Mass-User Satisfaction for NFV-Based Application Specific Network

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Summary

By virtue of advanced virtualization approaches such as network function virtualization (NFV) or software defined network (SDN), it has been recently possible to provide valuable network services dedicated to specific applications or users. In order to support those value-added services suitably, the network must be operated and managed according to not conventional per-flow-based QoS policy but service-oriented policy. This paper discusses typical application specific networks in terms of service-oriented metrics and then proposes mass-user satisfaction as one of application-oriented metrics. The proposed mass-user satisfaction can be transparently translated into physical resource management and can be optimized suitably according to service-oriented policy specific to applications or users. This advantageous feature is revealed through simulation results of a typical network configuration.

Key words:
Network function virtualization, Application specific network, Mass-user satisfaction, Virtual network management

1. Introduction

Recently, the more the communication devices, network applications, and user needs diversify, the more difficult it is to implement a network function or functionality by coupling it to a physical device or network tightly. Therefore, various virtualization approaches have been investigated, e.g., network function virtualization (NFV) and software defined network (SDN).

The NFV approach makes it possible to build, deploy, and operate network functions (NFs) virtually by decupling software from hardware, i.e., physical devices [1], [2]. Thus, network service providers can easily introduce new NFs without deploying additional physical devices. In order to introduce virtual network functions (VNFs) on an actual network, it is necessary to adopt an additional management mechanism such as the functionality provided by NFV Management and Network Orchestrator (NFV MANO). NFV MANO can also support various resource allocation functions to provide end-to-end services on the network [3]-[5].

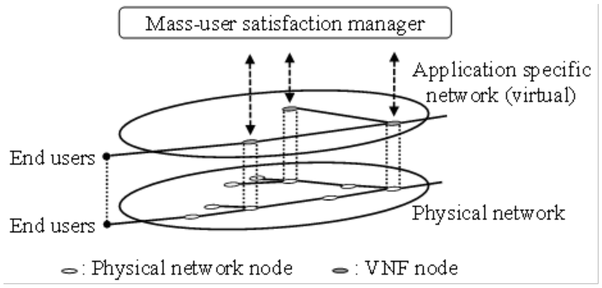

Fig. 1. An overview of NFV-based application specific network

SDN approaches [6], [7] enable us to virtualize the physical networks and to operate multiple virtual networks, called slices. There have been a lot of proposals to manage multiple slices on physical networks efficiently [8], [9]. Since SDN can harmonize with VNFs or an NFV MANO, every slice in SDN can be operated and managed flexibly by decoupling software from hardware, i.e., both physical devices and networks. Hence, it is prompt and flexible to provide valuable network services or applications to end users even if networking and computing resources environments are constrained.

In such an environment, network resources and costs should be utilized to improve valuableness or competitiveness of the network services as much as possible. That is, such virtualization approaches make it easy to provide application specific network services promptly. In this sense, conventional per-flow-based QoS policy is no longer crucial rather than application-oriented or provider-oriented management policy. In order to conduct the management of an application specific network, mass-user satisfaction is significant as a simple application-oriented metric for the network provider. In this paper, the NFV-based application specific network is defined as a network in which a network application is suitably classified and its classified packets are transferred according to the mass-user satisfaction, as shown in Fig. 1.

This paper discusses typical application specific networks in terms of service-oriented metrics and then proposes the mass-user satisfaction as one of application-oriented metrics. The proposed mass-user satisfaction can be transparently translated into physical resource management and can be optimized suitably according to the service-oriented policy specific to applications or users.

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This advantageous feature is revealed through simulation results of the typical network configuration in the paper.

2. Application Specific Networks

One of the most beneficial features in the NFV-based application specific networks is to build and operate various networks flexibly, even in temporal, compared with the conventional non-virtualized networks. Even if the requirements of the network alter eventually, the NFV-based network can be modified and operated adaptively. In addition, since the building effort and cost of the non-virtualized networks are generally higher than those of the NFV-based networks, the NFV-based networks can be built and operated with a cost-effective smaller scale.

This section discusses the following typical application specific networks and their characteristics.

i. Emergency network, e.g., disaster, terrorism-related incident.
ii. Massive event network, e.g., public viewing, exhibition.
iii. Service provider network, e.g., a mobile virtual network operator (MVNO), an application service provider (ASP).

In case of an emergency such as catastrophic disaster, there might be not enough network resource to meet various requirements of a large number of users. If a physical infrastructure is suddenly damaged, the users must share an access network such as a satellite internet access with heavier resource constraint. Even if the physical infrastructure has no damage, a specific network point such as an evacuation place will be temporally crowded with the user traffic.

