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Network Efficient Resource Management for Mobile Video Streaming based on Quality of Experience

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Abstract—This paper presents a novel experimental approach to quantify the performances of Quality of Experience (QoE)-aware resource management scheme in mobile network. The main goal of this paper is to improve network efficiency by exploiting knowledge of QoE information associated with online video streaming services. The investigations considered in the paper are performed using an innovative test-bed, developed to assess network efficiency for the provision of online video services of different qualities. The QoE model used in the proposed QoE-aware allocation scheme assumes a MOS-like grading function whose grades depend on both the duration of playtime interruption and the streaming video quality (resolution). The results show that the proposed resource management scheme can deliver more than 40 percent higher QoE to the users of the system as compared to current agnostic (not aware of QoE requirement and content characteristics) service models.

I. INTRODUCTION

As discussed in [1], by 2016 around 70 percent of mobile traffic is predicted to be generated by video. Classical approaches like deploying additional infrastructure (e.g. base stations), instituting data caps or limiting access to some mobile services are not likely to be economically viable for this challenge. Severe resource limitations in mobile networks can lead to dramatic levels of delays and interruptions in video streaming players, which can significantly affect user perceived experience (QoE). The current mobile networks resource management schemes are not designed to account for content-specific characteristics, potentially leading to sub-optimal resource allocation solutions which are myopic in respect to content providers, mobile operators and end-users requirements.

In this paper, an innovative architecture is designed for a QoE-aware resource management scheme for mobile video streaming based on the users' satisfaction level.

The investigations considered in the paper are performed using an innovative test-bed, developed to assess both QoE and network efficiency for the provision of YouTube streaming services of different qualities.

II. ARCHITECTURE

Fig. 1 shows the proposed architecture diagram that consists of six main parts, as follows:

A. Profiles

The current resource management schemes are not capable of adapting resources allocated to various streams based on individual users' expectation and perception of video quality for different video types. To implement a personalized resource management, this paper proposes the adoption of profiles which include users' expectation for video streaming service provision, content provider description on how different content items should be consumed and specification of the users' devices capabilities of reproducing various video qualities.

The profiles are the main input for the resource manager and are divided into three categories:

1) *User Profile*: Different users have different service quality requirements. For instance, a user might not accept interruptions during playback while another user might not be as sensitive to interruption, providing that high video quality is achieved. User profile updates the profile data regularly from the information and QoEs received from the past playback experiences of the various users.

2) *Device Profile*: Contains device specifications such as screen size, memory, processor, network interface type, etc. Device specifications can significantly affect resource allocation. For instance, users perceive the same QoE watching 1080p or 480p resolution video streams on small-size screens while the bit-rate and download size are more than 3 times higher for 1080p video resolution. On the other hand, users watching video streams with higher speed and more stable network interface have less probability of facing download-rate fluctuations and network resource problems. The Device profile collects the specifications of users' devices and updates it by received information from the players.

3) *Content Profile*: Includes the specifications of video content such as duration (length), content type (e.g. music, movie or etc.), available resolutions and similar content information, which can be used to customize the resource allocation. Content with different specifications can have different QoE for a user even in a same network and resource condition. For instance, a fairly static music video may not require a very high video quality in comparison with an action movie. A streaming video file is a series of pictures and audio frames

Fig. 1. Architecture

that may not require a high video resolution in all the frames to be perceived with high QoE. On the other hand, as discussed in [6], QoE can vary based on video duration (e.g. a user requesting long videos can be more patient for the video to start).

B. Network Resource Profile

Information about the available network resources in each network location can be acquired in three different ways:

1) *Prediction*: Prediction can be done by exploiting the information obtained from the previous playbacks including the location of players (access point, network segment or physical location[10]), time and date of playbacks, number and length of interruptions.

2) *Estimation*: In each network segment all the online players report the player and buffer information to the Network Resource Profile in each second. By using the information received from the current online players in the network segment, we can estimate the available data-rate of that segment.

3) *Operator*: The network providers can also provide information about the available resource and data-rate.

C. Resource Model

The Resource Model is the abstract information of the network segments' available resource. This model is generated to make the Network Resource Profile understandable for the Resource Manager.

