Computer Networks 102 (2016) 38–49

Contents lists available at ScienceDirect

Computer Networks

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

A quality of experience-aware cross-layer architecture for optimizing video streaming services

Qahhar Muhammad Qadir[a,*], Alexander A. Kist[a], Zhongwei Zhang[b]

[a] School of Mechanical and Electrical Engineering, University of Southern Queensland, Toowoomba, Queensland, Australia
[b] School of Agricultural, Computational and Environmental Sciences, University of Southern Queensland, Toowoomba, Queensland, Australia

A R T I C L E I N F O

Article history:
Received 30 July 2015
Revised 13 February 2016
Accepted 21 February 2016
Available online 19 March 2016

Keywords:
Quality of experience
Cross-layer architecture
Optimization
Video

A B S T R A C T

The popularity of the video services on the Internet has evolved various mechanisms that target the Quality of Experience (QoE) optimization of video traffic. The video quality has been enhanced through adapting the sending bitrates. However, rate adaptation alone is not sufficient for maintaining a good video QoE when congestion occurs. This paper presents a *cross-layer architecture* for video streaming that is QoE-aware. It combines adaptation capabilities of video applications and QoE-aware admission control to optimize the trade-off relationship between QoE and the number of admitted sessions. Simulation results showed the efficiency of the proposed architecture in terms of QoE and *number of sessions* compared to two other architectures (*adaptive architecture* and *non-adaptive architecture*).

1. Introduction

The increasing popularity of various video services [1] has made studying the Quality of Experience (QoE) important. The ITU-T defines QoE as a measure to evaluate the service quality as perceived by end users [2]. Various technical and non-technical factors affect this new quality measure [3]. Among these factors are those related to service preparation, delivery and presentation. This makes the task of maintaining QoE at an acceptable level a challenge. Many solutions have been introduced to tackle the challenge of video traffic quality. However, more promising architectures are required to meet the satisfaction of users and preserve the interest of service providers. This common goal has been targeted by various designs. Different approaches focusing on optimization metrics, scope and adaptation methods are available. They can be deployed individually or jointly to achieve the goal which is called cross-layer design in the latter case [4].

Optimization has to resolve the conflict between the interests of end users and network providers. From the end user perspective, maximum quality is expected; whereas low-cost and the number of served users are important from the network providers' perspective. These two can be jointly optimized through an intelligent design. This motivation has promoted the development of cross-layer designs for video transmission that are QoE-aware. The main objective is to utilize network resources efficiently and optimize video quality, throughput or QoE through a joint cooperation between layers and optimization of their parameters. This enables the communication and interaction between layers by allowing one layer to access the data of another layer. For example, having knowledge about the available bandwidth (network layer) helps the sender to adapt the sending rate (application layer). As a result of this cooperation, better quality for as many users as possible can be expected.

* Corresponding author.
E-mail addresses: safeen.qadir@gmail.com (Q.M. Qadir), kist@ieee.org (A.A. Kist), zhongwei.zhang@usq.edu.au (Z. Zhang).

http://dx.doi.org/10.1016/j.comnet.2016.02.030
1389-1286/

Although dynamic rate adaptation enhances video quality, accepting more sessions than a link can accommodate will degrade the quality. We have investigated how rate adaptation of video sources can provide a better QoE in our previous work [5]. However, the friendly behavior of the Internet's transport protocol accommodates every video session and makes room for everyone. This causes degradation of QoE of all video sessions in a bottleneck link. Adaptive sources attempt to reduce the transmission rate of all video sources in order to share the available link capacity. This process does not consider how much the QoE at the receiving end will be affected by the adaptation process. To overcome this problem, a mechanism is required to maintain the quality of on-going video sessions.

In this paper, we combine the rate adaptation capability of video applications and our previously proposed QoE-aware admission control [6] in a QoE-aware architecture for video streaming. The contribution of this paper is a novel QoE-aware cross-layer architecture for optimizing video streaming services. The proposed architecture addresses the issue of QoE degradation of video traffic in a bottleneck network. In particular, it allows video sources at the application layer to adapt their rate dynamically to the network environment; and the edge of the network at the network layer to protect the quality of active video sessions by controlling the acceptance of new session through a QoE-aware admission control.

