Prediction Based Clustering for Large-Scale Software Defined Networks

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***Abstract*—The controller placement problem (CPP), in software defined networks (SDNs), deals with placing an optimal number of controllers. The placement of controllers aims to maximize the network throughput and minimize the overall latency. In order to calculate the latencies among the switches and controllers, various distance metrics are used. Hop count is one such metric, which refers to the total number of hops or adjacent node jumps required to reach from source to destination. However, other properties of networks, for example– bandwidth, delay, traffic, etc., need to be addressed as well. To solve this problem, we propose a novel controller placement algorithm, namely, Mean Based Predictive Clustering (MBPC). MBPC can work with weighted representations of a network, where the weights can be fitted to be any variable like hop count, latency, congestion or traffic, etc. Simulation results show that our proposed algorithm outperform existing state-of-the-art SDN clustering algorithms in polynomial time complexity.**

***Index Terms*—CPP, SDN, latencies, clustering**

I. Introduction

Software Defined Networks (SDNs) decouple the traditional protocol stack into the 'control plane' and the 'data plane'. The control plane consists of "controllers" which take the routing decisions and relay this information to the data plane. The data plane is the collection of switches which forward the data according to the routing decisions provided by the control plane. The initial design of SDN [1] included only a single controller in the control plane. However, for moderate-sized networks, a bottleneck is created due to heavy traffic concentrated at the controller. Furthermore, problems like scalability [2], [3] and reliability surface as network size increases. In order to deal with these problems, most researches deploy multiple controllers [4], [5], [6], which results in the emergence of the controller placement problem (CPP). A solution to the CPP is to select an optimal number of controllers, placing them in the best possible locations, and assigning them switches in an optimal way [7], [8]. In addition, there are more than one constraints that need to be handled– minimizing the latency among switches and controllers, maximizing reliability and resilience, and minimizing deployment cost and energy consumption, which is why it is NP-Hard.

In recent years, several solutions have been proposed to address the CPP [9], [10]– some solutions minimize latency [11] or control traffic [12], some maximize reliability [13], [14] and resilience [15], while some optimize a composite metric [16], [17]. One such solution, Density Based Controller Placement (DBCP) [18], clusters the network to minimize latency and maximize reliability using hop count as the distance metric. However, hop count is not adequate to represent the overall condition of a network. Therefore, our proposed method clusters a network to optimize a variable which can be set to any parameter. The contribution of our work can be summarized as follows:

- Our proposed algorithm work with weighted links between switches, thus allowing us to create clusters based on network traffic, bandwidth, transmission rate, etc., which are essential in determining the condition of a network.
- Our proposed algorithms cluster SDN networks in polynomial time complexity.
- We define an improvement ratio to determine an optimal point of cessation when increasing the number of controllers.

The rest of the paper is organized as follows– We represent the CPP as a graph theory problem along with some notable works on CPP in Section II. We explain our proposed algorithm in Section III. Simulation results and Performance Evaluation are presented in Section IV and we conclude in Section V.

II. Problem Formulation and Related Works

In this paper, we consider the network as a bi-directional graph $G = (S, L)$ consisting of nodes and edges. Here the set of nodes S represent the switches and the set of edges L represent the links between the switches. The edges can be either weighted or unweighted based on the requirements. Our objective is to cluster the graph G into multiple sub-networks S_i such that, each sub-network is a set of switches $S_i = \{s_{i,1}, s_{i,2}, ...s_{i,j}\}$. There cannot be any common switch between two sub-networks and all of the switches of the network must fall into a sub-network, where each sub-network will have one and only one controller.

Let us assume that the network will be clustered into k partitions. The sub-networks can be presented as,

$$S_{net} \leftarrow \{S_1, S_2, ..., S_k\} \tag{1}$$

where, S_{net} is the entire network and $S_1, S_2, ..., S_k$ are k disjoint sets of switches or sub-networks.

III. Proposed Algorithm

MBPC assumes that the network will be clustered into k balanced sub-networks. We select k nodes with highest degrees as the cluster heads and assign each node to its nearest cluster head.

The nodes at the centre have higher probability of becoming cluster heads as they have higher degrees. Therefore, we define a threshold distance T_d which is the predicted cluster radius for a given k. If two cluster heads are within T_d distance of each other, then we omit one of the cluster heads, as one cluster cannot have more than one cluster heads. We assume that for a balanced clustering, each cluster will have $|S|/k$ number of nodes. If the average degree of all the nodes in the entire network is $avg\ deg$, then each node will be connected to approximately $avg\ deg$ number of nodes. We define $avg\ deg$ to be the average value of all the edge weights, which, in case of hop counts, will be equal to one.