In the management strategy for such networks, network resource should be preferentially allocated to users who collect essential information about present situations of utilities and distributed food. The users also want to keep in contact with a family, relatives, friends, and colleagues and might use some real-time network applications such as IP telephony. If the emergent situation changes with the time, the importance of the network applications might change along with users' requirements. In this case, the management strategy of the network must be adaptively applied according to the resource constraints with VNFs.

The massive-event network is a temporal network which has limited resources for the Internet connection. In addition, the network traffic depends on a time schedule of the event and the usage trends of time-dependent contents or applications. A flexible network function such as VNF is useful in the resource constrained network. Examples of such networks are temporal networks specialized for a public viewing, technical exhibitions, and technical conferences. In such networks, movies requiring high bandwidth are sometimes provided for attendees. For example, there are replay movies of impressive scenes in a public viewing and commercial movies of new products in a technical exhibition or conference. Many attendees may watch a movie at the same time once it is announced that the movie is available. This causes bursty traffic. Basically, capacity of a network constructed for an event is limited and traffic congestion occurs in such situation. Furthermore, satisfaction of the attendee depends on availability of real-time network application such as video streaming. Those features imply that the real-time application should be managed as not an essential one but a prior one.

Service provider network can be flexibly constructed by adopting the virtualization approaches such as NFV. A typical example network is a wireless access network of an MVNO, which is constructed virtually on a mobile access infrastructure of a mobile network operator (MNO). The MVNO provides an inexpensive internet connection service to customers. By managing network applications efficiently, the MVNO can reduce a usage cost of both a mobile access infrastructure and a transit network. As a result, the MVNO can provide moderate internet connection service as well as improve competitiveness by reducing the cost.

Due to the expensive extra charge of fixed rate service, a customer wants to offload his/her traffic onto a free wireless network. When the free wireless network is not available, the customer may not want to acquire a network resource more than necessary because the extra amount of packets beyond the upper limit results in expensive extra charge or low bandwidth regulation. Thus, the reputation of the MVNO is evaluated by total satisfaction of the customers, so that the management should be strategic and moderate on manageable network applications along with business model of the company.

Typical application specific networks discussed above require a management strategy according to physical resource constraints and characteristics of the networks. Under a resource limited environment, there may be a bottleneck that causes quality degradation of the network. In order to mitigate the bottleneck, a part of the network involving the bottleneck must be managed and operated appropriately, i.e., priority control and bandwidth allocation are performed because the managed network is congested due to overconcentration of flows of network applications. Based on the discussions in this section, the applications deployed in the NFV-based application specific network can be classified as summarized in Table 1. There are (a) essential application which must be accepted mandatorily, (b) manageable application whose priority is scaled along with the characteristics and resource constraints of the network, and (c) others that can be regarded as background traffic.

Table 1: Management strategy of network applications under resource constraints.

	resource constraint heavy <----> light
essential application	mandatory
manageable application	marginal <----> prior
others	marginal

A simple scenario is to introduce a service-oriented operation and management strategy only when the manageable application is marginal under heavy constraint, or when the manageable application is prior to others under light resource constraint.

3. Mass-User Satisfaction

In an application specific network, network applications are classified into three classes and managed by VNFs. Although a metric is required to conduct the management of network applications, not only conventional metrics used in per-flow-based QoS or quality of experience (QoE) management [10]-[18] but also a perspective metric including an application-oriented or provider-oriented metric must be considered.

This paper focuses on a mass of users and introduces mass-user satisfaction as a simple application-oriented metric according to the mass-user satisfaction in the NFV-based application specific network. Each network application flow is suitably classified and controlled.

Here, a single user satisfaction is introduced to translate physical QoS metrics into the application-oriented metric. In this paper, the user satisfaction related to the bit rate is calculated by Equation 1 derived from the Waver-Fechner Law as shown in Fig. 2. The Waver-Fechner Law can be used for measurement of QoE [19] because it describes the relationship between actual intensity of physical stimulus and perception. When U represents a set of users who use a network application, for any user i $\in$ U, the single user satisfaction $S(b_i)$ is formulated as follows:

$$S(b_i) = \frac{\log(b_i/b_{MIN})}{\log(b_{MAX}/b_{MIN})} \qquad (1)$$

where b_i represents an average bit rate of the network application which the user i uses. b_{MAX} and b_{MIN} are a maximum and minimum bit rate of the network application respectively. b_{MAX} is set to an upper boundary estimated under the service and network configurations. b_{MIN} is set to guarantee the practical use of the network application with the lowest quality.

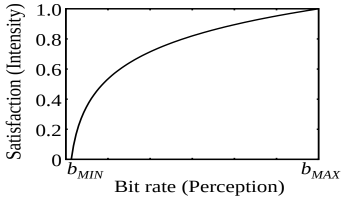

Fig. 2. Single user satisfaction based on bit rate.

