Markov Approximation Based Approach for Network Service Chain Embedding

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Abstract: Nowadays, the European Telecommunications Standards Institute (ETSI) introduces the concept of network function virtualization (NFV) that can run network functions (NFs) on industry standard servers (commodity servers). This opens significant ways to manage the network system of providers efficiently in terms of reducing the operation and management cost. Using the NFV architecture, NFs can share the physical resources by implementing NFs as software embedded on physical nodes. However, the providers need efficient methods to the shared resource pool. Finding the answer to this problem, in this paper, we formulate the network service chain embedding as an optimization problem and propose a framework based on the Markov approximation framework to find the close optimal solution. The simulation results show the efficiency of our model in comparison with the existing method, Best-fit.

1. Introduction

There are many aspects of the resource management of an operator's network, such as efficient resource allocation, reducing power consumption, improving the resource utilization and performance. Traditionally, the network functions (NFs), such as NAT, load balancers, firewall, are implemented on physical middle-boxes. Middle-boxes are based on special-purpose hardware and very expensive as well as too difficult to maintain and upgrade. Fortunately, the European Telecommunications Standards Institute (ETSI) introduces the concept of network function virtualization (NFV) that can run (NFs) on industry standard servers (commodity servers) [1]. This opens significant ways to manage the network system of providers efficiently in terms of reducing the operation and management cost. Using the NFV architecture, NFs can share the physical resources by implementing NFs as software embedded on physical nodes.

Typically, NFs do not run independently in the network. For example, to require a web service, a provider has to implement a firewall to secure the packets, a load balancer to distribute the workload, a web server to execute HTTP requests. That means a set of NFs is specified and the flows traverse these NFs in a specific order. The set of NFs for a specific service is called a service chain (SC).

Considering the implementation for SCs, we focus on how to reduce the cost that is incurred in the system when implementing NFs on physical nodes (named network service chain embedding). The diverse of SCs and NFs increases the complexity of this problem. Currently, allocation approaches (Best-fit, First-fit) [2] cannot achieve a good result due to relationship between NFs in a SC. Fig 1 shows an example of SC embedding with 3 SCs and 4 physical nodes. The relationship of NFs is represented in the table of Fig 1. To implement these SCs, all NFs can be hosted on nodes and virtual connections between NFs can be shared on physical links that connect physical nodes. Reducing the number of active nodes to implement can reduce the operational cost of the provider

In this paper, we formulate the SC embedding problem as a combinatorial optimization problem. We then study a Markov approximation mechanism that can find a close optimal solution for this combinatorial NP-hard problem. By using *log-sum-exp* to transform the original problem, we can apply the Markov approximation framework [3]. We design a specific Markov chain and derive the transition rate between states. Based on the stationary distribution, we design a distributed embedding algorithm to implement SCs.

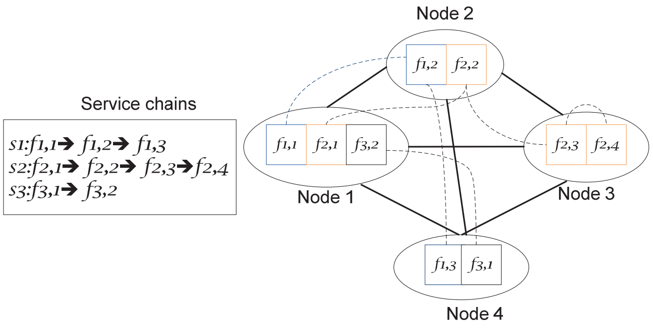

Fig 1: An example of network service chain embedding. There are 3 service chains that are embedded on 4 physical nodes

The rest of the paper is organized as follows. Section 2 discusses about the problem statement and the solution used in our work. Section 3 presents about the simulation results. Finally, we present the conclusion in Section 4.