Initially, we take the cluster radius as $avg\ dis$, or one hop in the case where the distance metric is hop counts. The total number of nodes in the cluster is $1 + avg\ deg$, for the center node itself and the nodes it is connected to. We increase the radius of the cluster, each time by adding $avg\ dis$. The number of nodes in the $boundary$ of the cluster increase by a multiple of $avg\ deg$. However, there are also links among the switches of the same cluster. We discard this excess number of nodes using the edge to node ratio $|L|/|S|$, which defines how many edges are there among a set of nodes in a given network. If $actual$ is the approximate number of nodes in the cluster, and $apparent$ is the number of nodes that is gained if the edges inside the clusters are not considered, then the following equation stands,

$$2 \times (actual \times |L|/|S|) + actual = apparent \tag{2}$$

Here, as each edge between two intra-cluster nodes gives two apparent node counts increments, we multiply term $(actual \times |L|/|S|)$ by 2. Solving the equation 2 gives the approximate number of nodes in the cluster as $apparent/(2.0 \times (|L|/|S| + 1))$. We keep increasing the radius of the cluster until the value of $actual$, that is the approximate number of nodes in the cluster, exceeds $|S|/k$, which is the expected number of nodes in a balanced cluster. Therefore, we select the highest degree node as the first cluster head, and continue to take the highest degree nodes of the remaining switches as cluster heads. If a node is within T_d distance of any cluster head, we omit it and continue with the next highest highest degree node. After k cluster heads have been selected, we assign each node to the cluster of the nearest cluster head.

We select the controllers of each of the k clusters using $inter\ cluster$ and $intra\ cluster$ distances. The $intra\ cluster$ distance for a switch s is the average of the distances from s to all other switches in the same cluster. It is denoted by $intra\ cluster(s)$ as given in equation 3.

$$intra\ cluster(s) = \frac{1}{|S_i| - 1} \sum_{u \in |S_i|} dis(s, u) \tag{3}$$

Here, $dis(s, u)$ is the shortest path distance between s and u of the cluster S_i. The $inter\ cluster$ distance for switch s is the average of the distances from s to all the nodes of other clusters and is denoted by $inter\ cluster(s)$ (equation 4).

$$inter\ cluster(s) = \frac{1}{|S - S_i|} \sum_{v \notin |S_i|} dis(s, v) \tag{4}$$

We select one node s, in each cluster which has the minimum sum of these two values, as the controller of that cluster. Our proposed pseudocode is given in algorithm 1.

Algorithm 1 : Mean Based Predictive Clustering (MBPC)

```
procedure PBC(k,S,L)
nodeList ← descending deg(S)
avg deg = avg(deg(S))
limit = 1 + avg deg
avg dis = avg(L)
boundary = avg deg
T_d = 0
    while (limit/(2.0 × (|L|/|S| + 1))) < (|S|/k) do
        boundary = boundary × avg deg
        limit = limit + boundary
        T_d = T_d + avg dis
    for each switch s in nodeList do
        if dis(s, clusterheads) < T_d then
            continue
        else
            s = new clusterhead
Assign each switch to cluster of nearest clusterhead
    for each switch s in nodeList do
        Calculate intra cluster(s)
        Calculate inter cluster(s)
        C(s) = intra cluster(s) + inter cluster(s)
CList ← descending C(S)
Select first k switches from CList as controllers
```

IV. Performance Evaluation

A. Simulation Environment

We perform the experiments using C++ (High-level language). We use randomly generated networks with different numbers of switches starting from 40 to 100, at regular intervals of 10. There are 10 different datasets for each interval, giving a total of 70 different networks. The link to switch ratio is kept from 1.3 to 1.45 to keep the networks considerably sparse (similar to current worldwide networks). The networks do not contain any self-loops or multiple links between two switches but may have cycles. The seven scenarios are given in the table I along with the average values of their total number of switches, links, and link to switch ratio.

B. Performance Metric

In software defined networks (

C. Result Comparison

V. Conclusion

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TABLE I: Randomized Networks used as Input

Scenario	Nodes	Edges	Edge/Node
1	40	54	1.35
2	50	66.7	1.334
3	60	81.4	1.35667
4	70	99.3	1.41857
5	80	111.2	1.39
6	90	125.5	1.39444
7	100	138.9	1.389

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