An Efficient Approach for Service Function Chain Deployment

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Abstract: Since the popularity and development of Cloud Computing, Network Function Virtualization (NFV) and Service Function Chain (SFC) provisioning have attracted more and more attentions from researchers. With the increasing of the number of users and demands for network resources, network resources are becoming extremely valuable. Therefore, it is necessary for designing an efficient algorithm to provision the SFC with the minimum consumption of bandwidth resources. In this paper, we study the problem of cost efficient deploying for SFCs to reduce the consumption of bandwidth resources. We propose an efficient algorithm for SFC deployment based on the strategies of layering physical network and evaluating physical network nodes to minimize the bandwidth resource consumption (SFCD-LEMB). It aims at deploying the Virtualization Network Functions (VNFs) of the SFC onto appropriate nodes and mapping the SFC onto reasonable path by layering the physical network. Simulation results show that the average gains on bandwidth consumption, acceptance ratio and time efficiency of our algorithm are 50%, 15% and 60%, respectively.

1 INTRODUCTION

In the traditional network, network functions (NFs) (e.g., network address translator (NAT), load balancer, firewall, gateway and intrusion detection system (IDS) (Min Sang Yoon and Ahmed E. Kamal, 2016)) are implemented by dedicated hardware, and it's expensively to join a new NF into the existing network (Minh-Tuan Thai et al., 2016). To solve this problem, the technology of network function virtualization (NFV) has been proposed. In the NFV environment, the network functions are migrated from the dedicated hardware to the software that run on the virtual machines (VMs) (Rami Cohen et al., 2015) and can implement the corresponding functions. The network functions running on the VMs are called the virtualization network functions (VNFs). Multiple VNFs form a service function chain (SFC) in a specific order (Juliver Gil Herrera et al., 2016) for catering the communication requirements (Sevil Mehraghdam et al., 2014).

NFV enables network operators to conveniently manage the infrastructure and instantiate software network functions on commercial servers (Carla Mouradian et al., 2015). Through NFV technology, infrastructure provider can flexibly deploy NFs on the VMs by virtualizing relevant appliances (Tachun Lin et al., 2016) (Bo Han et al., 2015). The commercial hardware can host several VNFs in the different time slots, thus it significantly improves the utilization of the physical resource and saves the cost for purchasing new equipment to meet the increasing demands. NFV brings many benefits to the network in both resource and cost efficiency, i.e., it can observably reduce the capital expenditure (CAPEX) and the operational expenditure (OPEX) (Maryam Jalalitabar et al., 2016) and accompany with the performance improvements, such as the decrease of latency and increase of adaptation. Thus, efficient deployment for SFC revolutionary promotes the network virtualization and makes the network more intelligently.

NFV brings benefit to both of infrastructure provider and users, however, there are some issues need to be solved. For example, the latency will influence clients' experience and the resource consumption of each SFC may relate to how many SFC requests can be provisioned by the physical network. Since reducing bandwidth resource

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consumption of each SFC can significantly improve the accept ratio of SFCs. It can product tremendous benefits under the proprietary nature of existing hardware and save the space and energy consumption of a variety of middle-boxes (Tachun Lin et al., 2016).

When we deploy a SFC into the network, we not only need to guarantee to satisfy clients' constraints, but also need to consider the resource efficiency (Rashid Mijumbi et al., 2016). With the increasing diversification of demands and the growing requirements for bandwidth resources, bandwidth resources become more and more scarce. Efficiently utilizing of bandwidth resources becomes the basic goal for each algorithm. The authors in (Zilong Ye et al., 2016) studied the joint topology design and the mapping problem for minimizing the total bandwidth consumption while there is room for improvement. In this paper, we restudy the problem of how to reduce the bandwidth consumption for provisioning SFC. To solve this problem, we propose a heuristic algorithm with layering the physical network and evaluating the physical network nodes to minimize the consumption of bandwidth resources, SFCD-LEMB, to minimize the bandwidth consumption and achieve a higher accept ratio and a short response time of SFC requests.

2 PROBLEM STATEMENT

In this work, we study the problem of deploying the SFC request with low bandwidth consumption. We consider a scenario in which each SFC request has two given clients which are in the given physical network nodes, and several VNFs with a specific order, we need to deploy these VNFs into the corresponding nodes. To reduce the bandwidth resources consumption, we should use less nodes and shorten the path as much as possible.

