DYNAMIC SHAPING METHOD USING SDN AND NFV PARADIGMS

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ABSTRACT

Traffic shaping controls communication traffic flow to prevent a specified communication rate from being exceeded. In conventional networks, the traffic shaping device is implemented at a predetermined location and only a communication flow passing through the device is targeted. If the traffic can be shaped dynamically on any selected communication flows at the optimal point only when necessary, it could use network bandwidths and packet relay processing capacity more efficiently and flexibly.

This paper proposes a dynamic shaping method using Software-Defined Networking (SDN) and Network Functions Virtualization (NFV) paradigms, which selects the optimal communication flows to be shaped, and the optimal shaping points dynamically. This paper also presented system configuration and functions for the proposed dynamic shaping, and the method to simplify the process of collecting the traffic data of each communication flow by SDN controller.

KEYWORDS

Traffic shaping, SDN, NFV.

1. INTRODUCTION

Traffic shaping (hereafter "shaping") is a form of bandwidth control. It controls communication traffic flow to prevent a specified communication rate from being exceeded. Any data that exceed the specified rate are stored in the communication device concerned and sent when the link concerned has spare capacity. It smooths a burst packet flow to produce a packet flow that is within the specified rate. The most common conventional way of shaping is to place-shaping devices in advance at predetermined points. These devices smooth out traffic according to a control policy specified for each application type or traffic type [1]-[3]. In most cases, traffic shaping is implemented in each network and only at points where there is regular traffic congestion, and only a communication flow passing through the device is targeted. Therefore, it has been difficult to apply shaping dynamically when and where it is necessary. If traffic can be shaped dynamically on any selected communication flows at optimal points only when necessary, it will be possible to use network bandwidths and packet relay processing capacity more efficiently.

This paper proposes a dynamic shaping method using Software Defined Networking (SDN) [11][12] and Network Functions Virtualization (NFV) [13]-[16] paradigms, which selects the optimal communication flows to be shaped and the optimal shaping points dynamically. This

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could make network resources much more economically available than conventional networks. The rest of this paper is organized as follows. Section 2 explains related works. Section 3 proposes a dynamic shaping method using SDN and NFV paradigms, which selects the optimal communication flows to be shaped and the optimal shaping points dynamically. Section 4 presents a system configuration for automating the proposed dynamic shaping. Section 5 confirms the operation of the proposed dynamic shaping with the evaluation system. Section 6 proposes the method to simplify the process of collecting the traffic data of each communication flow by the SDN controller, which is the key function for the proposed shaping method. Finally, Section 7 presents the conclusions. This paper is an extension of the study in Reference [19].

2. RELATED WORK

Reference [5] presents a comprehensive survey on the ON/OFF traffic shaping in the current Internet and summarizes the impacts of ON/OFF traffic on packet drop probability, real-time applications, and its interaction with TCP's congestion control mechanism. Reference [6] overviews the features of Asynchronous Traffic Shaping (ATS) discussed in IEEE. Reference [7] proposes algorithms that allow flattening the utilization profile of network resources by optimizing network resources. Reference [8] proposes a QoE-aware traffic shaping method that is based on two QoE maximization metrics. A key benefit of this approach is that it calculates the optimal shaping rate to help clients to adjust its request for the subsequent segment quality level. Reference [9] compares the effect of traffic shaping and traffic policing on aggregate traffic dynamics especially stochastic properties on traffic time series. Reference [10] proposes a framework of traffic shaping in which the shaping filters are designed to interwork with statistical multiplexers that use FIFO buffers. Reference [4] explores a software-controlled architecture to implement a hierarchical control and management framework for QoS provisioning at network cores and proposes an optimization followed by a two-dimensional queue management policy, called Hierarchical Two Dimension Queuing (H2DQ).

In most of the above studies, traffic shaping is implemented in each network only at points where there is regular traffic congestion and the pre-deployed traffic shaper device, and only a communication flow passing through the device is targeted. Therefore, it has been difficult to apply shaping dynamically when and where it is necessary. For example, if a receiving link between network C and the terminal at the receiving side in Figure 1 is congested, the shaping has been implemented at the receiving side of Network C as Figure 1<1>. The bandwidth and the packet relay processing capacity of the networks A, B, and C related to the communication flow will be wasted.