D. QoE Model

The QoE Model is the semantic version of the information in the profiles including user profile, content profile and device profile to be understandable for the Resource Manager.

E. Resource Manager

The Resource Manager is responsible for controlling the network resources in each network segment. It makes resource allocation decisions based on the QoE Model and Resource Model. Resource Manager can control video playbacks, buffers and the video quality in the online players.

F. Player

The video player in this paper, is a streaming video player that can report the information about the device, video playback and the buffer condition to the profiles. The Resource Manager should be able to control the online players.

III. INVESTIGATION

A. Experimental Test-Bed

The investigations considered in this paper are performed by streaming YouTube video files from the Internet. YouTube is the most popular video streaming service provider over the Internet and generates a large share of traffic[4]. Fig. 2 shows the test-bed diagram.

Fig. 2. Test-Bed Structure

1) *MSL Player*: MSL player[9] is an Android video streaming player that is developed based on Adobe Flex Framework to stream the Flash Video files (FLV) from YouTube. The MSL player is able to capture, monitor and report the traffic and buffer information to the MSL Server. The MSL Player can be configured in a way to play a video file in a predefined time and date with a preset video quality and number of repetitions. During the video playback the Management Module can change the video quality of the players remotely.

2) *MSL Server*:

- **Management Module**

In the experiments, the Management Module's tasks are problem detection and resource allocation.

Problem Detection

In order to detect potential network resource problems in the segment, a variable called (ω) is defined. ω is calculated as (1) where S is total size of the video, T is the length of the video, E is the number of elapsed seconds of the playback and L is the loaded bytes in the buffer. ω estimates the number of seconds to the next interruption in the player. The first device with the ω value less than the problem-threshold (10 seconds for this paper) is considered as a proxy for an upcoming network resource problem in the network segment.

$$\mu = \frac{S}{T}$$

$$\omega = \frac{L - (\mu * E)}{\mu} \quad (1)$$

Resource Allocation

When a problem is detected in the network segment, the Management Module calculates the quality downgrade cost for all the simultaneous players (sessions) in the network segment using the *QoE Model*.

The Management Module downgrades the player with the minimum cost by sending a quality change signal to the appropriate player and returns to the problem detection state.

- **Monitor Module**

The Monitor Module's task in the test-bed is to monitor download rate and buffer condition in the players each second. The Monitor Module prepares the necessary data for the Management Module for detecting resource problems in the network segment.

- **Control Module**

The Control Module is responsible for controlling the MSL Players at the initiation of the experiments. The module is used to set the experiment video file, video quality, number of playback loops and the experiment start-up time and date.

- **Profile Module**

The Profile Module is responsible for assigning the players to the appropriate QoE Model. This profile assignment can be done automatically based on the device and the user history or either manually by the users.

B. Experimental Approaches

The experiments in this paper are divided to two different approaches.

1) *Single User Approach*: In the single user approach, we cannot control all the players in the network segment and the Management Module can only control a limited subset of the players (i.e. one), in a given network location (e.g. same BS or AP). In this approach we want to investigate the application of our QoE-aware approach as a service for the end users. This approach adapts the provided content quality based on the users' demand and resource condition.

In order to emulate realistic mobile network conditions in the experiment, we have used experimentally recorded traces of real recorded data-rate values. The $\mu^{tot}(2)$ for traffic shaping is based on the data-rate values during the experiments. The data-rate vector was captured using an Android mobile phone (Google Galaxy) covered by a 3G network in Mobile Service Lab at KTH university, Kista Campus.

In the single user approach we have two experiment cases.

- *High Quality Case*

In this case, the players start with the maximum quality and keep it until the end of the video. In case of detection of resource limitation, players interrupt the video playback and buffer the video content.

- *QoE-aware Case*

In this case, when a problem is detected, The Management Module performs a quality downgrade according to the QoE Model.

2) *Multi-User Approach*: Here we have control of all the players that are simultaneously streaming video from YouTube. The Management Module can make decisions for all players in the network segment.

In this approach we have four different experiment cases.

