A Survey of Network Measurement in Software-Defined Networking

Lu Wang¹, a), Yan Lu²

¹ Qilu University of Technology (Shandong Academy of Sciences), Shandong Computer Science Center (National Supercomputer Center in Jinan), Shandong Provincial Key Laboratory of Computer Networks Jinan, China
² Shandong Transport Vocational College Taian, China

a) wanglu@sdas.org

Abstract. The huge size of network and diversified business characteristics make network traffic difficult to predict and manage. Network measurement is an effective way which can ensure QoS (Quality of Service) and network optimization. However, due to the differences in the implementation rules of equipment (such as switches, routers etc.), it is difficult to achieve accurate and timely network measurement in traditional networks. Recently emerging software defined network (SDN) separates the network control plane from the data forwarding plane and manages the whole network through the centralized controller platform which improves the efficiency of the network management. The new network model adopting unified south bound(SB) interface protocols (OpenFlow is the commonly SB protocols) to access network equipment which shields the different implementation details of the underlying network equipment. The SDN solves the problems that the heterogeneous devices statistical information which is difficult to obtain and greatly simplifies the complexity of network measurement. On the basis of extensive research, this paper introduces the network measurement methods commonly used in Sandwich including sampling method, link latency measurement and link packet loss measurement method. We believe that the network measurement technology in SDN will greatly optimize the performance and accuracy of network measurement and can provide better guarantee for network quality.

Key words: SDN; QoS; SB; network optimization.; control plane; interface protocols; centralized controller.

INTRODUCTION

With the swelling of the network scale and the emergence of a variety of applications, as an important part of the social infrastructure, the network architecture has more complexity [1]. There huge size and complexity of network have created some troubles. First, the network operators are unable to timely and accurately get network status information’s and emergencies. Second, it is difficult to obtain different granularity of measurement information based on application types. Last, the network managers cannot effectively improve network utilization. Therefore, network measurement has become a crucial task, which can ensure Quality of Service(QoS) and optimize the network. Now, the commonly measurement method can have divided into two categories, one is active method, the other is passive method. The active method injects detection packets into the network and monitor the network characteristics by calculating and observing the behavior of packets. The passive method attaches the dedicated devices on network and analyze the network by the data captured by these equipment’s. In the traditional network architecture, there are various vendor's equipment’s, and each vendor's equipment adopts its own proprietary protocol, it is impossible to obtain the state data of the device through uniform interfaces. This makes the management of large-scale heterogeneous network difficult to realize. So, both the active and passive methods are difficult to monitor and measure the network under the traditional network.

Recently emerging Software-Defined Network (SDN) separates the network control plane from the data forwarding plane and manages the whole network through the centralized controller platform which can collect statistics from the network elements by using SouthBound(SB) protocols. The southbound(SB) protocols shield the
different implementation details of the underlying network equipment and provide a unified interface to access these 
devices. Currently, the OpenFlow [2] protocol is the most commonly used protocol for the southBound interface, 
which has become the standard of the SouthBound protocol. The SDN and openflow solve the problems that the 
heterogeneous devices statistical information which is difficult to obtain and greatly simplifies the complexity of 
network measurement. Furthermore, network measurement in SDN can be used to obtain several characteristics that 
cannot be measured in traditional large networks by a direct, non-intrusive and flexible ways. In this paper, we present 
a survey of monitoring in Software-Defined networks.

TYPICAL SDN ARCHITECTURE AND OPENFLOW PROTOCOLS

In 2008, professor McKeown of Stanford published the results of research on OpenFlow in ACM SIGCOMM, 
which is a top international conference. Based on the programmable characteristics of OpenFlow, professor McKeown 
further proposed the concept of Software Defined Network (SDN). In 2011, the Open Network Foundation(ONF), an 
international organization, was established to focus on the standardization and commercialization of SDN. ONF 
proposes a three-layer SDN architecture [3], as shown in figure 1, which is divided into three levels: the infrastructure 
layer, the control layer and the application layer. The infrastructure layer represents the underlying forwarding device 
of the network, which support the OpenFlow protocol; The control layer include OpenFlow controller and network 
operating system, it focus on the maintenance of the network status, getting the infrastructure information’s through 
Southbound protocols and provide scalable northbound interface to the application layer.; The application layer is 
composed of applications and provides corresponding control algorithms for specific applications (such as load 
balancing, etc.),In terms of current influence, the three-tier SDN architecture proposed by ONF is more widely 
concerned.

The most important protocol in the SDN architecture is the southbound protocol, which is responsible for the 
information exchange between the controller and the devices. One of the most popular southbound protocol standards 
is Openflow. The openflow protocol is first proposed by Stanford. The reference implementation of the OpenFlow 
includes three main parts, controller, openflow switch, and OpenFlow message.

openflow switch: Includes flow tables and dedicated channels. A dedicated channel is used to establish secure 
connections, exchange commands and transmit packets between openflow switches and controller. A flow table is a 
collection of table entries which contains a number of matching fields and an action on packets. There are three typical 
operations, forwarding packets to a specific port, encapsulating packets to the controller and dropping packets.

controller: A controller is usually a software module that be used to manage multiple openflow switches. The 
controller can push, delete and update flow entries on the switch by using openflow protocols.

openflow messages: The openflow protocol defines three types of messages, which are controller to switch 
message, asynchronous messages, and symmetric messages.

