Modeling and Performance Analysis of the Multiple Controllers' Approach in Software Defined Networking

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***Abstract*—We model the multiple controllers' approach of SDN and analyze the performance of the model by using the queuing theory. Extensive experiments are conducted and the simulation results are compatible with the theoretical analysis which validates the correctness of the simulation. Through the analysis, we find that multiple controllers' approach is an effective way to increase the control plane's scalability of SDN, but it also results to longer sojourn time. In this point of view, the multiple controllers' approach can be regarded as a tradeoff between the scalability and the sojourn time.**

***Index Terms*—Software Defined Networking; Queuing theory; Modeling; Performance Evaluation;**

I. Abstraction Multiple Controllers' Approach of SDN

There are many different strategies which can be adopted to realize the multiple controllers' approach. We simply utilize the approach which is presented in [1] as our research object, as it represents the most general approach related to the multiple controllers.

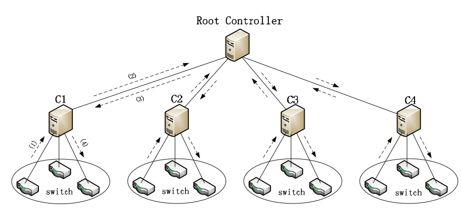

Fig. 1. The multiple controller and switch SDN network

As illustrated in Fig. 1, the multiple controllers' control plain is composed of local controllers and the root controller. Each of the local controllers is responsible for handful of switches which deal with the local traffic. The local controllers are managed by the root controller to handle the flow table request which is mismatched in the local controllers. In the data plane, multiple switches are regarded as the switch pool which can generate multiple new flow requests.

II. Model

We regard the local controllers as a M/M/1/m system which is adopted in [2]. The root controller is regarded as a M/M/1 system for the following reasons. First of all, the root controller is usually running in a more powerful server with a larger memory, so it is reasonable to suppose the buffer size is infinite. In addition, the infinite buffer size can simplify our simulation when cascading the M/M/1 and M/M/1/m system by using the Kleinrock model [3].

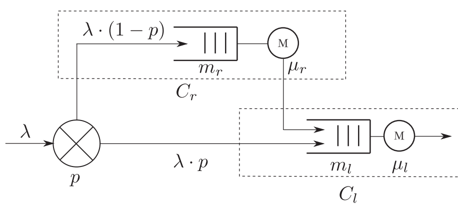

Fig. 2. A simple model of the multiple controllers

As depicted in Fig. 2, our model is mainly composed of two kind of controllers: the local controller (C_l) and the root controller (C_r). Most frequently, the flow tables requesting packets will be handled by the local controller. However, if local controller fails to match the incoming packets, the packet will be forwarded to the root controller. After being processed by the root controller, this packet will go back to its local controller and install flow tables to the relevant switches. The probability that the coming request is successfully processed by the local controller is defined as p. λ represents the flow table requesting rate from the switches. μ_l and μ_r represent the processing rate of the local controller and the root controller, respectively. m_l and m_r are the queuing size of the local controller and the root controller, respectively. It should be noted that m_r is infinite as it is modeled as a M/M/1 system.

According to the queuing theory, the average waiting time of the root controller (W_r) can be given by Eq. (1).

$$W_r = \frac{1}{\mu - \lambda} \tag{1}$$

The average waiting time of the local controller (W_l) can be given by Eq. (2).

$$W_l = \frac{1}{\mu(1-\rho)} \cdot \frac{1 + (m+1)\rho^{m+2} - (m+2)\rho^{m+1}}{1 - \rho^{m+2}} \tag{2}$$

Based on the above information and the Kleinrock model [3], the total waiting time (ΔW) of the system can be given by Eq. (3).

$$\Delta W = W_l + (1-p)W_r \quad 0 \leq p \leq 1 \tag{3}$$

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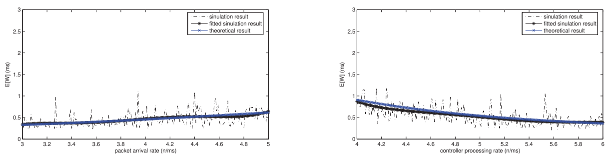
III. Simulation

We analyze the performance of the multiple controllers' approach in this section. Each performance contains three type of performance curve, including the simulation result, the fitted simulation result and the theoretical result.

