shortest path first fit (GP-FF) algorithm. The major difference between RSP-FF and GSP-FF is that RSP-FF selects the next AN randomly. And GP-FF is actually a specific case of GK-FF when $k \to +\infty$.

We assume that DCs support 6 type of SFs, 10 type of SFCs. Each SFC requires 1-6 FSs randomly, and contains 1-3 SFs randomly in fixed order. IT resource of each required SF is set from 1 to 4 randomly. Each node can only support one SF with 40 IT resources for simplicity, and each link can provide 384 available FSs, which are separated by 12.5GHz for resulting into 4.8THz available spectrum. Requests' arrival and leave follow Poisson process, whose source and destination are selected randomly, and required SFC are selected randomly.

The performance has been evaluated in terms of blocking probability and running time (see Fig. 4-6). From Fig. 4 we can see that the proposed algorithms performs much better than RSP-FF, while perform worse than GP-FF. GK-FF performs better than GSP-FF, whose blocking probability becomes lower and lower when *k* increases from 2 to 4. There are two reasons for SFC request blocking. One is lack of FS resource, the other is lack of SF resource. Fig.5 shows the ratio of blocked requests for lack of SF resource (RLSF). The RLSF of RSP-FF and GSP-FF are relatively low, which indicates that the two proposed algorithms use FS resources inefficiently. However, RLSF of GK-FF and GP-FF

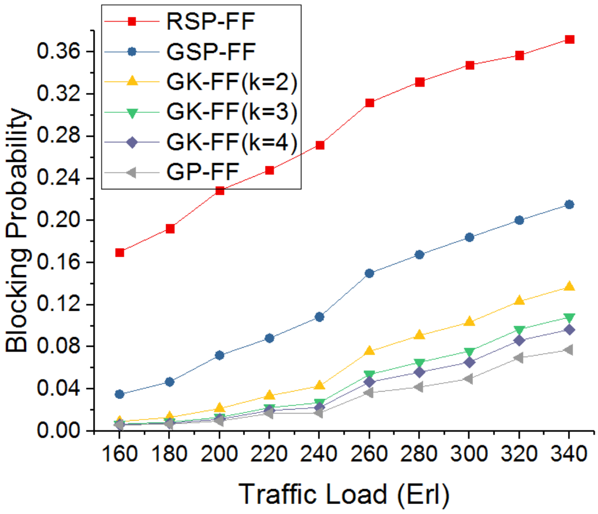


Figure. 4. Blocking Probability

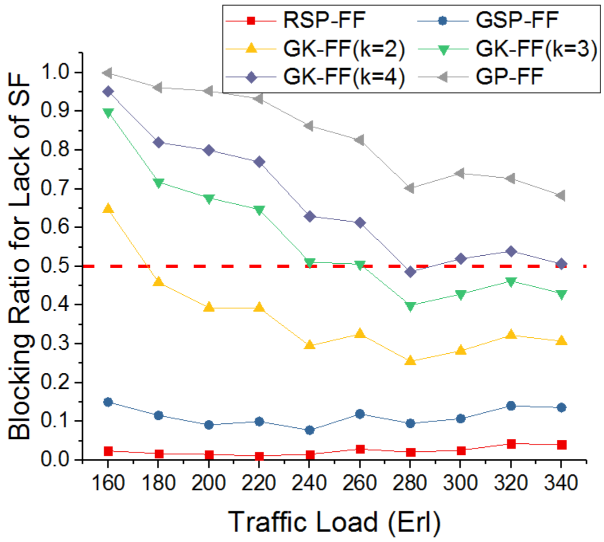


Figure. 5. BP for lack of IT resource

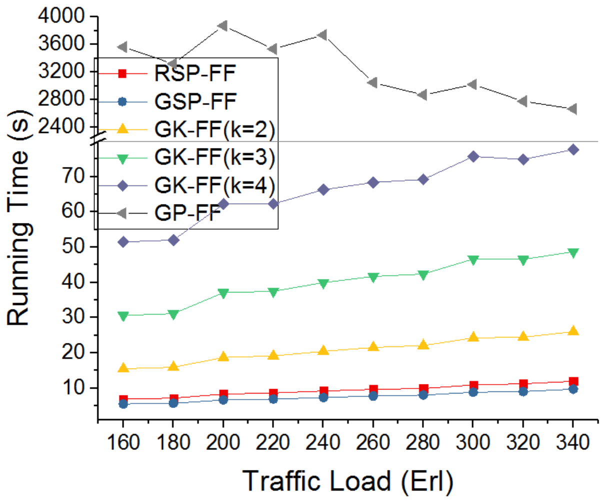


Figure. 6. Running Time

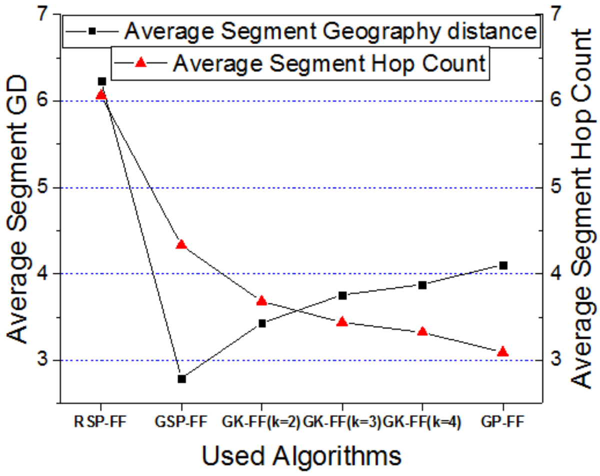


Figure. 7. Distance and Hops

decrease when traffic load increases, because SF resource utilization is positively correlated with traffic load. As to GK-FF, it's obvious that ratio becomes lower when *k* is lower, and GP-FF achieves the highest ratio because it's a special case of GK-FF when $k \to +\infty$.

Fig. 6 shows average running time for handling SFCs generated in an hour, with traffic load increasing from 160 to 340 *Erlang*. Running time of RSP-FF and GSP-FF are similar, while both of them are lower than GK-FF. Running time of GK-FF becomes higher when *k* increases, and running time of GP-FF is hundreds of times of GK-FF. However, blocking probabilities of GK-FF(k=4) and GP-FF are similar.

Fig. 7 shows the relationship between average segment GD and average segment hop count under 260 *Erlang*. GDs are calculated based on longitude and latitude. GD and hop count of RSP-FF are higher than other algorithms obviously, which indicates the minimal GD normally leads to small hop counts. From GSP-FF to GK-FF with different *k*, and to GP-FF, average GD becomes larger and larger, because there will be more segment choices when *k* becomes larger, and AN may not be the one with minimal GD, but the one with sub-minimal GD. However, hop count becomes smaller when *k* is larger, because we use minimal hop count as the rule to select the choices at **Step 4** and **6** in GK-FF. The more choices are, the smaller hop count will be.

4. CONCLUSION

SFP provisioning is a key problem in SFC scenario that influences utilization of IT resource and network resource directly. Traditional solutions don't consider geographic information that contains potential useful knowledge. Then, in this paper, we proposed two geography-based algorithms to calculate SFPs for SFC requests by utilizing geographic location information. Simulation results showed that the proposed algorithms can achieve lower blocking probability with lower running time compared with the benchmark algorithms.

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