Mass-user satisfaction S_M, an extension of the single user satisfaction, is formulated by the sum of single user satisfactions as follows:

$$S_M = \sum_{i \in U} w_i\, S(b_i) \qquad (2)$$

where w_i is a weight of the user i, which is set to 0 or 1. The mass-user satisfaction of all users can be calculated by assigning all weights to 1. When focusing on specific users, weights of selected users are set to 1 and those of other users to 0 as follows.

$$w_i = \begin{cases} 1 & (selected\ users) \\ 0 & (others) \end{cases} \qquad (3)$$

Normalized mass-user satisfaction S_{NM} can be obtained by averaging the S_M by the number of users |U| as follows.

$$S_{NM} = \frac{1}{|U|} \sum_{i \in U} w_i\, S(b_i) \qquad (4)$$

In this paper, the weight w_i is set 0 or 1 for the mass-user satisfaction. Although the weight can be set to a real number for more flexible metrics, this effectiveness will be investigated in future study.

4. Resource Management Guidelines

Network resource management based on the mass-user satisfaction will be conducted along with individual operation and management strategy of each network. For the optimal management, it is necessary to study various applications and networks and then to select a better control scheme according to each situation. In this section, useful resource management guidelines are discussed by reporting the simulation results of a typical NFV-based network configuration with some applications.

Resource management becomes effective only when the network involves some resource bottlenecks. The simplest situation is represented as a bottleneck link between two application specific networks. Our simulated network shown in Fig. 3 consists of the network NA and NB, where one VNF node configured on a physical node of the network NA and the network NA is managed based on the proposed mass-user satisfaction. Each link capacity is assumed 1 Gbps because 1 Gbps is an affordable capacity used for wired access link or wireless backbone.

Admission control, priority control, and bandwidth control are performed as network management. In the admission control, the number of flows is regulated according to a network operation policy of each network. In other words, each flow may establish its connection as a result of the admission control. Priority and bandwidth controls are performed according to classes of flows.

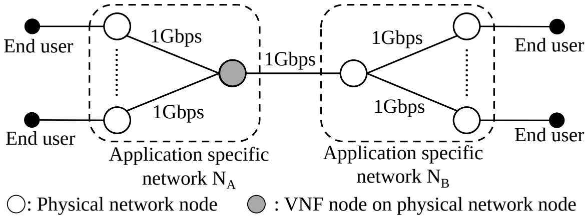

Fig. 3. Simulated network configuration.

In the simulations, all flows of network applications are classified into three classes listed in Table 1. Flows of essential application in the network are categorized as the highest priority class A, e.g., broadcast application for present availability of utilities and distributed food. Flows of manageable application are classified into class B, e.g., real-time video streaming application. Flows of other applications are classified into the lowest priority class C, e.g., web surfing. As numerical examples, simulation parameters for each application class are shown in Table 2. As for protocol of transport layer, TCP is used for the class A and C and UDP for the class B. The bit rate of the class B is set to 6 Mbps. The number of flows is set to 100 for the class A, from 100 to 300 for the class B, and 50 or 200 for the class C. Each flow passes through the bottleneck link between two networks. Each flow is initiated at a random timing within 1 second and it is terminated by 65 seconds in simulation time.

The Network Simulator ver. 2 (NS-2) [20] was adopted as a network simulator in order to trace connections and queuing. Priority and bandwidth controls are performed with a component of class based queueing (CBQ). CBQ is applied to a bottleneck link for the outgoing flows of the network NA. When priority control works, priorities 1, 2, and 3 are assigned to the class A, B, and C, respectively. Fractions of link bandwidth assigned to the class A, B, and C are 0.3, 0.6, and 0.1, respectively.

The formulas of the single user satisfaction and the mass-user satisfaction introduced in Section 3 are adopted, where one user corresponds to only one flow. b_{MAX} for the class A and C are set to 4.189 Mbps, which was measured in case of no congestion, and b_{MAX} for the class B is set to 6 Mbps. b_{MIN} for all classes are set to 128 kbps. b_{MAX} for the class B and b_{MIN} for all classes are set by referring to the Main tier of level 3 and level 1 of H.265 (High Efficiency Video Coding: HEVC) [21]

. Table 2: Specifications of network simulation.

		class A (essential)	class B (manageable)	class C (others)
Protocol		TCP	UDP	TCP
Bit rate		Variable	fix (6 Mbps)	Variable
Number of flows		100	100-300	50, 200
CBQ	Priority	1	2	3
	Fraction of link bandwidth allocation	0.3	0.6	0.1

On simulation results, each single user satisfaction is calculated from an average bit rate of each flow and the mass-user satisfaction is also calculated from specific single user satisfactions and their weights with the formula of the mass-user satisfaction. Simulation results are shown in Fig. 4 to 6, in which x axis is the number of flows classified into the class B and y axis is user satisfaction of each perspective.