In this paper, the SFC request can be modelled as $S = (F_S, E_S)$, where $F_S = \{f_1, f_2, \ldots, f_m\}$ represents the set of VNFs, $E_S = \{e_1, e_2, \ldots, e_q\}$ denotes the virtual links of SFC. And the physical network can be modelled as an undirected weighted graph $G = (N, L)$, where $N = \{N_1, N_2, \ldots, N_y\}$ is the set of the physical nodes, L presents the set of the links in the physical network. We define C_B^T as the total bandwidth consumption. And the C_B^T is defined as Equation (1).

$$C_B^T = \sum_{e_i \in P} C_B^{e_i} \tag{1}$$

where $C_B^{e_i}$ represents the bandwidth consumption of virtual link e_i. We define $R_C^{N_i}$ as the available computing resource of the physical node N_i and $C_N^{f_j}$ denotes the computing resource requirements of the VNF f_j. $R_B^{L_i}$ is the available bandwidth resource of the physical link L_i.

For deploying a SFC request, we need to map the VNFs and virtual links of the SFC, and the available bandwidth resources must satisfy the requirements of the corresponding links in the SFC. In addition, the path must have enough nodes to deploy corresponding VNFs. We assume that each physical network node at most can host one VNF from the same SFC. The deployment of the SFC can be formulated as follows.

$$\begin{aligned} & Min \ \sum_{e_i \in P} C_B^{e_i} \\ & s.t. \ \sum_{N_i \in N} R_C^{N_i} - \sum_{f_j \in F_S} C_N^{f_j} \geq 0 \\ & \qquad \sum_{L_i \in L} R_B^{L_i} - \sum_{e_j \in E_S} C_B^{e_j} \geq 0 \end{aligned} \tag{2}$$

Formulation (2) is used to minimize the total bandwidth consumption while provisioning the SFC request. And there must be enough available computing resources to deploy all the SFC requests and the bandwidth resource should be enough to satisfy the communication demands of SFCs.

Figure 1 gives an example for provisioning a SFC request, which can reduce the bandwidth consumption while meeting the clients' demands. As shown in Figure 1, it deploys the VNF f_1, f_2 and f_3 onto physical node A, F and H, respectively. In this way, the deployment solution can directly reduce bandwidth consumption. Then it finds the shorter path $P = \{A\text{-}B, B\text{-}F, F\text{-}H\}$ as shown in the red line in Figure 1, which can deploy all the VNFs to meet the clients' demands, and the total bandwidth consumption of this path is only 220 units. By using the scheme in the Figure 1, the network can provision more SFC requests between nodes A and H without reusing links

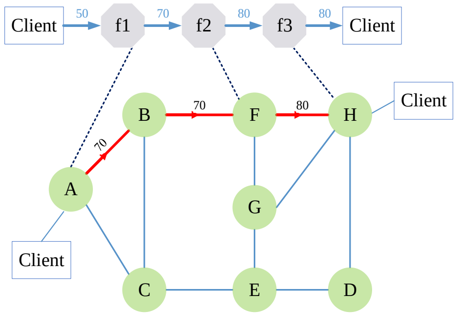


Figure 1: An example for SFC deployment.

3 ALGORITHM DESIGN

For solving the researched problem, we design an efficient algorithm with the strategies of layering the physical network and evaluating the physical network nodes to minimize the bandwidth resource consumption, SFCD-LEMB. The basic idea is that finding the shortest path to save bandwidth as much as possible while satisfying all of the constraints from users. When a SFC request arrives, the SFCD-LEMB algorithm begins to deploy it. It firstly calls *Algorithm* 2 to layer the network and achieves the layering information of the network nodes and links, and then calls the *Algorithm* 3 to evaluate the physical network nodes and select the most suitable node to deploy the corresponding VNF. Through layering network and selecting most suitable node, the SFCD-LEMB algorithm can deploy SFC in an appropriate path which can save the bandwidth resource as much as possible. The path must contain the request client node N_r and the destination client node N_a and has enough available node resources to place the VNFs of the SFC. Here, we assume that the path is simple path without circle.