2. Problem Statement and Algorithm

2.1. System Model

We consider a service provider scenario that users request a set $S = \{s_1, s_2, \dots, s_I\}$ of service chains (SCs). Each service chain i includes a set N_i of virtual network functions (VNFs). Using physical infrastructure, the controller of the provider determines a scheme to embed VNFs on physical nodes (servers). Furthermore, VNFs in a specific service chain require virtual connections (links) to forward packets (e.g., in a web service chain, a network address translation (NAT) is implemented in front a firewall (FW). This implementation requires a virtual connection to forward packets from NAT to FW). The virtual connections are also embedded and shared the network traffic on the physical links. We consider the computation resource of each VNF with the unit of CPU, and define f_{ij}^c as the amount of CPU unit requirement of VNF j in SC i. The constraint ensures that all VNFs embedded on a node n cannot exceed the capacity of that node as follows:

$$\sum_{i=1}^{i=I} \sum_{j=1}^{j=N_i} x_{ijn} f_{ij}^c \le n^c, \forall n \in N, \qquad (1)$$

where N is the set of physical nodes, n^c is the capacity of node n, and x_{ijn} is the indication variable (x_{ijn}=0 if VNF j of SC i is hosted on n, otherwise x_{ijn}=1).

Moreover, each SC i is a directed path. We define $d_i(l_v^i)$ as the data rate flowing in the link l_v of SC i. Also, we denote $d(l_p)$ as the capacity data rate of the physical link l_p belong to the set L of physical links. The total amount of traffic passing through the shared link l_p should not exceed its processing capacity. Thus, we have the following constraint:

$$\sum_{i \in I} y_{vp} d_i\left(l_v^i\right) \le d\left(l_p\right), \ \forall l_p \in L, \qquad (2)$$

where y_{vp} is the indicator variable to indicate virtual link l_v that is embedded on the physical link l_p.

The objective in embedding SCs is to reduce the cost to operate the physical nodes. We define a_n as the active variable for node n; $a_n = 1$ if $\sum_{i=1}^{I} \sum_{j}^{N_i} x_{ijn} > 0$, otherwise $a_n = 0$. The objective function now can be formulated as follows: $\sum_{n=1}^{N} a_n$.

Combining the constraints (1) and (2), we formulate the optimization problem of SC placement as follow:

$$\boldsymbol{P_{SCP}}: \text{Min} \sum_{n=1}^{N} a_n$$
$$\text{s.t. constraints (1) and (2).}$$

The problem is combinatorial optimization problem, which cannot find the solution in polynomial time.

2.2. Approximation framework

Let $f \in F$ be a feasible solution to problem P_{SCP}, where F is the set of all feasible solutions. We denote C_f as the objective function value of P_{SCP} corresponding to the solution f and p_f as the percentage of time that f should be in use. We adapt the approximation version of P_{SCP} using *log-sum-exp* approximation as follows;

$$\boldsymbol{P_{SCP} - \delta}: \min_{p_f} \sum_{f \in F} p_f C_f + \frac{1}{\delta} \sum_{f \in F} p_f \log p_f, \qquad (3)$$
$$s.t. \sum_{f \in F} p_f = 1,$$

where δ is a positive constant that controls the accuracy of the approximation. $P_{SCP} - \delta$ is a convex problem that can be solved to derive p_f^* [3].

2.3. Algorithm Design

Following the theoretical insights from [3].we design the transition rate between two state f and f' to ensure that in the Markov chain: (i) any two configurations (states) are reachable from each other (irreducible); and (ii) the balance condition is satisfied. For two states f and f with direct transitions, we design the transition rate between two states as

$$q_{f \to f'} = \tau \exp\left(\frac{1}{2} \delta\left(C_f - C_{f'}\right)\right), \qquad (4)$$

where τ is a positive constant.

We propose a distributed algorithm to embed service chains. The algorithm is executed separately for each service chain. At one time, only one service chain can change its configuration, others have to be silent at that time. We schedule for all service chains following first-come-first-serve (FCFS and the next service chain has to wait the free message to execute its procedure.