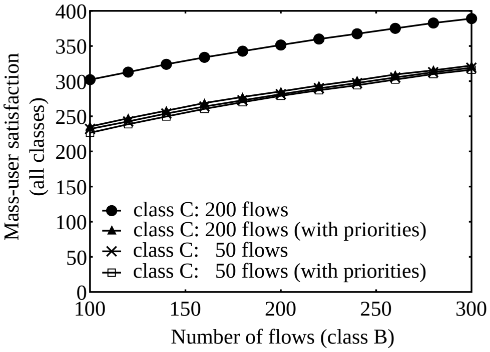

Fig. 4. Mass-user satisfaction (all classes).

Firstly, Fig. 4 shows the mass-user satisfaction focusing on all application classes. In the figure, triangle and square plots denote the case of priority control and circle and x-mark plots denote the case of no priority control. Circle and triangle plots represent conditions that the number of the class C flows is 200, and x-mark and square plots represent conditions that the number of the class C flows is 50, respectively. The mass-user satisfaction of circle and x-mark plots is relatively higher than that of triangle and square ones. In this case, the normalized mass-user satisfaction shown in Fig. 5 is not degraded so much when the number of flows in the class B increases. To increase the number of flows in the class B implies to cause heavier resource constraint. Therefore, if it is necessary for the manageable applications to be assigned marginal resource under heavy resource constraint, network resources should not be allocated with class-based traffic management. This situation can be associated with early phase of the emergency network as discussed in Section 2.

Otherwise, the network affords to accept more flows of the class B. In this case, it is necessary to consider user satisfaction of each class. Fig. 6 shows the normalized mass-user satisfaction focusing on the class B and boxplots of single user satisfaction of each flow classified into the class B when whiskers span 95 % of all points. Outliers of boxplots are omitted because degrees of single user satisfaction of upper 95 % users are considered as targets of evaluations in the results. In this figure, each normalized mass-user satisfaction decreases as the number of flows increases. Single user satisfaction represented at the lower end of the whisker also decreases. From the results, as resource constraints become lighter, network resources should be further allocated to the class B in order to improve the total satisfaction of all users as well as the lower bound of upper 95 % users' satisfactions.

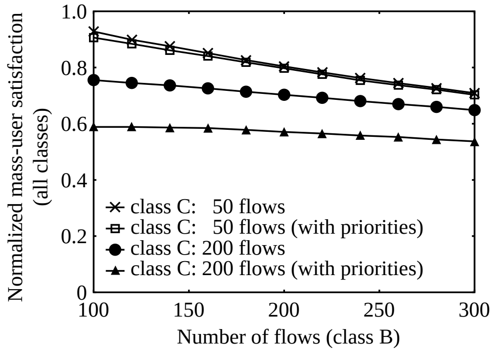

Fig. 5. Normalized mass-user satisfaction (all classes).

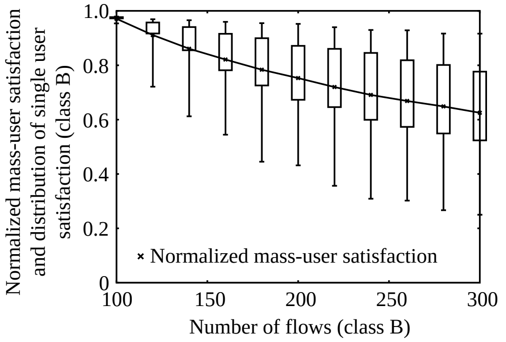

Fig. 6. Normalized mass-user satisfaction and distribution of single user satisfaction (class B).

This situation can be applied to the MVNO network discussed in Section 2. Moreover, when resource constraint is light and resource allocation to manageable application is requested to be prior to others, network resources should be allocated to manageable applications as much as possible by using class-based traffic management. This improves minimum satisfaction of the applications such as time-dependent video streaming in the massive event.

These resource management guidelines are derived from the simulation results of the typical NFV-based network configuration. The significant point is to clarify the management purpose of the NFV-based application specific network and then to maintain a well balance between the mass-user satisfaction and the normalized mass-user satisfaction in the network as well as a range of target users of applications.

5. Conclusion

This paper discussed management characteristics of NFV-based application specific networks and then proposed the mass-user satisfaction as one of service-oriented metrics for them. Network resource management guidelines based on the mass-user satisfaction were presented through analyzing simulation results of a typical application specific network.

In future extensions of this research, we plan to enhance the proposed mass-user satisfaction by introducing sophisticated integration of user satisfaction with various QoE metrics. We also plan to investigate novel VNF or SDN modules operating with resource management guidelines of multiple slices.

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