In our SFCD-LEMB algorithm, G_L is used to model the layered physical network, V_X denotes the set of nodes in the X-*th* layer (L.X), E_X represents the set of links connecting the nodes in L.X-1, and L_{MAX} is the number of layers in the G_L. G_L^X indicates the inner layered network about the X-*th* layer (L.X). $V_{(X,Y)}^i$ represents the set of nodes which are in the L.X of the G_L and in the L.Y of the G_L^X about the node N_i. $E_{(X,Y)}^i$ denotes the corresponding links connecting the nodes in the L.Y-1 and L_{MAX}^i is the corresponding maximal layer. N_T indicates the total number of nodes in the physical network and L_T represents the total number of the links in physical network G. The pseudo-code of the SFCD-LEMB algorithm is shown in *Algorithm* 1.

In the following, we give detailed description for the network aware based *Algorithm* 2 to layer the physical network in our proposed method. The *Algorithm* 2 is responsible for layering the physical network and achieving the layering information of the network nodes and links by layering the physical network. It's the basis of our SFC deployment scheme.

$$G_L = \sum_{X=1}^{L_{MAX}} (V_X, E_X) + \sum_{X=2}^{L_{MAX}} G_L^X \quad (3)$$

$$G_L^X = \sum_{V_i \in V_X} \sum_{Y=1}^{L_{MAX}^i} \left(V_{(X,Y)}^i, E_{(X,Y)}^i\right) \quad (4)$$

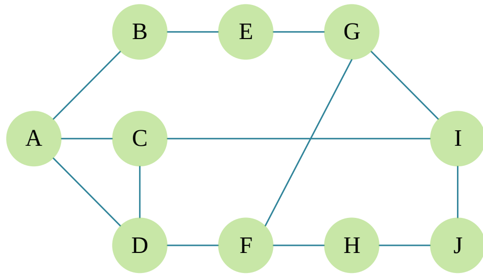
Algorithm 1: SFCD-LEMB algorithm
Input: (1) Substrate network G;
(2) SFC request.
Output: Deployment result for SFC.
SFC request arrives;
$N_a \rightarrow$ Path; $N_L = N_a$;
Run Algorithm 2(;N_r; N_L);
Get L_A: the layers that destination client is located in;
while $L_S > \mathrm{Max}(L_A) + \sum_{X=1}^{L_{MAX}} \mathrm{Max}(L_{MAX}^i)$; **do**
  if Max L_A = L_{MAX}
    N_{TEMP}=Algorithm 3(;;L_{MAX};true);
    $N_{TEMP} \rightarrow$ P;
    N_L = N_{TEMP} ;
  else
    N_{TEMP}=Algorithm 3(;;L_{MAX};false);
    $N_{TEMP} \rightarrow$ P ;
    N_L= N_{TEMP} ;
  end if
  L_S = L_S - 1;
  VNF $\rightarrow N_{TEMP}$;
  Algorithm 2(;N_r; N_L);
  Update L_A;
end while
if L_S =< Max L_A
  choose Min L.X $\in L_A$ && L.X > L_S;
  while $N_r \notin$ P ; **do**
    N_{TEMP}=Algorithm3(;;L.X;true);
    $N_{TEMP} \rightarrow$ P;
    N_L = N_{TEMP};
    L.X =L.X - 1;
    VNF $\rightarrow N_{TEMP}$;
  end while
end if
SFC $\rightarrow$ **P.**

$$\sum_{X=1}^{L_{MAX}} V_X - N_T \ge 0 \quad (5)$$

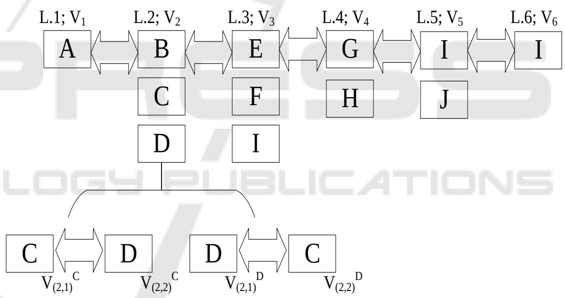
$$\sum_{X=2}^{L_{MAX}} E_X + \sum_{X=2}^{L_{MAX}} \sum_{V_i \in V_X} \sum_{Y=2}^{L_{MAX}^{i}} E_{(X,Y)}^{i} - L_T = 0 \tag{6}$$