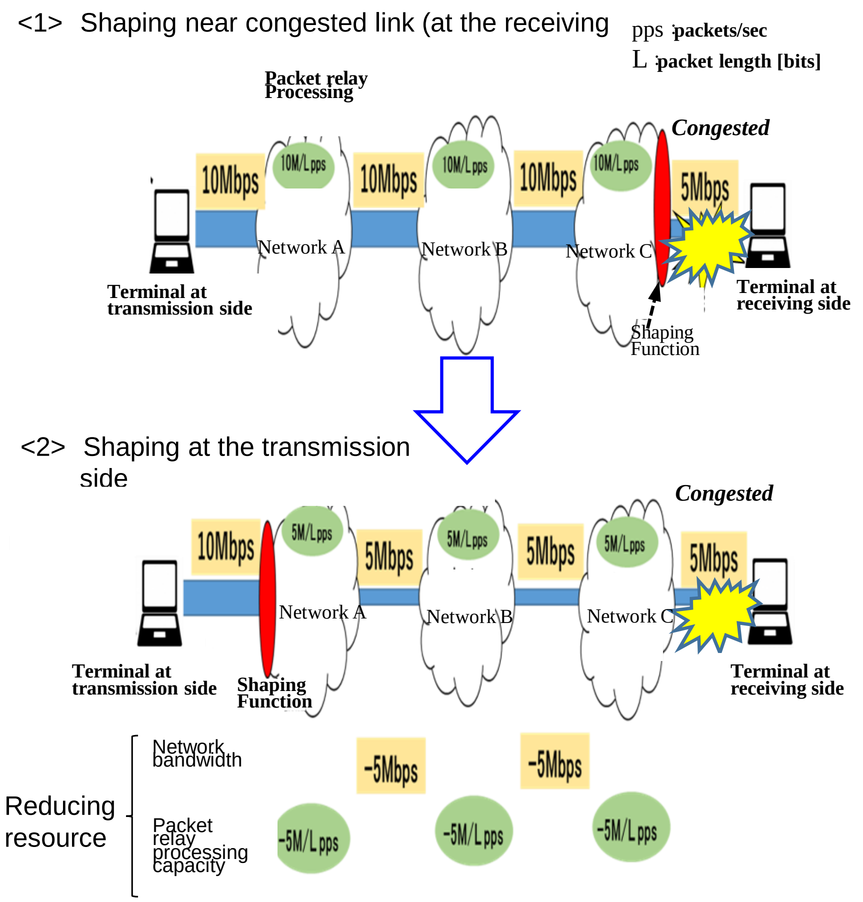


Figure 1. Example of network cost reduction effect by shaping location

3. Proposed Dynamic Traffic Shaping Method

3.1. Overview of Dynamic Traffic Shaping Method

The proposed dynamic shaping method is implemented with SDN- and NFV-based networks. It does not need to place-shaping functions at predetermined points in advance, as is the case conventionally. Instead, it detects the link congestion and dynamically selects communication flows to be shaped and the shaping points that are both optimal for resolving the congestion. It also places virtual shaping functions at the selected points and makes the selected communication flows pass through these points.

In the example of Figure 1, the shaping will be performed at the transmission side as in Figure 1 <2>. This can avoid wasteful use of network bandwidth and packet relay processing capacity, and consequently, can reduce the network cost.

Conventionally, it has been common to shape traffic not only for each link, but also for each application type and for each traffic type. If the shaping is to be applied to each application type in the conventional method, for example, the one that results in the greatest reduction in wasteful use of network bandwidth and packet relay processing capacity is selected. This paper discusses cases where traffic is shaped for each link but the same discussion applies to cases where traffic is shaped for each application type or for each traffic type.

If the dynamic traffic shaping is to be implemented in a conventional network, it would be necessary to introduce a system dedicated to measuring the traffic of each communication flow. If the traffic is shaped at optimal points, it would be necessary to place-shaping functions economically at all the points where communication flows pass through. However, the implementation of the above-mentioned functions is not economical. This paper proposes to take advantage of the features of the SDN and NFV, as shown in Figure 2. Specifically, SDN features make it possible as a basic function to measure the traffic data of each communication flow. Since the SDN controller keeps track of the route of each communication flow as a basic function, it is also possible to specify the route of each communication flow and perform shaping at an appropriate point. In addition, NFV features make it possible to place a shaping function of any capacity (even with a small capacity) at any point more economically than before. Additionally, by automating the dynamic shaping method, shaping can be performed quickly and maintenance operations can be significantly reduced.

