Computer Networks 92 (2015) 357–368

Contents lists available at ScienceDirect

Computer Networks

journal homepage: www.elsevier.com/locate/comnet

Learning-based approach for layered adaptive video streaming over SDN

Tuba Uzakgider, Cihat Cetinkaya, Muge Sayit*

International Computer Institute, Ege University, Izmir, Turkey

ARTICLE INFO

Article history:
Received 31 October 2014
Revised 11 September 2015
Accepted 22 September 2015
Available online 3 October 2015

Keywords:
OpenFlow
Scalable video coding
Reinforcement learning
QoE

ABSTRACT

Software-defined networking is a recently emerging paradigm that decouples the control and data planes of computer networks. It allows for the implementation of application-specific routing algorithms, and the advantages that the SDN architecture enables can be used to enhance the performance of multimedia communication applications. In this paper, we propose an adaptive video streaming system with a learning-based approach, running over SDN. In the proposed video streaming system, we use a novel learning model to determine the optimal time to re-route the traffic flows and to change the bitrate of the video. The learning model aims to minimize the packet loss rate, quality changes and controller cost while adapting the flow routes and video quality. We have tested the performance of the learning-based approach by comparing it to traditional Internet routing and the greedy approach. The results show that the proposed system significantly outperforms the traditional Internet routing approach and the greedy approach in terms of quality of experience (QoE) and network cost under different network scenarios.

1. Introduction

Multimedia applications are among the most prevalent applications running over the Internet. Although traditional best effort routing cannot guarantee a certain amount of bandwidth and cannot provide a delay limit to the packets, these applications serve a wide range of users. The performance of video streaming applications running over a traditional Internet architecture is acceptable thanks to remarkable rate adaptation and buffering techniques. One of the challenges of providing high performance to streaming application users is coping with changing network conditions. Video streaming applications can change the video bitrate according to the underlying network capacity by performing quality adaptation techniques. Quality adaptation regulates the bitrate of the video and minimizes the packet losses or outages during streaming. Using layered video data can be a method to adapt quality when the capacity of the end-to-end path between the server and the client changes. The video bitrate can be adjusted by adding or extracting video layers according to the available bandwidth.

Software-defined networking (SDN) [1], a recently emerging paradigm, proposes an abstraction of forwarding functionality in computer networks. With the SDN architecture, the control and data plane are decoupled, and this approach provides a programmable control plane. The programmable control plane allows network operators to develop flexible routing algorithms that can be configured according to the characteristics of different network applications. Forwarding abstraction can be used for improving existing routing algorithms or for developing novel ones to increase the performance of the applications.

There are several proposals for implementing new routing algorithms for video streaming applications running over SDN. The purpose of developing new routing algorithms is to

* Corresponding author. Tel.: +90 2323113230.
E-mail addresses: tubauzakgider@gmail.com (T. Uzakgider), cihat.cetinkaya@ege.edu.tr (C. Cetinkaya), muge.fesci@ege.edu.tr, mugefesci@gmail.com (M. Sayit).

http://dx.doi.org/10.1016/j.comnet.2015.09.027
1389-1286/

increase the quality of experience (QoE), a measure of client experience with a video streaming application. Commonly used QoE parameters are the received bitrate, percentage of lost packets, outage duration, number of quality changes and startup delay [2]. The routing algorithms for sending video packets over SDNs proposed in the literature aim to increase QoE parameters in terms of the received bitrate, outage duration and startup delay [3–5].

If we consider developing an adaptive video streaming application running over SDN, then we have control of both the routing of flows for the video packets and adjusting the bitrate of the streamed video. One reasonable method could be selecting the path having the maximum capacity among the paths between the server and the client and then sending as many as video layers that can be conveyed over the selected path without losing the packets. If new clients join the system, network conditions and link capacities change. Thus, re-routing packets by assigning different paths other than the current path may be needed as well as adjusting the bitrate according to the current underlying capacity. However, frequent path changes increase the complexity of control plane functionalities. On the other hand, frequent changes in video quality may annoy users and cause a decrease in QoE [6,7]. This tradeoff raises the following questions: (i) When should the paths be changed? (ii) Should path and quality be changed at the same time? (iii) At what quality should the video be streamed? In this work, we develop a learning model to find optimal actions related to these three questions. The output of the learning model determines when the path should be changed and which quality should be selected.

Reinforcement learning [8] techniques are used for an entity to gather some information regarding the environment and to utilize its experience after receiving intuition concerning system facts. An entity is a decision maker that observes the environment, takes actions and receives rewards related to its actions in a system. In a reinforcement learning model, the entity begins at the exploration phase and it passes to the exploitation phase in time. Its experiences are obtained by performing actions and observing the results of these actions. In this paper, we propose to use a reinforcement learning model for an adaptive video streaming application running over SDN because the results of some actions are not known in advance. Based on the output of the learning model, the system learns the optimal actions of when to re-route video packet flows and when to add or extract video layers. The aim of the learning model is to maximize QoE in terms of the received bitrate, percentage of lost packets and number of quality changes while minimizing the complexity of SDN elements.

The contributions of our work can be listed as follows:

(i) We design an adaptive layered video streaming system running over SDN. To the best of our knowledge, an adaptive video streaming application using layered video and managed by SDN elements has not been proposed previously.
(ii) We design a learning model for determining when to change the flow route and video quality. This is the first study that develops a learning model for multimedia applications running over SDN.
(iii) We implement a set of experiments to tune the parameters that give the best performance for the learning model.
(iv) In addition to developing a learning model, we also develop a heuristic greedy approach to re-route video packet flows and to regulate the video bitrate. We present the results of the learning-based approach and the greedy approach comparatively and show the performances of both approaches in different network scenarios.

The rest of the paper is organized as follows. In Section 2, related works regarding multimedia communications over SDN are given. The proposed adaptive video streaming system with a learning-based approach and the learning model are detailed in Section 3. In Section 4, we present the performance results of the proposed learning-based adaptive video streaming system. In Section 5, the conclusions are given, followed by the references.

2. Related work

In SDN architecture, the control plane is separated from the data forwarding plane and its functionality is given to an external device called the controller. The controller has the network topology view of its domain. It communicates with the switches to obtain real-time traffic information. By using the information regarding topology and traffic volume, the controller can determine the flow routes. Hence, SDN develops the application specific routing strategies by taking the underlying network topology and the real-time traffic information into consideration.

OpenFlow [9] is the first protocol that allows the controller to communicate with the switches. The OpenFlow protocol establishes a secure communication channel between the controller and the switches. The forwarding rules in the flow tables of switches are determined by the controller flow route decisions that are sent by using OpenFlow. The controller can add a new flow table entry or modify/delete existing ones and can query traffic statistics via OpenFlow.

Because SDN is a recently emerging paradigm, there are only a limited number of studies on implementing multimedia communication services and providing a multimedia specific quality of service (QoS) model over SDN. In [3], assigning suitable flows to the users according to their service negotiations is discussed. An IPTV service running over SDN and assuring a certain level of service quality were proposed in [10]. In the proposed service, there are two paths between the server and the client, and if a problem is detected on the default streaming path, then the alternative path is selected to stream the video packets. Because there is one alternative path, the methods of path selection are not discussed in this work. In [4], based on the client download capacity information obtained from the switches, the controller enables the video to be sent at a suitable quality in accordance with the capacity of the clients. Similar to [10], in this study, there is one path between the server and the clients and all video packets are sent through this path; no path selection method is defined. In [11], a network caching service based on the SDN framework is proposed for video on demand