Performance of SDN Routing in Comparison with Legacy Routing Protocols

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***Abstract*—Legacy routing protocols such as OSPF and BGP have been developed very comprehensive, but its rigid complex system has been difficult to adapt to the fast growing Internet. The emergence of Software Defined Network (SDN) has brought hope for the solution of this problem. Benefit from the advantage of the centralized control, SDN can achieve efficiency in routing computation and fine-grained control for packets. However, is the performance of SDN routing really better than legacy routing when networks in churn? This paper studies the convergence performance of legacy routing mechanisms and SDN routing. We measure the performance in term of packet forwarding delay and convergence time after link/node failure. The experimental results show that the recovery of routing in SDN network has advantage in large-scale network topology. Compared with SDN routing, the routing convergence in legacy network is much more influenced by link delay. When the link delay of network is high and the network is large, the routing convergence time in SDN network is less than legacy network.**

Keywords- SDN; routing performance; openflow; Mininet

I. INTRODUCTION

The Internet has been deeply involved in every corner of human life, and as a protocol cluster of carrying Internet communications, TCP/IP protocol contributed. The routing protocols, such as Open Shortest Path First protocol (OSPF), play a key role in TCP/IP protocols that allows distant Internet hosts for data communications in large-scale network [1, 2]. Due to the rapid development of Internet, legacy network architecture has exposed more and more performance bottlenecks. Existing closed disordered architecture and network element architecture destined uncertain network behavior, which makes it difficult to support Quality of Service (QoS), scalability, security and other requirements. In 2008, Nick Mckeown introduced the concept of OpenFlow [3] in detail for the first time. After that, Nick Mckeown further proposed SDN [4] concept which received wide support from academia and industry. SDN technology transfers the control power of data packets from node equipment distributed in the network to a centralized control unit, and solves many problems in the legacy network. In this paper we study the performance of SDN routing applications in comparison with legacy routing protocols.

There are researchers studying routing mechanism in SDN network. Researchers of ETH zurich studied the hybrid BGP-SDN inter-domain routing (IDR) protocol in the Internet. The authors built an emulation framework based on Mininet [5] that has been modified to support Quagga - a popular BGP software. It also evaluated the effect that an IDR controller has on IDR convergence time [8]. Reference [9] use Pyretic to implement the extended Dijkstra's algorithm which consider not only the edge weights but also the node weights for an underlying graph of SDN topology. RouteFlow [10] is an open source project to provide virtualized legacy IP routing services over OpenFlow enabled hardware. A typical RouteFlow architecture is composed by a Controller application, an independent RouteFlow server, and a virtual network resource pool that reproduces the physical network topology and runs legacy IP routing engines (e.g. Quagga [13]). Overall, this design transfers part of the controller's functions to another special resource pool through virtualization technology, which will undoubtedly increase the cost and the actual performance remains to be verified. Arpit Gupta proposed software-defined internet exchange points solution–SDX [11]. The experiments demonstrate that the SDX can implement representative policies for hundreds of participants who advertise full routing tables while achieving sub-second convergence in response to configuration changes and routing updates. The other related work is Google's Cardigan project [12]. Cardigan runs a routing server based on RouteFlow, but it is lack of flexibility and scalability.

The remainder of this paper is organized as follows. The second part introduces the distributed routing and centralized routing mechanism, and we model the convergence time both for distributed routing protocols and SDN based centralized routing mechanisms. The third part describes settings of our experiments. The experiment results are demonstrated and analyzed in the fourth part. Paper is summarized in the fifth part and future research work are discussed.

II. ROUTING PROTOCOL AND CONVERGENCE ANALYSIS

A. *Distributed routing vs. centralized routing*

OSPF is an open standards-based link-state routing protocol, specifically applied to the internal of autonomous system. In legacy IP network, each router maintains a database which describes structure of the network, and then calculates the routing table by building the shortest path tree. Legacy routing protocol is a typical distributed routing mode, only the link status information transmitted over the link, and the routing computation is finished by each router alone. OSPF has strong scalability and suitable for large networks.

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SDN network is a typical centralized routing model, its topology discovery and routing calculation are finished by SDN controller alone. The Floodlight [7] controller integrates the LinkDiscoverManager module as well as the TopologyService module, which collaborate to complete the routing calculation. The LinkDiscoverManager is responsible for discovering and maintaining the status of links through using both LLDPs and broadcast packets in the SDN network. TopologyService maintains the topology information for the controller, as well as to find routing in the network.

Centralized routing is more flexible in routing, thus creating favorable conditions for the deployment of Internet business and network optimization. Compared with centralized routing, the advantages of distributed route are good robustness, scalability and self-healing. However, due to the distributed routing mode relies on flooding way to transmit link-state update information between routers, the cost or convergence time is greatly influenced by link delay.