The interaction between the openflow switch and the controller is shown as the figure below:
Initially, the openflow switch is connected to the controller via port 6633/6653. The controller acquires the state of the switch by the Echo message and obtains the capability of the devices through the feature message. In switch, the flow table is empty. The table can be modified by the incoming packet. When a new packet arrives, if there is no matching flow entry, the packet is encapsulated in a packet-out message and forwarded to the controller. By analyzing the global topology, the controller obtains the data path of the packet and push the flow entry into the underlying switch. With continuous additions, deletions, and updates operations, the flow table items in the openflow switch are constantly changing, thus the forwarding of packets is achieved. Openflow and SDN allow network measurement to quickly and flexibly get the statistics of the openflow switch by an unified interface, so they brings a new opportunities for network monitoring.

NETWORK MEASUREMENT IN SDN

Sampling method, link latency measurement and link loss measurement are three important research issues in network monitoring and measurement. We will discuss these three aspects of the research work.

Sampling Method

The commonly used sampling methods are periodical sampling and adaptive sampling. The former adopts fixed time as the sampling interval, such as [4], which cannot deal with the sensitive changes of the flow. Moreover, when the flow is relatively stable, this method will produce a higher overload. By adjusting the sampling interval time through comparing the differences of some network indexes, the latter can effectively improve the accuracy of sampling and reduce the load of the monitoring, which has become the emphasis in current research. Pangwei Tsai et al. [5] presents a method of polling frequency adjustment based on grouping. First, the system divides some groups which have difference sampling interval. Then each active flow is assigned to these groups. Every group is given a timer to trigger the polling operation. When a round of polling operation is completed, the group of different flow is dynamically adjusted by comparing the change in flow with a specific threshold. This realizes the adjustment of different flow monitoring frequency. The experiments show that this method can effectively balance efficiency and accuracy. He Qiang and Shengbao Wang [6] proposes a method of sampling frequency adjustment based on flow rate. The core idea of this method is: the more the traffic varies, the smaller the polling interval is. Firstly, the low-pass filter function was defined, and then the function was optimized by using proportional linear prediction (PLP) with weighted linear prediction (WLP) method. Finally, the changes of flow rate were obtained. After obtaining the flow rate, the paper achieves the adjustment of sampling frequency of three different situations by comparing the change of flow rate with the pre-setted threshold. An adaptive sampling interval adjustment method based on throughput is proposed in [4]. The method first calculates the changes of throughput in two sampling intervals. It will increase the sampling interval when the throughput change value less than $\alpha \times prev_{throughput}$ ($\alpha$ is a adjustment constant). It will reduce the sampling interval when the throughput change value greater than $\beta \times prev_{throughput}$ ($\beta$ is a adjustment constant). When fluctuation does not belong to above two situations, it will increase the small sampling interval. For the sampling method, the exciting method mainly adjusts the sampling time by the fluctuation of a specific network characteristic.
**Link Latency**

Phenius and Bouet [7] propose a latency measurement method. The solution uses four types of OpenFlow messages: `STATISTICS_REQUEST`, `STATISTICS_REPLY`, `PACKET_OUT`, and `PACKET_IN`. The method first creates a basic Ethernet frame using the broadcast address as a destination and the hardware address of the port which will be used to send the packet as a source. The controller sends this packet to S1 by using the `PACKET_OUT` message, when S1 forwards the packet to S2, S2 will not find an entry about this packet, then S2 sends the packet back to the controller by the `PACKET_IN` message. The controller then retrieves the packet and calculates the total time for this process by using the received time and the packet's Time-stamp. Furthermore, the method can get the Round-Trip Time (RTT) between the controller to S1 and controller to S2 through the `STATISTICS_REQUEST` and `STATISTICS_REPLY` messages. Now, we get three variables: $T_{total}$, $T_{s1}$, $T_{s2}$, then the link latency can be estimated as follows:

$$Latency(S1, S2) = T_{total} - \frac{T_{s1}}{2} - \frac{T_{s2}}{2} - C$$

The variable $C$ in the equation corresponds to the calibration value of the controller. This is the most commonly used method in link delay measurement. Most measurements are based on this method.

**Link Packet Loss**

Adrichem and Doerr [8] introduce the OpenNetMon, a tool to monitor network metrics, especially packet loss in software-defined networks. OpenNetMon calculates the packet loss rate of the link by polling the flow statistics of the source switch and the target switch. The packet loss rate is calculated by calculating the difference between the number of bytes sent by the source node and the number of bytes received by the target node. Santos [9] introduces a similar packet loss measurement approach for individual links and discussed the cost of measuring the packet loss of a path based on an individual link loss measurement. Chunyan and Wolfgang [10] realize low load and automated packet loss detection by extending the OpenFlow protocol. EPLE defines the microflow identifier and measurement strategy associated with the microflow in the controller. When ingress switches identify the microflow according to the policies delegated by the controller, it will inform the controller to select the monitor path. The controller then installs the same microflow descriptors on all the other switches in the measurement path. When the microflow in the path expires, the flow statistics are reported to the controller, and the controller can obtain the packet loss by calculating the difference of the flow in the interval. All the above methods measure the loss rate of one-way links. Xinchang [11] proposes a method to measure two-way link packet loss based on graph theory. The method first divides the network topology into several connected subgraphs, and then homogenizes the connected subgraph which makes the size of the subgraph similar. When the subgraph is homogenized, the symmetric two-way link of the subgraph is obtained by using the Euler circuit method. For the two-way link, the previous flow statistics method is used to calculate the link loss.
CONCLUSION

In this paper, we review the main architecture of SDN, and introduce the network measurement techniques in SDN, including sampling method, link latency measurement and the link packet loss monitoring in SDN. In SDN, the controller has a global view, and can obtain the switch statistical informations flexibly through the unified Southbound interface protocols. Therefore, we believe that the monitoring techniques in SDN has better potential performance than that in traditional network.

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