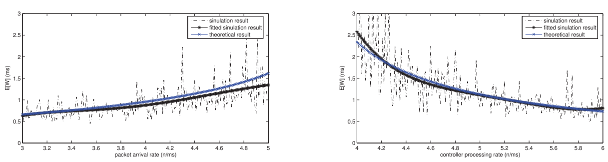
We firstly evaluate the performance of the local controllers without the aid from the root controller. This situation happens frequently as it represents the most common scenario [1].



(1) Impact of the λ (2) Impact of the μ

Fig. 3. The performance of controllers without the aid from the root controller

Fig. 3(1) illustrates how the packet arrival rate (λ) affects the average waiting time (E[W]) in the system. It can be seen from Fig. 3(1) that with the increase of the packet arrival rate, the average waiting time increases accordingly. Fig. 3(2) illustrates how the local controllers' processing rate affects the average waiting time in the system. The increase of the controller's processing rate will decrease the average waiting time, which means a better performance. Additionally, the fitted simulation result is compatible with the theoretical result.



(1) Impact of the λ (2) Impact of the μ

Fig. 4. The performance of controllers that have to forward every packet to the root controller

Fig. 4 depicts the performance of controllers that have to forward every packet to the root controller. As can be seen from Fig. 4, with the increase of the packet arrival rate as well as the decrease of the controllers' processing rate, the trend of the average waiting time is similar to the result in Fig. 3. However, the average waiting time has been doubled, which indicates that the interaction with the root controller will decrease the whole performance. The fitted performance is also close to the theoretical result.

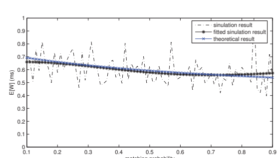


Fig. 5. Impact of the matching probability

Fig. 5 illustrates the simulation that the value of p increases from 0.1 to 0.9. The the packet's arrival as well as the controller's processing rate is set to the same value as we discussed in Fig. 3. It can be seen from Fig. 5 that with the increase of p, the average waiting time decrease gradually. It indicates that if the arrival packets are processed locally, the whole performance will be increased. Therefore, in order to increase the performance of the system, it is quite reasonable to reduce the frequency of interaction with the root controller.

IV. Conclusion

Through the analysis and the simulation, what we learnt is presented as the follows.

(1) The capacity of single controller of SDN is limited and the multiple controllers approach is an inevitable trend. Although the flow arrival rate from switches can be suppressed to alleviate the stress of controller, it falls short when it has to handle frequent events such as network-wide statistics collection. Therefore, more sufficient methods should be provided to tackle the scalability of SDN.

(2) Hierarchical control plane is an effective and practical way to alleviate the load of controllers. Compared to the distributed control plane, the advantage of the hierarchical control plane is that it does not have to share huge amount of information to ensure fine-grained network wide consistency.

(3) In the hierarchical control plane approach, frequent events should be handled by the local controller and the frequency of interaction with the root controller should be reduced. The interaction with the upper controller will inevitably increase the packets processing time, as the processing time for each packet is indeed the sum of all the controllers' processing time.

(4) If the network scale is overlarge, the control plane should be divided into multiple hierarchies to decrease the press of the root controller. This should be carefully designed and evaluated as it will result to more amount of the sojourn time.

(5) It still works to suppress the flow arrivals by pro-actively pushing the network state in multiple controllers' approach as it can reduce the flow table request from controllers. Besides, increasing the processing rate of the controllers is also effective to decrease the sojourn time.

V. Acknowledgment

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