Algorithm 1: SEMA-Distributed service chain embedding

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For service chain $i$:
1. Randomly choose feasible nodes in the set N that have sufficient resources to host the service chain $i$.
2. Randomly replace one chosen node by select a node in the set of N. The new chosen subset must have sufficient resources to host the service chain $i$.
3. Migrate to the new configuration $f'$ with probability proportional to the transition rate (4).
4. Broadcast a “free message” to other session.
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3. Simulation results

In this section, we make a simulation for our work with 20 service chains including 150 VNFs. We create 30 physical nodes and create a network connection between them. The link capacities of these links are set from 5 to 10. The virtual link bandwidth requirements are set from 1 to 2.

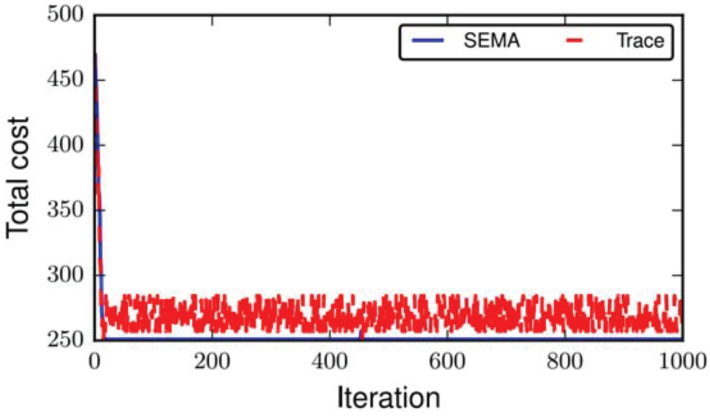

Fig 2: Evaluation of the convergence of SEMA.

Fig 2 shows the convergence of SEMA during 1000 iterations. Fortunately, within 30 iterations, the best configuration is selected and is kept until ending. We also depict the total cost of the new propose subset at each iteration by Trace. After selecting the best subset, all new proposed subsets are ignored due to higher total cost as shown in Fig. 2

Furthermore, we make a comparison to Best-fit approach as shown in Fig 3. The number of node in our method is used smaller than Best-fit. By reducing the amount of active nodes, we can reduce by 32.7% the total cost compared to the Best-fit approach.

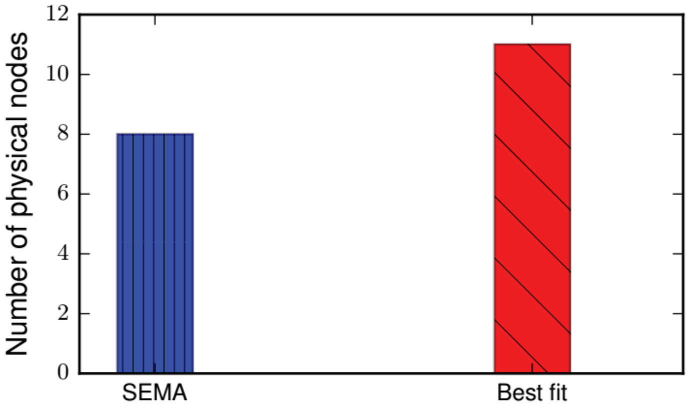

Fig 3: Comparison between SEMA and Best-fit.

4. Conclusion

In this paper, we have studied about SC embedding problem. This problem is combinatorial and NP-hard problem that cannot be found a solution in polynomial time. Furthermore, due to the diversity and the relationship of NFs, current allocation approaches (First-fit, Best-fit) cannot achieve the efficient solution. We have proposed a distributed SC embedding based on the Markov approximation method. Our solution can obtain the close optimal solution and outperforms compared to Best-fit.

ACKNOWLEDGMENT

"This research was supported by the MSIP, Korea, under the G-ITRC support program (IITP-2016-R6812-15-0001) supervised by the IITP." *Dr. CS Hong is the corresponding author.

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