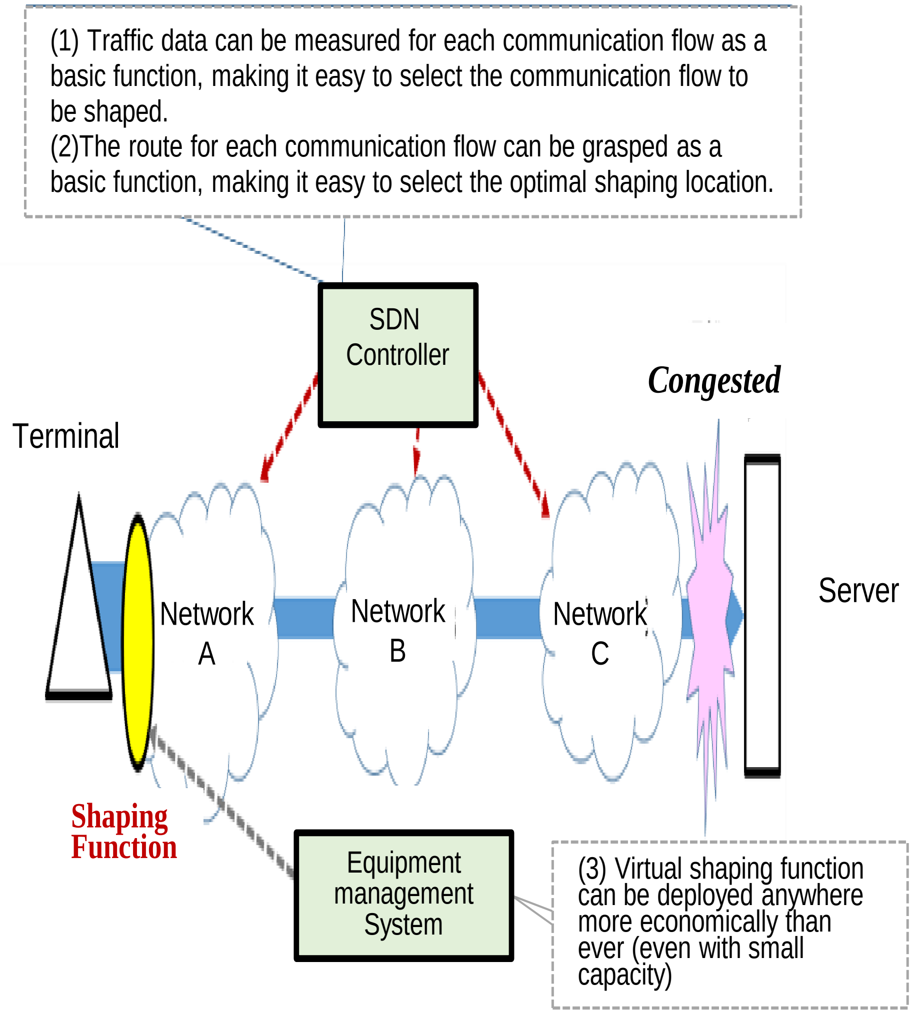


Figure 2. Features of SDN and NFV suitable for the proposed dynamic shaping

3.2. Issues in Implementing The Proposed Dynamic Shaping Method

1) Trigger for shaping

It is assumed in this paper that a link is congested and shaping is executed if the link's average usage rate exceeds Pmax (e.g., 0.7). This also could apply to cases where shaping is executed for each application type or for each traffic type, as mentioned in Section 3.1.

2) Selection of shaping points

Shaping at a point near the transmission side can reduce more network bandwidth and packet relay processing capacity than shaping at the congested point. Therefore, it is proposed to create a virtual shaping function with NFV features dynamically at a point near the transmission side when necessary, and the SDN controller changes the route so that the communications flow to be shaped will pass through that point.

3) Selection of the communication flow to be shaped

It is not efficient to shape all the communication flows that pass through the congested link. It is proposed to select the communication flow to be shaped as follows:

<Step 1> Among all the communication flows that pass through a link that is congested and requires traffic shaping, up to N (e.g., 10) fastest communication flows are selected as candidates for shaping.