The remaining of the paper is organized as follows: related work is reviewed in Section 2. We introduce our proposed QoE-aware cross-layer architecture in Section 3. The evaluation environment is explained in Section 4. Section 5 presents and discusses the results. Finally, Section 6 concludes the paper.

2. Related work

Extensive research has been done in the area of QoE optimization for video traffic. Some have focused on the optimization of the video's QoE through mechanisms on a single network layer. Classification and survey of these mechanisms can be found in [7–9]. In this section we only focus on cross-layer designs that have been proposed to optimize the QoE of video traffic.

The optimal rate of competing scalable video sources for QoE optimization has been found in [10]. Loss-induced distortion caused by video sources has been minimized and QoE has been maximized by obtaining the optimal rate and capturing the exact effect of packet loss in [11]. The resulting rates from [10,11] are proposed to be used by video encoders for online rate adaptation. In [12], a rate adaptation scheme and the IEEE 802.21 media independent handover are integrated for a single and scalable coding. In [13], the source rate at the application layer and modulation schemes at the radio link layer are optimized for the quality of video streaming using an application-driven objective function. The link adaptation of the high speed downlink packet access and rate adaptation of multimedia applications are integrated in a QoE-based cross-layer framework that is capable of maximizing the QoE [14].

Work in [15] combines link adaptation based on an online QoS to QoE mapping, buffer-aware source adaptation and video-layer dependent packet retransmission techniques to provide delay-constrained scalable video transmissions with optimized perceptual quality. The impact of power allocation on bit error rate and video source coding structure for Scalable Video Coding (SVC) video over Multi-Input Multi-Output (MIMO) with the aim of QoE maximization has been considered in [16].

The work presented in [17] extends the Pre-Congestion Notification (PCN)-based admission control, determines the required redundancy bits for coping with packet loss, and scales video rate to optimize the QoE in multimedia networks. Two different rate adaptation algorithms have been proposed in [18]; an optimal one to adapt the video rate based on the maximization of service provider's revenue or QoE and a heuristic one based on the utility of each connection. Relying on subjective tests, Chen et al. [19] proposes a rate adaptation algorithm and devises a threshold-based admission control strategy to maximize the percentage of video users whose QoE constraints can be satisfied. Per user's QoE constraint was defined by the empirical Cumulative Distribution Function (eCDF) of the predicted video quality.

The cross-layer design presented in [20] has optimized the QoE of the region of interest for mobile physicians by using advanced error concealment techniques. The work in [21] has combined the SVC optimization optimum time slicing for layered coded transmission and adaptive Modulation and Coding Scheme (MCS) to trade between the QoE and energy consumption of wireless broadcast receivers.

In [22], a QoE-aware joint subcarrier algorithm and a power radio algorithm are combined for a QoE-based resource allocation of the heterogeneous Orthogonal Frequency Division Multiple Access (OFDMA) downlink. The model presented in [23], efficiently allocates resources for video applications by mapping between Peak-Signal-to-Noise Ratio (PSNR) and Mean Opinion Score (MOS). Admission control and resource reallocation have been deployed in [24] to increase the session admission rate while maintaining an acceptable QoE of multimedia services in Long-Term Evolution (LTE). The authors of [25] utilized the QoE prediction model of Khan et al. [26] to rate the QoE of multimedia services and allocate resources dynamically.

The QoE-aware cross-layer Dynamic Adaptive Streaming over Hypertext Transfer Protocol (HTTP) (DASH) friendly scheduler introduced in [27], allocates wireless resources for each DASH user. The video quality is optimized based on the collected DASH information through an improved SVC to DASH layers mapping and a DASH proxy. The QoE of multi-user adaptive HTTP video in mobile networks has been optimized by adapting the transmission rate of DASH clients that can be supported by lower layers in [28]. In [29], an efficient video processing, an advanced real-time scheduling and reduced-reference metrics across the application and network layers are combined as components for a QoE-driven cross-layer design of mobile video systems.

The automatic architecture proposed in [30] monitors quality related parameters such as packet loss, video frame rate and router queue sizes. Proper actions such as lowering bit rate or adding more Forward Error Correction