In Equation (3), G_L consists of the overall layer network and the inner layer network G_L^X about the X-*th* layer (L.X). V_X is the set of nodes in L.X, E_X denotes the set of links connecting the nodes in L.X-1, and L_{MAX} represents the maximal layer in the overall layer network. The process of layering begins from the request node N_r, so $V_1 = N_r$, $E_1 = \emptyset$ and $G_L^1 = \emptyset$. In Equation (4), each layer excludes the layer L.1 and get the inner layer information about each node, so that G_L can be closer with the physical network G, and L_{MAX}^i is the maximal inner layer of the inner layer topology about the node. After layering the physical network, all nodes must be in the corresponding layer as described in the Equation (5). Each link should be in the corresponding overall or inner layer as described in Equation (6).

An example of layering network topology is shown as in Figure 2. Figure 2 (a) shows the original physical network, and Figure 2 (b) shows the information of the layered topology. We assume that the request client node N_r is the node *A*, and the destination client node N_a is the node *I*. We put the request client node *A* in the L.1 (V_1 is the set of nodes in L.1) and put the nodes *B*, *C*, *D* which are all directly connect with the node *A* in the L.2, then we put the nodes *E*, *F*, *I* which are directly connect with the nodes of L.2 in the L.3. In our network layering strategy, the nodes in the next layer must directly connect with the nodes except for the destination client node *I* in the last layer. Thus, *G*, *H*, *J* directly connect with the nodes in the L.3, while *J* connects with the destination client node *I*, it can't be put in the next layer L.4. We only put the node *G* and *H* into the L.4. And *I*, *J* connect with G, H which are in the L.4, so we put node *I*, *J* in the layer L.5 (all nodes except for the destination client node *I* can be belong to only one layer) and *I* connect with the node *J*, we put it in the L.6. The overall network layering process finishes when all of the nodes in *G* are included into corresponding layers. All nodes except for the destination client node *I* can be in only one layer. For each layer, we need to layer the inner layer network topology, and get the inner information G_L^X about the L.X. In the example, only the L.2 has the inner layer and it includes two layers. So the *Algorithm* 2 layers L.2 composed by node *B*, *C* and *D*, and then gets the corresponding information of inner layers. As G_L^2 shown in the Figure 2 (b), for each layer X<= L_{MAX} and each node $N_i \in V.X$ should be set as the request client node N_r and let $N_a = \emptyset$, then we get the inner layer information about all the nodes. In G_L^2, the L_{MAX}^C and L_{MAX}^D both are 2, while L_{MAX}^B is 1. As a result, the physical network is layered into six layers. The source client node N_r is only in the layer L.1 and the destination client node N_a is in the layers L.3, L.5 and L.6. It means that there are at last three paths to connect N_r with N_a. We use L_P to denote the length of the path (the length of the three paths are respective three, five and six), which equates the number of the VNFs that the path can hold, meanwhile the notation L_S is the length of SFC that denotes the number of VNFs in a SFC.



(a) The physical network



(b) The layered topology

Figure 2: Example for layering a physical network.

Algorithm 2:Physical network layering
Input: (1) Substrate network G;
(2) N_r; (3) N_a.
Output: G_L;

```
Nr → V1; LMAX = L.1;
for V_LMAX ≠ ∅ ; Nm ≠ Na; do
 for each Nn ∈ G; do
   if Nm ↔ Nn && Nn ∉ Σ_1^LMAX VX
       Nn → V_LMAX+1;
    else Nm ↔ Nn&&Nn ∈ Σ_1^LMAX VX&&Nn= Na
          Nn → V_LMAX+1;
    end if
  end for
  LMAX ++;
end for
for L.X =< LMAX; do
```

for $N_m \in V_X$; **do**
    $N_m \rightarrow V_{(X,1)}$;
    $L^m{}_{MAX} = L^m.1$;
  for $V_{(X,L^m{}_{MAX})} \neq \emptyset$; **do**
  if $N_n \in V_X \&\& N_m \leftrightarrow N_n \&\& N_n \notin \sum_1^{L^m{}_{MAX}} G_L^X$
    $N_n \rightarrow V_{(X,L^m{}_{MAX})}$;
    end if
    $L^m{}_{MAX}$ ++;
 end for
end for
end for
return G_L