<Step 2> As stated in 2), shaping at the transmission side can reduce the network bandwidth by L*V, where L is the link length between the transmission side and the congested link, and V is communication speed. As it is not easy to estimate the link length, it is proposed to use the number of hops (H), instead. The term x1 calculated by (1) is the reduced network bandwidth:

$$x1 = \text{communication speed (V)} \times \text{number of hops (H)} \quad (1)$$

Similarly, x2 calculated by (2) is the reduced number of packets to be relayed:

$$x2 = \text{communication speed (V)} \times \text{number of hops (H)} / \text{packet length (P)} \quad (2)$$

Here, the packet length P is considered for the following reason. That is, even at the same communication speed, the shorter the packet length, the larger the number of packets to be relayed.

Finally, the communication flow with the largest x3 value calculated by (3) is selected to be shaped:

$$x3 = x1 * Cb + x2 * Cp \quad (3)$$

where Cb and Cp are cost-coefficients which are used to calculate the cost of two different units at the same level.

For example, Flow b in Figure 3 is subject to shaping as it has the largest x3value.

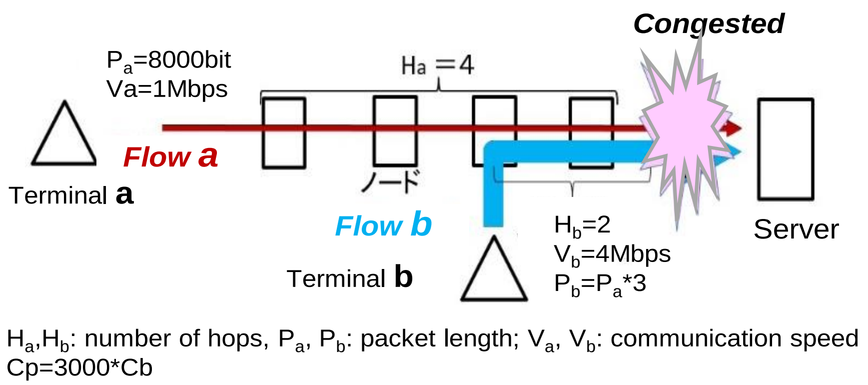


Figure 3. Example of selection of communication flow to be shaped

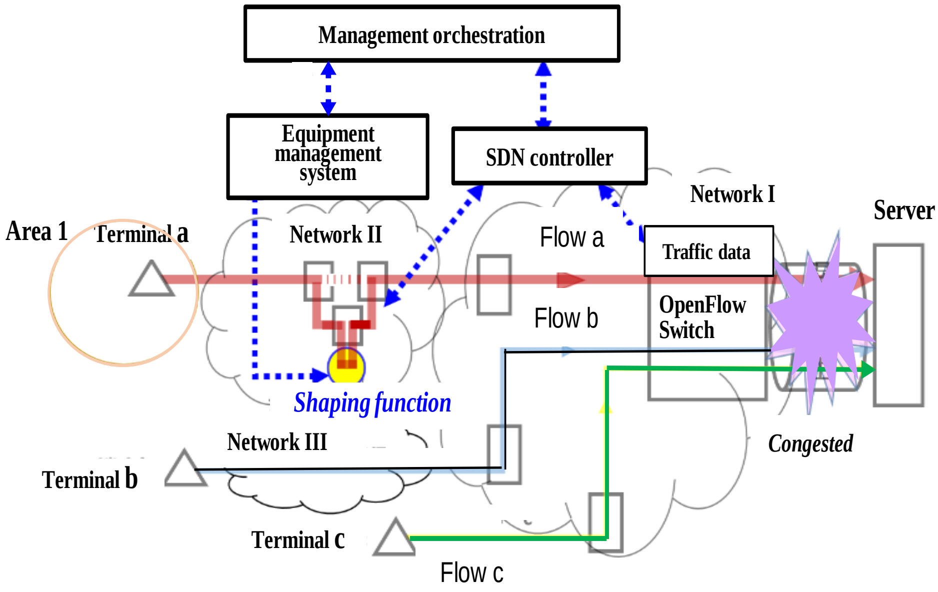
4) Determination of shaping rate

It is desirable that the shaping rate that will resolve the congestion is selected. However, to guarantee a certain degree of quality of service, it is reasonable to limit the shaping rate so that the communication rate after shaping does not go below half of the original communication rate of each flow. If the congestion cannot be resolved by shaping the first flow with the largest x3 value, the flow with the next largest x3 value will be subject to shaping. This is continued until the congestion is resolved.