B. Routing Convergence Mechanism

First, we need to understand the routing convergence process of legacy network and SDN network. When one link of the network is failure, the convergence process of OSPF routing algorithm in the legacy network is shown in Fig. 1 while the process of SDN network is shown in Fig. 2.

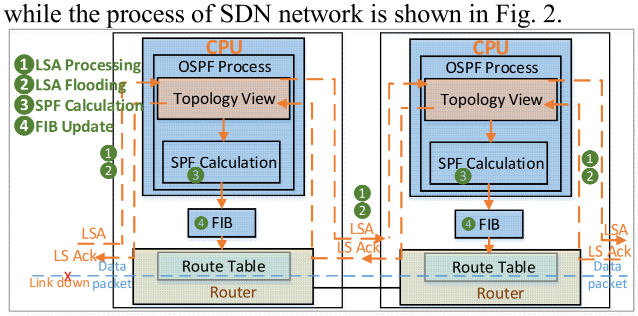

Figure 1. The routing convergence process of OSPF in legacy network.

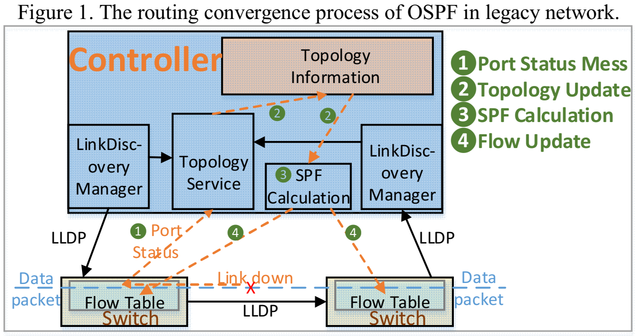

Figure 2. The routing convergence process of SDN network.

As seen in Fig. 1, the routing convergence time of legacy network can be calculated by the following formula:

$$Time = link\ down\ discovery\ time + LSA\ delivery\ time + SPF\ execution\ time + FIB\ update\ time \quad (1)$$

The above formula shows that LSA delivery time and SPF execution time are the key factors of the routing convergence time. The larger the network size, the higher the link delay, the longer the routing convergence time.

From Fig. 2, the routing convergence time of SDN network can be calculated by the following formula:

$$Time = link\ down\ discovery\ time + topology\ update\ time + SPF\ execute\ time + flow\ table\ update\ time \quad (2)$$

Formula 2 shows that the key factors of the routing convergence time include the topology update time, the SPF execution time and the flow table update time. Typically, the controller will use the high-speed link connecting switches, so the performance of the controller has become a key factor of routing convergence time in SDN network, and the link delay of network link has little effect.

III. EXPERIMENT DESIGN

A. Experiment Settings

In the experiment, we chose Floodlight as the controller of SDN network. We use Mininet as the simulation platform to compare and analyze the routing convergence time of legacy network and SDN network. Mininet is a unique open-source network simulator which creates a network of virtual hosts, switches, controllers, and links. Mininet hosts run standard Linux network software, and its switches support OpenFlow for highly flexible custom routing and Software Defined Networking. However, Mininet will not simulate a legacy IP network composed of hosts, switches, and routers without modification.

In order to complete the performance analysis experiments of legacy OSPF algorithm in Mininet, we used a Mininet based extended application – Mininext [6]. Currently, Mininext only support Mininet 2.1 and the function is imperfect. For example, the experiment needs to set the bandwidth of the link as well as the delay and packet loss rate, while the API provided by Mininet cannot receive two interface parameters. We modified the code of the TCLink class in Mininet, so that Mininext can simultaneously define the interface parameters at both ends of the link.

The routing engine running in Mininext is Quagga [13]. Quagga is a routing software suite, providing implementations of OSPF, RIP, RIPng and BGP for Linux platforms. Using Quagga, we can run OSPF algorithm on the virtual host in Mininet, thus simulating the legacy network.

B. Experimental Topologies

In the simulation, we first use Mininet to create the network topology, then carry on the experiments of legacy network and SDN network.

There are two experimental topologies, which contain 16 nodes and 120 nodes. In the simulation of legacy network, the node is the router. We individually configure each router, and make all the routers run in area 0. In the simulation of SDN network, the network node is the Open vSwitch. All switches are directly connected with the Floodlight controller. Two topology diagram are shown below.