Algorithm 3 focuses on evaluating the nodes and choosing the most suitable node to host corresponding VNF. After layering the physical network, *Algorithm* 3 can directly judge that whether the physical network can meet the requirement of SFC request. When the sum of all the inner layers and the maximal layer L_A of the destination client node N_a are still smaller than the length of SFC (denoted as L_S), the physical network is hard to meet the user's demand. For example, when we need to deploy a SFC request into the physical network shown in Figure 2 (a), the clients respectively are located at the node *A* and the node *I*. The maximum layer L_A is 6, and the layer L.2 has the inner layer and there is a layer in the inner layer, the total number of layering network is 7. So the physical network can meet the requirement of SFC request whose length is no more than 7. If the length of the SFC request is longer than 7, it is heavy for the network. Although it can find ways to place the SFC request, but it may consume more time and bandwidth resources since the length of SFC L_S is too long for the physical network. Our proposed *Algorithm* 3 can solve the problem by searching the nodes in the opposite direction. To address this issue, *Algorithm* 3 usually find the next node in the next layer V_N rather than in the upper layer V_U and then it can directly increases the maximum length of path (denoted as L_P). Considering an extreme situation, the client is in the L_{MAX} without the next layer, our algorithm allows to firstly find a node in the upper layer V_U and then layers the physical network again. And then, the found node just now isn't in the L_{MAX}.

Finally, we need to choose the suitable nodes from the layered network to deploy the VNFs. *Algorithm* 3 follows the strategy mentioned above to find the path from N_a to N_r. The algorithm chooses the nodes among the layers according to Equation (7). The chosen node must directly connect with the node in the next layer V_N.

$$\delta = Min\left(\frac{B_{si}-B_{ri}}{B_{si}}, \frac{B_{se}-B_{re}}{B_{se}}\right) \times \frac{C_s - C_r}{C_s} \quad (7)$$

We define δ to measure a node's justifiability for the SFC request. Where B_{si} means the available bandwidth of all links which connects the nodes in the next layer V_N, and B_{ri} represents the requested bandwidth for the communication between this VNF and the next VNF. B_{se} denotes the available bandwidth of the path which connects the nodes in V_U , and B_{re} represents the request bandwidth between this VNF and the last VNF. C_s represents the available computing resources in node and C_r represents the requested computing resources of the corresponding VNF. And then, we choose the node which has the minimum value of δ.

***Algorithm* 3**: Node evaluation

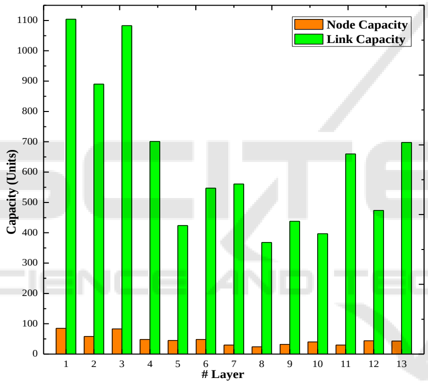
Input: (1) G_L ;
 (2) SFC request;
 (3) **X:** $N_L \in V_X$;
 (4) **bool:** direction;
Output: N_C: the node has minimum δ;
Temp = $+\infty$
if (direction)
 int i = 1;
else
 int i = -1;
for $N_m \in V_{X-1}$; **do**
 if $N_m \leftrightarrow N_L$;
   if $B_{si} > B_{ri}$ && $B_{se} > B_{re}$ && $C_s > C_r$;
    Compute δ based on Equa.(2);
   if δ < Temp
    Temp $= \delta$;
    $N_C = N_m$;
   end if
  end if
 end if
end for
return N_C.