4. System Configuration and Functions for the Proposed Dynamic Shaping

To execute the proposed dynamic shaping automatically, 'the management orchestration' is introduced in addition to the existing SDN controller and the equipment management system, which tries to minimize further additions to the existing system. The configuration of the system is illustrated in Figure 4. Terminals a, b and c communicate with the server individually. Their respective communication flows are called Flows a, b, and c. In this example, the link from the OpenFlow switch to the server is congested.

The management orchestration manages and executes the control scenario for dynamic shaping. Specifically, it observes the entire situation and executes the necessary processes. When it detects a congested link, the management orchestration instructs the SDN controller to collect data on the communication rate, the number of hops, and packet length for communication flows that pass through the congested link. The SDN controller gets these items of data from the OpenFlow Switch. However, if data on a large number of communication flows are to be collected, the performance of both the OpenFlow Switch and



**OpenFlow protocol applied between OpenFlow controller and switch is required to be modified for the proposed system.*

Figure 4. Proposed system configuration that automates dynamic shaping

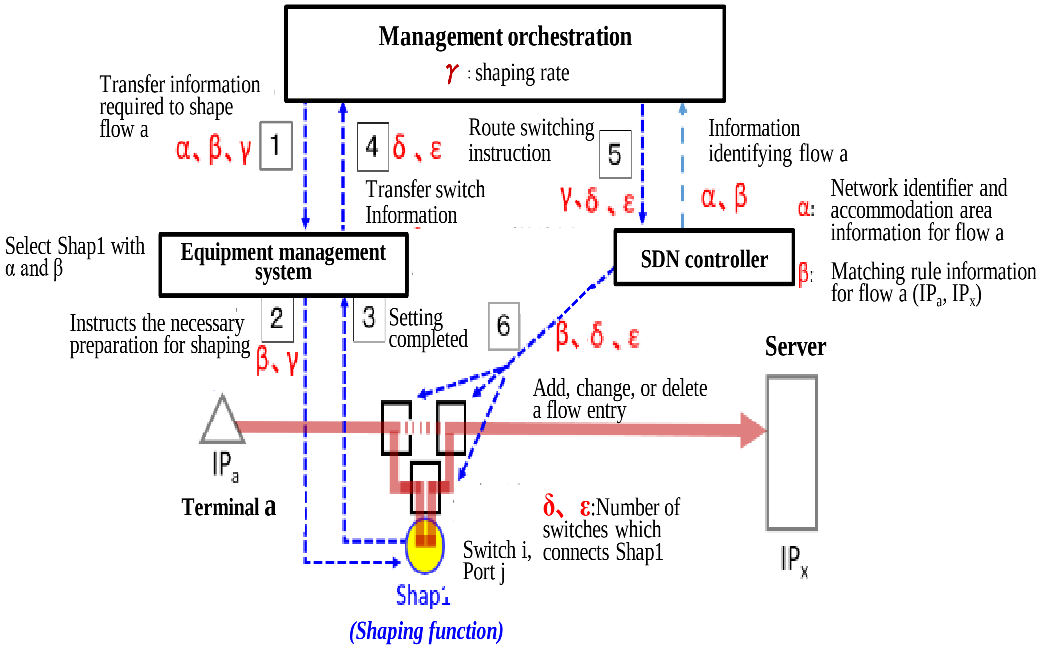


Figure 5. Cooperation method from selection of shaping function to route switching

the SDN controller degrades dramatically. To avoid this, the OpenFlow Switch monitors the traffic counter of each communication flow and notifies the SDN controller, in advance, of the communication flows whose traffic counters exceed a certain threshold. The SDN controller requests the OpenFlow Switch to send traffic data of only these communication flows.

Since the SDN controller knows the route in the network of each flow in advance, it sends the numbers of hops of these communication flows to the management orchestration. Based on the collected data, the management orchestration instructs the equipment management system to set the shaping control parameter and to provide information about the positions of shaping functions. It also instructs the SDN controller to change the route (route switching) so that the communication flows subject to shaping will pass through the specified shaping functions. The main functions that the management orchestration should have, as stated above, are summarized in Table 1.

