



Video encoding adaptation for QoE maximization over 5G cellular networks

Ya-Ju Yu^a, Ai-Chun Pang^{b,c,d,*}, Ming-Yu Yeh^b

^a Department of Computer Science and Information Engineering, National University of Kaohsiung, Taiwan

^b Department of Computer Science and Information Engineering, National Taiwan University, Taiwan

^c Graduate Institute of Networking and Multimedia, National Taiwan University, Taiwan

^d Research Center for Information Technology Innovation, Academia Sinica, Taiwan

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ABSTRACT

With the unprecedented growth of mobile video data traffic every year, increasing users' video quality of experience (QoE) under limited network radio resources becomes a critical issue in next-generation cellular systems. However, videos compressed with unsuitable video encoding parameters will waste the network radio resources and users even may not be able to get satisfied video QoE. Specifically, a video with higher bit rate requirement (determined by the video encoding parameters) does not imply that a user will have better QoE. This paper studies the QoE optimization problem via carefully determining a combination of video encoding parameters for each user under the radio resource block constraint. The objective is to maximize the total QoE of all users. We prove that our target problem is $\mathcal{NP}$ -hard and propose an algorithm based on dynamic programming to solve the problem. Then, we prove that our proposed algorithm is a pseudo-polynomial time optimal algorithm. We construct a series of simulations with realistic video sequences encoded by H.264 and network settings to evaluate the performance of our proposed algorithm. Compared with two baselines, the simulation results show that the proposed algorithm can significantly improve the total QoE of all users and indicate that the video encoding adaptation is an important issue in the QoE optimization problem.

1. Introduction

With the evolution of wireless communication technologies and popularity of mobile devices, users are expected to enjoy their mobile applications and services. In Fifth-Generation (5G) mobile networks, telecom operators and service providers are switching their focus from network quality of service (QoS) to user quality of experience (QoE) because various emerging services indicate the requirement to improve the overall performance from a user's subjective view (Miyanabe et al., 2015). Because QoE is determined by user satisfaction and is different measurements compared with QoS values, only considering QoS values cannot improve the overall QoE of all users (Dong et al., 2014). Therefore, supplying a better quality of experience (QoE) for users will be a key issue in the future markets of mobile video services to make sure profit and service continuity (4G–Americas, 2013). Under this trend, adaptive bit rate (ABR) streaming has become a popular video delivery technique such as Apple HTTP Live Streaming (HLS) and Microsoft smooth streaming. Moreover, Dynamic Adaptive Streaming over HTTP (DASH) has been developed as a new standard for ABR with the aim of improv-

ing video QoE (Pedersen and Dey, 2016). In ABR streaming, each video can be divided into multiple chunks, and chunks can be compressed at different video qualities with different bit rate requirements. However, how to maximize the QoE of users by dynamically determining the video quality with a series of video encoding parameters is still a challenging issue.

Recently, in order to maximize the QoE of users, many works have studied how to evaluate video QoE of users and attempted to build video QoE models based on a series of experiments (ITU-R, 2012). QoE models are generally represented as mean of score (MOS) and comprised of several networks and/or application parameters. For examples, in network parameters, the works (Lee et al., 2010; Khan et al., 2010, 2012) consider video transmission bit rate and bit error rate as the important parameters in their QoE models and generally think that higher video transmission bit rate implies that users will have higher QoE. Furthermore, in application aspect, there have been several works studying the impacts of video encoding parameters on perceptual video quality. The video encoding parameters include quantization parameter (QP), video frame rate, video content types, etc.

* Corresponding author. Department of Computer Science and Information Engineering, National Taiwan University, Taiwan.

E-mail addresses: yjyu@nuk.edu.tw (Y.-J. Yu), acpang@csie.ntu.edu.tw (A.-C. Pang), ss0918473921@gmail.com (M.-Y. Yeh).

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(Ou et al., 2011; Feghali et al., 2007; Lu et al., 2007; Slivar et al., 2016), each of which will have influences on the users' QoE and the video transmission bit rate requirement. Specifically, receiving a video with a higher bit rate requirement does not imply that a user will have better QoE. On the other hand, a user will have different QoE for watching two similar bit-rate versions of a video encoded by two different combinations of video encoding parameters. Therefore, if the video encoded by inappropriate encoding video parameters, a user may not be able to get satisfied QoE and the network resources will be wasted to transmit the video with high bit rate requirement so that the QoE of other users will be sacrificed. A challenging issue is how to determine that each video (or chunk) should be encoded with which combination of video encoding parameters for each user such that the QoE of all users is maximized under the network radio resource constraint.

Recently, numerous works have addressed QoE optimization issues. Since QoE is an important concept, Pierucci (2015) introduced QoE acceptability in 5G networks and addressed how the key challenges of 5G can improve user satisfaction. He and Wang (2016) considered power and modulation rate allocation for multimedia services to improve multimedia QoE. Zhang et al. (2017) proposed a game approach to allocate power and spectrum and schedule users to improve users' service experience in 5G networks. Piran et al. (2017) managed spectrum handoff delays by allocating channels based on the user QoE expectations to provide seamless multimedia service and improve QoE.