4 SIMULATION RESULT AND ANALYSIS

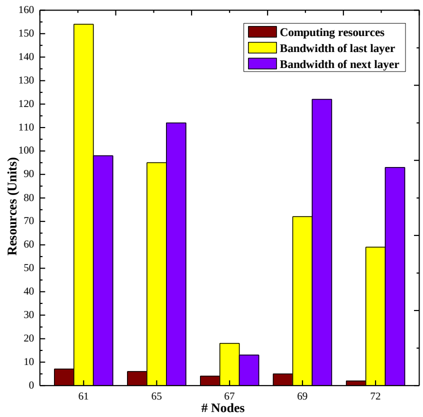
With the increasing of SFC requests, to deploy SFC requests in a static network will become more and more challenge, thus it's important to improve the scalability of network. Network-aware scaling strategy is important for extending the network rather than changing the network blindly. Here, we define the perceiving information G^S of network G as in Equation (8).

$$G^S = \sum_{X=1}^{L_{MAX}} \sum_{N_i \in V_X} (C_s + B_{si} + B_{se}) \qquad (8)$$

Our SFCD-LEMB algorithm layers the network and finds the "*weak*" *layer* (i.e., the layer has minimum resource) and analyses its inner information and then gets the "*weak*" *nodes* or *links* which influence the network's capacity. Then the SFCD-LEMB algorithm extends corresponding resources to make the network more robust. Figure 3 shows the results for running the SFCD-LEMB algorithm in a small scale network. Figure 3 (a) shows the information of whole network. Obviously, L.8 limits the overall capacity of the network and thus influences the users' experience. Whereas Figure 3 (b) gives the information about the nodes in L.8. Node 67 has minimum bandwidth and node 72 has minimum compute resources. Both of them are the "*weak points*" of the network and increasing the corresponding resources will enhance the capacity of physical network.



(a)

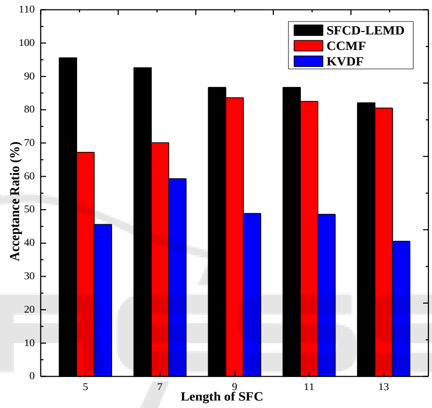


(b)

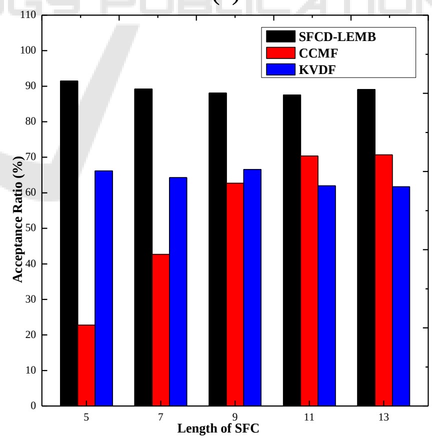
Figure 3: Simulation results for scaling the network.

In order to evaluate the performance of our algorithm, we introduce two algorithms which are Closed-Loop with Critical Mapping Feedback (CCMF) (Zilong Ye et al., 2016) and Key-VNF Deploy First (KVDF) which firstly deploy the key VNF for more efficiently placing the SFC to compare with our SFCD-LEMB algorithm.

We respectively evaluate three algorithms in small and large scale networks. Both network topologies are generated by using GT-ITM. In the small scale networks, there are 100 physical nodes and about 400 links. In the large scale networks, there are 1000 physical nodes and about 4000 links. In the two networks, the computing resources of each node are 10 units, and the bandwidth resources of each link are uniformly distributed at 100~200 units. We generate SFC requests with the L_S varies from 5 to 13, and under each L_S, we randomly generate 10000 SFC requests.



(a)

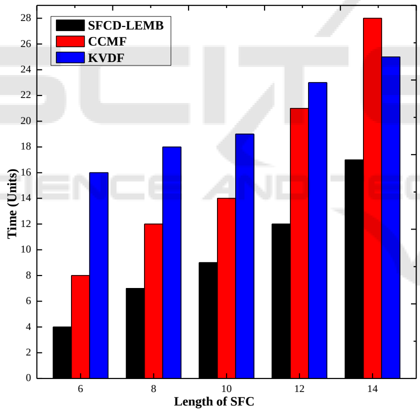


(b)

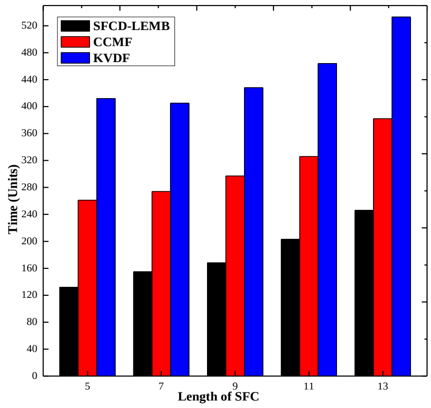
Figure 4: Acceptance ratios in small and large scale networks.