The cooperation method from the selection of shaping function to route switching is illustrated in Figure 5, in which the number enclosed in squares indicates the process number.

- Process 1: The management orchestration instructs the equipment management system to select the optimal shaping points and to set shaping control parameters. It specifies the identifier of the network to which shaping is applied and information about the area, (α), where the terminal concerned is located, information about the matching rule [2], (β), of Flow a, which is subject to shaping, and the shaping rate (γ).

- Process 2: The equipment management system selects the optimal shaping point (Shap1 in this example) based on α, β, and the usage status of the shaping points.

- Process 3: After setting the shaping control parameters, the shaping function of the shaping point notifies the equipment management system of the completion of the parameter setting.

- Process 4: The equipment management system transfers the switch number (δ) of the switch to which the selected shaping point is connected and the switch port number (ε) to the management orchestration.

- Process 5: The management orchestration notifies the SDN controller of γ, δ, and ε, and instructs it to change the route so that Flow a will pass through the selected shaping point.

- Process 6: The SDN controller rewrites the flow entry of the OpenFlow switch concerned based on δ and ε to change the route so that Flow a will pass through the shaping point. When shaping becomes no longer necessary, an instruction of the reverse operations is issued.

TABLE 1. MAIN FUNCTIONS OF MANAGEMENT ORCHESTRATION

- Summarize the flow of processing and controls other functions. Check the progress of each function and manage the processing order.
- Collect line usage rate
- Collect communication speed for each flow
- Collect hop count for each flow
- Select shaping target flow
  **Select the largest x3 value*
- Determine shaping data for shaping target flow
- Decide shaping function (or create by NFV)
- Set shaping function parameter
- Route switching
- Link with SDN controller
- Link with equipment management system

5. CONFIRMATION OF THE OPERATION OF THE PROPOSED DYNAMIC SHAPING

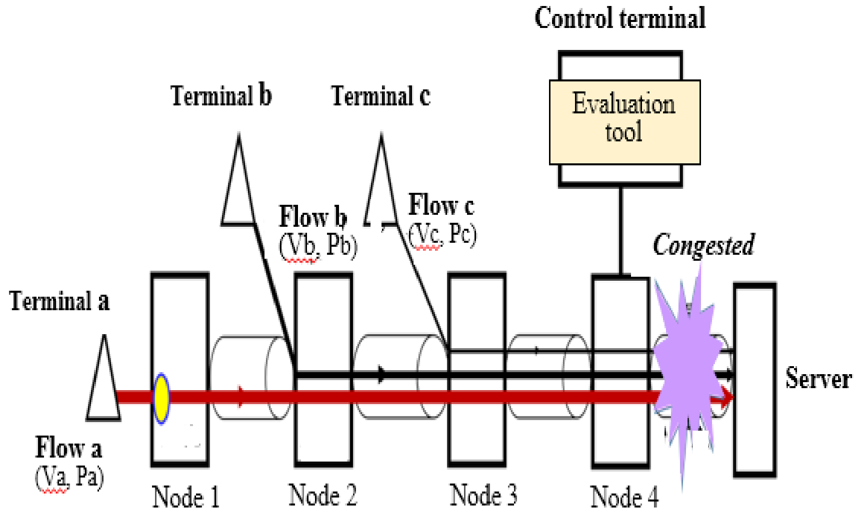
5.1. Design and Construction of an Evaluation System

Since the main aim of the evaluation is to confirm the operation of the management orchestration function, we implemented the SDN controller, the OpenFlow switch, and the equipment management system using substitute devices (Software router VyOS [17]). The evaluation tool (C#-based software program) was designed and constructed to implement the management orchestration functions proposed in Section 4. An example of the evaluation system is shown in Figure 6. It consisted of four VyOS nodes, three terminals, one control terminal, and one server. Terminals a, b, and c individually communicated with the server. It is assumed that the link from node 4 to the server will be congested. The shaping function was implemented using the VyOS function, not dedicated functions.