In (Zhang et al., 2013; Shen and Akella, 2013), the authors developed cache policies to store a set of video files with different transmission bit rates under a limited storage budget. The video files stored in the cache can be dynamically chosen according to network conditions such that the QoE of all users can be maximized. In (Deep Singh et al., 2013), Singh et al. addressed scalable video coding multicast transmissions with the objective of maximizing the global QoE of all users and determined which layer should be transmitted with which modulation based on channel conditions. Some researchers addressed radio resource allocation problems for maximizing the QoE of users. Zhou et al. (2013) considered that a QoE model is unknown and can only be observed over time. Then, the authors proposed an online dynamic bandwidth allocation scheme based on the observed QoE model to maximize the QoE of users. In (Chen et al., 2015), Chen et al. developed a QoE-driven power allocation scheme with the joint consideration of the bit error rate and transmission bit rate. Rugelj et al. (2014) presented two cross-layer QoE-aware subcarrier and power resource allocation algorithms for the downlink of a heterogeneous system. However, the recent studies have not addressed the relationship between the video encoding parameters and network transmission bit rates in the QoE optimization issue and not studied how to determine a value of each video encoding parameter for each user. More recently, Cheng et al. (2016) studied the video encoding adaptation for the QoE optimization problem. The paper considered that only the quantization parameter can be adjusted based on the proposed QoE model. However, the paper has not investigated the QoE optimization problem when multiple video encoding parameters and different QoE models can be chosen in video encoding adaptation strategies.

In this paper, we observe that video encoding parameters will significantly affect the network radio resource consumption and a user's QoE. This paper is motivated by the above observation to study the video QoE optimization problem through the video encoding parameter adaptation under the radio resource constraint. Our objective is to maximize the QoE of all users based on a QoE model. We show that our target problem is a $\mathcal{NP}$ -hard problem and then design an algorithm based on dynamic programming to tackle the problem. We prove that our algorithm is a pseudo-polynomial time optimal algo-

rithm. Our proposed algorithm is designed with the consideration of multiple video encoding parameters and is applicable no matter which QoE model is adopted, where the QoE model can also take the delay, jitter, and other factors (e.g., video freezing) into account. Finally, we conduct a series of simulations, with realistic video sequences encoded by H.264 and the parameters set according to LTE systems, to evaluate the developed algorithm. Compared with two baselines, simulation results justify our motivations and indicate that our proposed algorithm can significantly increase the total QoE of all users.

The remainder of this paper is organized as follows. Section II describes system model and problem formulation. In Section III, we show the $\mathcal{NP}$ -hardness of the problem and develop a pseudo-polynomial time optimal algorithm based on dynamic programming to solve the problem. Simulation results and analyses are presented and discussed in Section IV. Finally, Section V concludes this paper.

2. System model and problem formulation

2.1. System model

According to Cisco's white paper (Cisco Business Video Arch, 2011), it suggested that video service provider should cooperate with telecom operators to perform better service quality for users. For cellular wireless systems, when a user requests a video service, a video with a data rate requirement will be transmitted from a video service provider. According to the channel quality of the user, the base station has to consume the radio resource blocks to transmit the video to the user. Each user may experience different channel conditions because of the distance to the base station, fast fading, and shadow. Therefore, the base station should adaptively use a modulation-coding scheme based on the channel conditions for each user. A user with good channel conditions (e.g., when close to the base station) can potentially receive the video data by using a higher rate modulation-coding scheme such as 64-QAM. In other words, the base station can consume fewer radio resource blocks to transmit the video to the user. In contrast, a user with poor channel conditions must receive the video data with a lower rate modulation-coding scheme such as QPSK in order to tolerate the bit error rate. In this case, the base station will consume more resource blocks for the user with bad channel conditions.

For the video service provider, according to video applications, a video sequence can be encoded in real time or pre-encoded to several video qualities in the storage. When we encode a video, we should determine a series of video encoding parameters. The value of each video parameter will affect a user's QoE based on a QoE model and the bit rate requirement for transmitting the video. Specifically, the value of a video parameter in a range may not have an impact on a user's QoE but have significant influences on bit rate requirement in network side. A user's QoE can be estimated based on a video QoE model, which is generally presented as the mean of score (MOS) and studied in literature e.g., (Ou et al., 2011; Feghali et al., 2007; Lu et al., 2007). The QoE model can also take delay, jitter, video freezing, and other factors into account. If a video encoded by unsuitable encoding parameters will waste network resources, users even cannot get satisfied QoE. Therefore, in order to maximize the total MOS (QoE) of all users, a third party or a server can collect the information of the video service provider (e.g., video encoding parameters) and telecom operators (e.g., network capacity and wireless channel conditions of each user) to calculate/determine the suitable encoding parameters for the video requested by each user. When the video quality is determined by the base station for a user, the video quality will not be frequently changed and can be adjusted at the beginning of each video chunk. This paper can also adopt a QoE model considering the switching delay and jitter.

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