Figure 4 shows the evaluation result about the acceptance ratios of the compared algorithms. Figure 4 (a) and (b) respectively show the evaluation results in small and large scale networks. We can see that SFCD-LEMB algorithm has a higher acceptance ratio than CCMF algorithm and KVDF algorithm. Furthermore, the SFCD-LEMB algorithm has a relatively stable acceptance ratio in the different scale network and different L_s. It's because that the SFCD-LEMB algorithm has a perception about the network after layering the physical network and it can deploy the SFC appropriately. In addition, our SFCD-LEMB algorithm has a better performance in the large scale network than that in small scale network.

Figure 5 shows the evaluation results about the running time of SFCD-LEMB, CCMF and KVDF algorithms. Figure 5 (a) and (b) show the evaluation result in the small scale network and the large scale network, respectively. In the compared algorithms, SFCD-LEMB algorithm accomplishes the deployment in the shortest time in both small and large scale networks. Moreover, the running time of SFCD-LEMB algorithm increases slowly with the growth of the value of the length of SFC (i.e., L_s). This is because that SFCD-LEMB algorithm can more quickly find the corresponding node to deploy VNFs and the corresponding path to deploy SFC by using the layering information of the network.



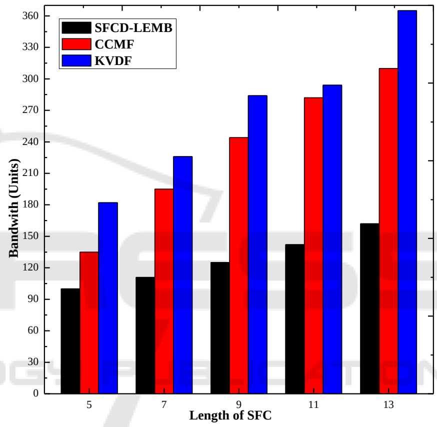
(a)



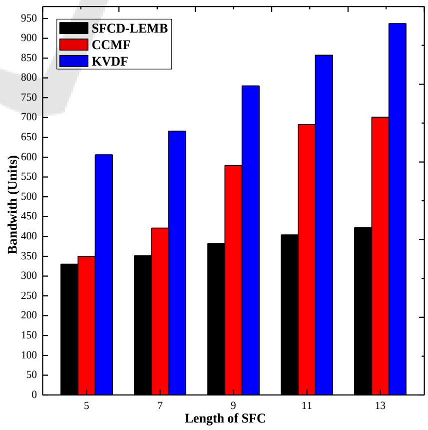
(b)

Figure 5: Running time of small and large scale networks.

Figure 6 (a) and (b) show the evaluation results about the bandwidth consumptions in small scale network and large scale network, respectively. From Figure 6 we can see that the SFCD -LEMB algorithm can deploy SFC with less bandwidth consumption whereas the CCMF algorithm and the KVDF algorithm need to consume more bandwidth to deploy the same SFC requests. With the increasing of L_s and the network's scale, the SFCD-LEMB still has an outstanding performance in saving the bandwidth resource. This is because that the SFCD-LEMB algorithm can get the layering information of the network nodes and links through layering the physical network, which is one of the main contributions of SFCD-LEMB. Due to layering the physical network, the SFCD-LEMB algorithm can save much bandwidth consumption while increasing the capacity and scale of network.



(a)



(b)

Figure 6: Bandwidth consumption in different networks.

5 CONCLUSIONS

In this paper, we study the problem of efficiently deploying service function chains. To solve this problem, we propose an efficient algorithm, SFCD-LEMB, which achieves the layering information of the network nodes and links by layering the physical network and evaluates the physical network nodes and then chooses the most suitable node to host the VNFs of SFC. Simulation results show that our proposed algorithm has good performance on acceptance ratio, running time and bandwidth consumption for provisioning SFC requests. In addition, we can extend the network to satisfy the increasing demand according to the layering information.

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