Controller Placement Problem to Enhance Performance in Multi-domain SDN Networks

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***Abstract*—As the use of Software-Defined Networking is extended, the deployment of multiple controllers has been required to deal with scalability and reliability issues. In such an SDN network, a network can be partitioned into sub-networks as controller's domains. In this case, there are mainly two issues to consider: 1) how to partition a network and 2) where to place controllers. Our previous work has concentrated on the network partitioning to satisfy several aspects in Software-Defined Networking. As an idea of our future work, this paper discusses and formulates the controller placement problem in multi-domain networks on the basis of network partitioning in our previous work.**

Keywords*—*Software-Defined Networking; multiple controllers; network partitioning; controller placement; graph theory.

I. INTRODUCTION

Software-Defined Networking (SDN) has been emerging as a new networking paradigm. The fundamental concept of SDN is to achieve programmable networking by separating the control and the data planes in individual network devices, such as switches and routers. As the use of SDN is extended, SDN networks with multiple controllers have been proposed to deal with scalability and reliability issues [1].

In such an SDN network with multiple controllers, a network can be divided into sub-networks, and controllers are in charge of one of them as their administrative domains. This could reduce the overall complexity of the whole network management and the computational load of each controller as well as handling flow setup requests faster and more efficiently. Furthermore, when a controller failure occurs, it could alleviate spreading its negative effects to the rest of the network [2].

Here, there would be two major aspects to consider for such a network:

1) How to partition a network to decide controller domains
2) Where to locate controllers in each domain.

Because network partitioning determines network resources and topology distribution, it could affect the various aspects of network performance, such as controller load balance and reliability [3]. This issue is referred to as *the network partitioning problem* in our previous work. On the other hand, the selection of controller locations has been discussed in many research papers as it has various influences on communications between switches and a controller in terms of latency, stability, or efficiency. Generally, this issue is called *the controller placement problem*.

Our previous work has mainly focused on network partitioning methods based on graph clustering [4]. Thus, aiming at more effective management of multi-domain SDN networks, this paper addresses the controller placement problem based on the network partitioning as an extension of our previous work.

The rest of the paper is organized as follows. Section II describes the related work of the network partitioning and controller placement. Section III presents the model and problem formulation. Section IV addresses the conclusion and our future work.

II. RELATED WORK

A. Network Partitioning

As mentioned earlier, network partitioning could be related to the various aspects of network operations and performances of SDN.

For instance, the load balance among controllers would be one of the major issues. The controller load is mainly network provisioning and status collection overhead within a domain [5]. Hence, simply, the more switches a controller needs to manage, the heavier load the controller has to bear.

Moreover, in case of a link failure, it would be preferable that a network topology in a domain ensures redundancy so that the failure can be recovered within the domain; otherwise, additional inter-controller communication would be required.

In addition, from the perspective of traffic load balancing, switches in each domain might need to have multiple paths to controllers and other switches to distribute data traffic.

Considering those issues above, our previous work has proposed network partitioning methods based on the concept of conductance and cycle structures in networks [4][6].

B. Controller Placement

After the first proposal by Heller et al in [7], the controller placement problem has been studied in many researches. The most common objective for the problem is to minimize controller-switch latency [8][9]. Particularly, it has been widely studied to locate a controller based on the closeness to switches.

In addition to controller-switch distance, survivability is also the other metric for the controller deployment [10][11]. In this type of metric, the number of disjoint paths, which do not share links among them, between switches and a controller is maximized to ensure logical connections between them in case of link failures in SDN in-band model.

 ISBN: 978-1-61208-450-3

As stated above, the controller placement problem and its metrics have been well studied. However, the controller placement in partitioned networks has not been discussed in detail. By using those existing metrics, this paper formulates the controller placement problem based on the network partitioning in our previous work.

III. Problem Formulation

This section describes the graph definitions and the metrics for the control placement.

A. Graph Definitions

For a network graph $G = (V, E)$, a set of nodes $V = \{v_i\}$ denotes network devices, such as routers and switches, and a set of edges $E = \{e_k\}$ represents links between those devices. Considering the network partitioning, local domains of controllers and its set are defined as follows:

$$G_1^l = (V_1^l, E_1^l), G_2^l = (V_2^l, E_2^l), \ldots, G_k^l = (V_k^l, E_k^l), \quad (1)$$

$$\mathbf{G^l} = \{G_1^l, G_2^l, ..., G_j^l ..., G_k^l\}. \quad (2)$$

B. Evaluation Metrics for Controller Placement

The controller placement problem in multi-domain networks can be formulated as an optimization problem to find an appropriate node c_j for a controller location in each domain where a given evaluation function is optimized. Here, assume that domains are given by network partitioning, and a set of controller locations in domains is denoted as

$$C = \{c_1, c_2, \ldots, c_j, \ldots, c_k\}. \quad (3)$$

1) Controller-switch latency: The most commonly used metric is the longest distance between a switch $v_i \in V_j^l$ and a controller $c_j \in C$, which represents the worst controller-switch latency. Supposing that the distance is the shortest path length between them denoted as $dist(v_i, c_j)$, the longest distance between a switch and controller in a domain is defined as

$$L(G_j^l) = \max_{v_i \in V_i^l \setminus \{c_j\}} dist(v_i, c_j). \quad (4)$$

Thus, for a network as a whole, the task is to find a set of controller locations C to satisfy the following function:

$$\text{Minimize} \sum_{G_j^l \in \mathbf{G^l}} L(G_j^l). \quad (5)$$

2) Survivability: In the controller placement problem, survivability is denoted as the number of edge disjoint paths between switches and a controller. By representing the number of edge disjoint paths between a switch v_i and a controller c_j of a domain G_j^l as δ_{ij}, the survivability of a domain is denoted as

$$S(G_j^l) = \frac{\sum_{v_i \in G_j^l \setminus \{c_j\}} \delta_{ij}}{|V| - 1}. \quad (6)$$

Then, the evaluation function is described as

$$\text{Maximize} \sum_{G_j^l \in \mathbf{G^l}} S(G_j^l). \quad (7)$$

Therefore, the whole algorithm will include two phases: 1) partitioning a network and 2) finding the locations of controllers in individual partitioned networks so as to satisfy the metrics.

IV. Conclusion and Future Work

In multi-domain SDN networks, two issues have been discussed: 1) Network partitioning and 2) Controller placement. This paper has formulated the controller placement problem for multi-domain networks, which considers the network partitioning in our previous work.

As the first step in future tasks, the generally defined metrics of the controller placement, such as controller-switch latency and survivability will be examined on the partitioned networks.

Acknowledgments

This work was supported by JSPS KAKENHI Grant Number 26330120.

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