5.2. Results and Evaluation

The operation of the dynamic shaping was confirmed under the following conditions:
- Maximum bandwidth between Node 4 and the server: 20Mbps
- Pmax: 0.7; Va: 2Mbps, Vb: 7Mbps, Vc: 8Mbps
- Pa: 5000 bytes, Pb: 3000 bytes, Pc: 500 bytes; Cp = 3000 * Cb

As the ratio of x3 value of flow a, x3 value of flow b, and x3 value of flow c is 6.5 : 11.8: 9.3, flow b with the largest x3 value among three flows is selected as the communication flow to be shaped in this example. In order to eliminate congestion, it is necessary to reduce the total communication speed from 17 Mbps to 14 Mbps (=20Mbps*Pmax), and therefore the shaping rate of flow b will be 4Mbps. Figure 7 shows changes in the measured speed from Node 4 to the server. As had been expected, the speed of Flow b was reduced to 4 Mbps.



Terminal, server: Windows 10Pro (64-bit) laptop; Node: VyOS (1.1.4) desktop PC
Va,Vb,Vc: communication speed; Pa, Pb, Pc: packet length

Figure 6. Example of evaluation system

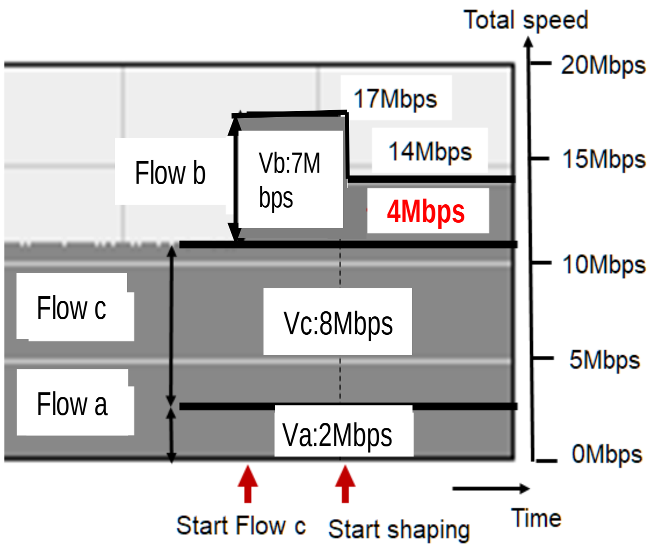


Figure 7. Measured speed from Node 4 to server in Figure 6

6. METHOD TO SIMPLIFY THE PROCESS OF COLLECTING THE TRAFFIC DATA OF EACH COMMUNICATION FLOW BY SDN CONTROLLER

6.1. Basic Concept and Overview

The dynamic shaping method proposed in Section 4 requires the SDN controller to continuously collect traffic data at regular intervals for each communication flow, which is the key function for the proposed dynamic shaping method. As a result, the load on the SDN controller becomes very large and the performance of the SDN controller degrades dramatically. To avoid this performance degradation, the following policies can be considered:

<Policy 1>Reduce the number of communication flows for speed measurement.

For example, one method is to measure the speed continuously only for the communication flow with a higher speed measured after the start of communication. Another method is that OpenFlow Switch notifies the SDN controller of the communication flow in which its traffic counter value is greater than a certain value in advance, and the SDN controller queries the OpenFlow switch for only the traffic data of the notified communication flows.

<Policy 2>Speed measurement for communication flows after when the congestion is detected

Instead of constantly monitoring the speed of all communication flows, the speed of communication flows passing through the congestion link is measured after the congestion is detected.

<Policy 3>Increase the speed measurement interval for each communication flow.

<Policy 4> Stop the traffic data inquiry processing itself at the SDN controller.

The switch side periodically collects traffic data of communication flows to be monitored and estimates the communication speed (no inquiry from the SDN controller). Then, only when the speed has increased or decreased significantly compared to the previous cycle, the speed change is reported to the SDN controller. This is similar to the trap function of Simple Network Management Protocol (SNMP) [18], and the SDN controller instructs the switch in advance of the communication flow to be monitored.

In this paper, we propose a method based on the approach of policy 4, in order not to reduce measurement accuracy.

6.2. Extension of Openflow Specification

To implement the method proposed in Section 6.1, the following extensions to OpenFlow specification [11] are required:

(1) Add the following new fields to the Meter Modification message.
-Communication flow ID to be monitored
-Communication speed measurement cycle
-Degree of changes in communication speed and the packet length (Z0s, Z0p)
* SDN controller is notified only when these are exceeded.
(2) In order to notify the SDN controller from the switch side, a “Report message” including the following fields is newly established.
-Communication flow ID
-Communication speed and packet length

6.3. Message Sequence of Proposed Method

Figure 8 shows an example of the message sequence of the proposed method based on Sections 6.1 and 6.2. A broken line indicates a message which is used in the conventional method but becomes unnecessary this time, and a dashed line indicates a message which is added this time.