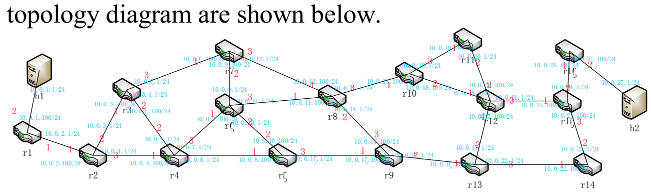

Figure 3. 16 nodes topology.

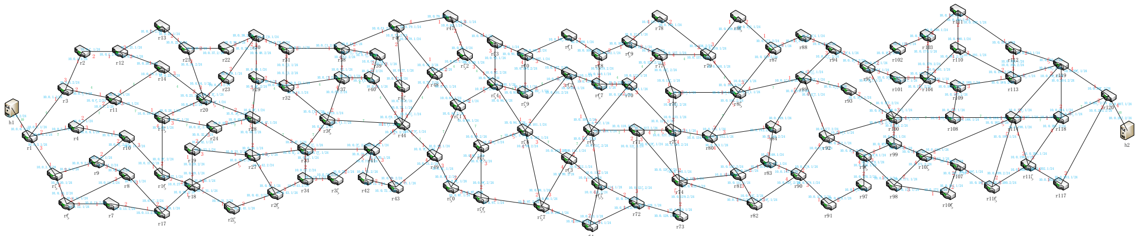

Figure 4. 120 nodes topology.

C. *Experimental Scheme*

This paper compares the forwarding speed of the network nodes, analyzes the changes of routing convergence time under different network scale or different link delay.

1) Node Forwarding Speed: First, we statistics the response time of Ping command between the two hosts in network, and use the response time to analyze the forwarding speed of network node. In a legacy network, the response time is mainly composed of link delay, routing table query time and packet forwarding time; and in SDN network, the response time is mainly composed of link delay, flow table matching time and packet forwarding time. Because in router and Open vSwitch, the realization mechanism of routing/flow table as well as packet forwarding mechanism are different, so the forwarding speed of nodes is different in different scale networks.

2) Routing Convergence Time: This experiment uses the httping [14] tool to test the routing convergence time. When two hosts in the network established a stable httping communication, we use Link Down command to simulate a certain link down from the network and test the recovery time of the two hosts from the communication interrupt to establish stable communication again. Because the OSPF algorithm in Quagga uses the load balancing mechanism, when two hosts resume stable communication, the route state of the whole network can be deduced to converge. The routing convergence work in SDN network is completed by controller. When the two hosts resume stable communication, the whole network routing has been convergent. So the communication recovery time is approximately equal to the routing convergence time of the network.

3) Routing Convergence Time under Different Link Delay: Considering the link delay has a great effect on the routing convergence time of the legacy network, we compare the effect of different link delay on the routing convergence time under the same network topology in this experiment. In this experiment, the link delay is set to 2ms, 16ms, 26ms, while other parameters are the same as the second experiment.

IV. SIMULATION RESULTS AND ANALYSIS

TABLE I. EXPERIMENTAL ENVIRONMENT CONFIGURATION.

VMware	Operating System	CPU	Hard Disk	RAM	Mininet	Floodlight
11.1.0	Ubuntu 14.04	Quad core	20G	6G	2.1	0.91

The experiment of this paper is finished in the vmware workstation virtual machine. The experimental environment is shown in Table I.

A. *Comparing the Forwarding Speed of Nodes under Different Network Scales*

In this experiment, we set the link bandwidth as 10Mbps, link delay as 2ms, and packet loss rate as 0, then test the response time of ping command between two hosts with a far distance distributed in the network. Fig. 5 shows the response time of 16 nodes topology and 120 nodes topology in legacy network and SDN network.

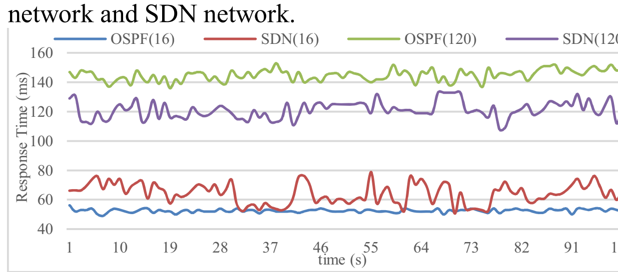

Figure 5. The response time of legacy network and SDN network.

Fig. 5 shows that in 16 nodes network topology, the response time of legacy network is less than SDN network, the legacy network has advantages in forwarding speed. But in 120 nodes network topology, the response time of legacy network is more than SDN network, the advantages of SDN network is obvious. In legacy network, after the routing table has been established, each packet must be queried and forwarded. With the expansion of network scale, the routing table scale of the router expands, resulting in the slow speed of query and forward. In SDN network, first the data packets received by the switch are forwarded to the controller, then the controller pushes flow entries to the switch, after that packets can be forwarded through query the flow table. In similar network topology, the scale of flow table in Open vSwitch is smaller than the scale of routing table in router, so the forwarding speed of Open vSwitch will be faster when the network scale is large. In addition, Quagga has optimized the OSPF algorithm to improve its performance, such as load balancing strategy. But the routing mechanism in SDN network is imperfect, it needs to optimize from many aspects.