1) The SDN controller sends the switch a Meter Modification message containing the fields described in Section 6.1.

2) Unlike the conventional method, periodic exchange of the Flow_Stats multipart Request message, which is a request for statistical information for each communication flow, and the Reply message, which is a response to the request, is unnecessary. If the number of monitored flows is F for N times until the communication speed is notified, F*N messages processing could be eliminated in the entire SDN controller, and the processing load is greatly reduced.

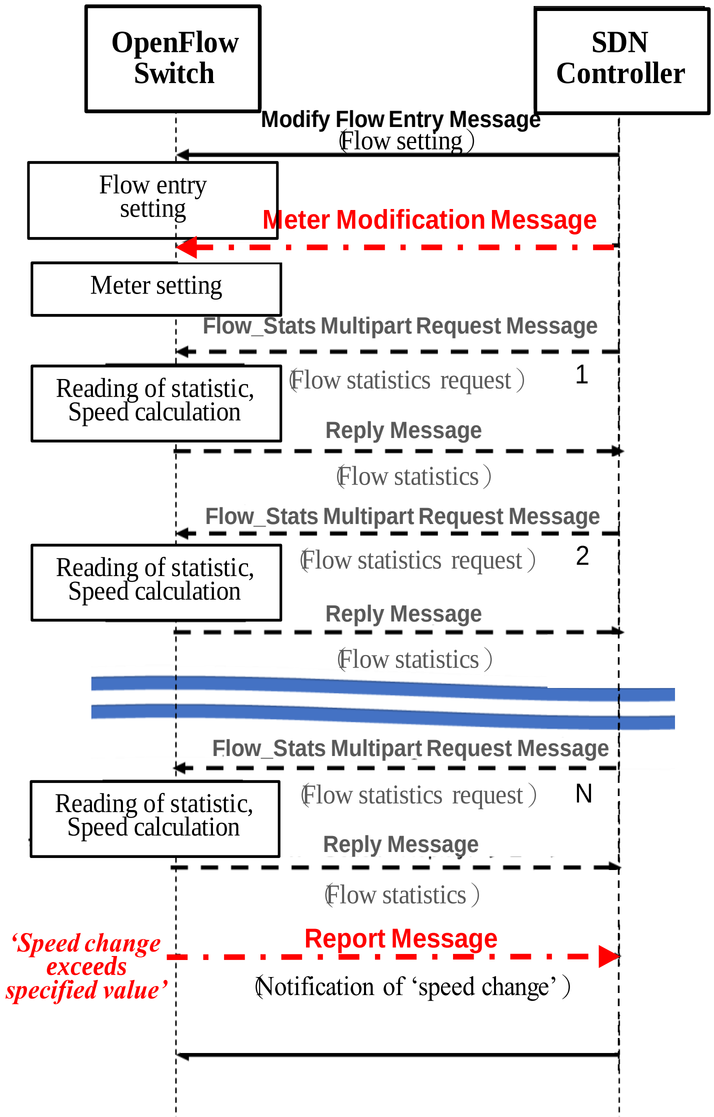


Figure 8. Message sequence of the proposed dynamic traffic shaping

7. CONCLUSIONS

This paper has proposed a dynamic shaping method using SDN and NFV paradigms. This method can select the optimal communication flows to be shaped and the optimal shaping points dynamically. This method can also avoid a many number of wasteful uses of network bandwidth and packet relay processing capacity as compared with the conventional method, and consequently, can significantly reduce the network cost. It has also presented a system configuration for automating the proposed dynamic shaping and the method to simplify the process of collecting the traffic data of each communication flow by SDN controller. The feasibility of the proposed method has been confirmed by an evaluation system.

It is required to evaluate the proposed dynamic shaping method experimentally in terms of resource utilization and stability comparing with the existing methods. It is also required to study how multiple SDN controllers and multiple equipment management systems collaborate.

CONFLICTS OF INTEREST

The author declares no conflict of interest.

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