B. *Comparing the Routing Convergence Time of Different Scale Networks*

This experiment set the link bandwidth as 10Mbps, link delay as 2ms, and packet loss rate as 0, then test the routing convergence time of two hosts from the communication interrupt to resume stable communication in the network. Fig. 6 shows the routing convergence time of 16 nodes topology and 120 nodes topology in legacy network and SDN network.

Fig.6 shows that with the expansion of network scale, the routing convergence time of network will increase, but the convergence time of legacy network is smaller than SDN network. This shows that when the link delay is 2ms, the routing convergence speed of legacy network is faster than SDN network. In SDN network, due to the controller needs to push flow entries after calculation of route, this operation will lead to slow routing convergence.

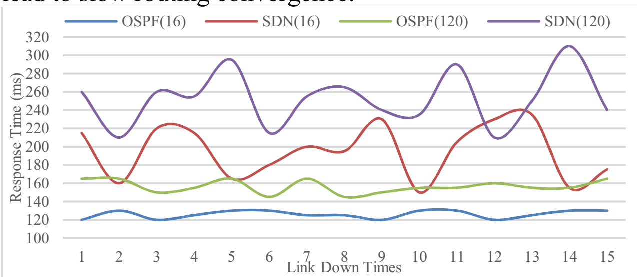

Figure 6. The routing convergence time of 16 nodes and 120 nodes.

C. *Comparing the Routing Convergence Time under Different Link Delay*

This experiment use the 120 nodes topology and set the link bandwidth as 10Mbps, packet loss rate as 0. We test the routing convergence time of two hosts from communication interrupt to resume stable communication when the link delay is set to 2ms, 16ms, and 26ms. Fig. 7 shows the routing convergence time of legacy network and SDN network under different link delay and different network scale.

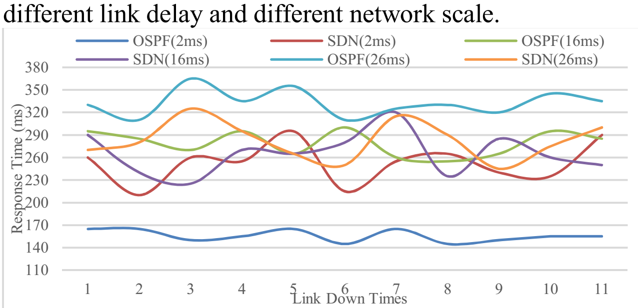

Figure 7. The routing convergence time under different link delay and different network scale.

We can see from Fig. 7 that in legacy network, when the link delay is increased from 2ms to 16ms, the routing convergence time of the network obviously increased. But in SDN network, when the link delay is increased from 2ms to 16ms, the routing convergence time of SDN network did not change significantly. This shows that the routing convergence time is less affected by the link delay in SDN network. When the link delay increases from 16ms to 26ms, the convergence time of legacy network continue to increase, while the SDN network still does not change a lot. This is because in legacy network, update packets of link state need to be transmitted to every router through the network links, so the convergence time is greatly affected by the link delay. However, in SDN network, the routing convergence work is done by the controller, and the network topology update message do not need to transmit in the network, so the convergence time is less affected by the link delay. This shows that the routing convergence speed of legacy network is faster when the link delay is small. But if the link delay is large, SDN network has a greater advantage in routing convergence time.

V. CONCLUSIONS AND FUTURE WORK

In the paper, we learned that, when the network scale is small, the packet forwarding speed in legacy network is faster than SDN network. But when the network scale is large, the advantages of SDN network gradually showed, and its forwarding speed is faster than legacy network. This shows that the query time of routing table or the matching time of flow table have a great impact on the forwarding speed of node. The advantage of SDN network is that its switch do not need to maintain the entire network topology information, thereby improving the forwarding speed.

The routing convergence time of legacy network is greatly influenced by the link delay. When the link delay of network is small, the distributed routing mechanism of legacy network has advantages, and can complete the routing re-convergence quickly. The centralized routing mechanism of SDN network is better when the network link delay is large. Because the SDN network does not need to transmit network information between switches, the link delay has little effect and the routing convergence time is relatively fast stable.

In future research, we will analyze the routing convergence mechanism of these two types of network from the aspects of routing/flow table scale, other routing protocols, number of convergence messages in more details.

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