- *High Quality Case*

In this case, the players start playback with maximum quality (1080p) and keep it until the end of the video.

- *QoE-aware Case*

In this case, when a problem is detected, The Management Module performs a quality downgrade according to the users' profile. The Management Module chooses the best player for the quality downgrade based on the calculated costs using the QoE Model.

- *Interruption Case*

In this case, when a problem is detected, Management Module downgrades only one player's video quality in each state. The device with ω less than the problem-line will be downgraded.

- *Distributed Interruption Case*

In this case, we downgrade all the devices which are predicted to face an interruption without consideration of users' profiles. In other words, all the devices with ω less than problem-line will be downgraded.

C. QoE Model

The QoE model used in the proposed QoE-aware allocation scheme assumes a MOS-like grading function whose grades depend on both the duration of playtime interruption and the streaming video quality (resolution). This QoE model is specific and specialized for each of the video stream sessions according to the users' profile.

The study of users' QoE from different quality and interruption perspectives is out of this paper's scope. In our experiments we assume that the information about the users' expectation from the video quality and interruption aspects are available.

D. User Profiles

In this paper two different user profiles have been discussed.

- *Profile A*

These users prefer to have minimum interruption rather than a high-resolution video quality. For instance, a user listening to music from YouTube videos may belong to this profile. In this profile, users want to start the playback as soon as possible and without interruption at any possible video resolution. Fig. 3 shows the profile chart of Profile A.

Fig. 3. Profile A

- *Profile B*

These users prefer to have high-resolution quality even with interruption. These users require higher data-rate in the network segment in comparison with the other profile. A user watching an artistic video or an action movie with special effects may belong to this profile. Fig. 4 shows the profile chart of Profile B.

E. Data rate

The data-rate required to download video packets of all the simultaneous devices in one access point (or network segment) is called μ^{tot} which is calculated as (2) where N is the number

Fig. 4. Profile B

of simultaneous online devices, S is the video file size and T is the video duration (Length).

$$\mu^{tot} = \sum_{n=0}^{n=N} \frac{S_n}{T_n} \quad (2)$$

F. Experiment Content

For the experiments discussed in this paper we have used the same video from YouTube which was available in 5 different qualities from 240p to 1080p[11] the the length of 291 seconds.

G. Performance Measurement

The QoE_{min} is the worst QoE perceived by a user during a video playback. $Qo\bar{E}_{min}$ is the average of the QoE_{min} for all the playbacks in one network segment and is calculated as (3) where N is the number of playback sessions.

$$Qo\bar{E}_{min} = \frac{\sum_{i=0}^N QoE_{min(i)}}{N} \quad (3)$$

I is the length of playback interruption for one session and is calculated as (4), where P is the total time of the playback and T is the video duration (length).

$$I = P - T \quad (4)$$

The $\bar{I}$ is the average interruption in the network segment and is calculated as (5) where N is number of playback sessions in the network segment.

$$\bar{I} = \frac{\sum_{i=0}^N I(i)}{N} \quad (5)$$

IV. RESULTS

A. Single User Approach

In the Single-User approach we control the video resolution for a specific user based on the QoE Model. The QoE Model used for this experiment was a Profile A user. The data-rate was following the data-rate vector that has been previously experimentally recorded. Table I shows the cumulative distribution function of QoE_{min} for a Single-User approach experiment. According to the results obtained from

TABLE I
 QoE_{min} DISTRIBUTION FOR SINGLE-USER APPROACH

MOS	0	1	2	3	4	5
QoE-aware	0.00	0.1	0.00	0.00	0.50	0.40
High Quality	0.80	0.00	0.10	0.10	0.00	0.00

TABLE II
 QoE_{min} DISTRIBUTION FOR MULTI-USER APPROACH

MOS	0	1	2	3	4	5
QoE-aware	0.00	0.01	0.00	0.04	0.29	0.66
High Quality	0.31	0.00	0.09	0.13	0.05	0.42
Interruption	0.00	0.00	0.00	0.06	0.41	0.53
Distributed Interruption	0.00	0.03	0.00	0.18	0.14	0.65
QoE-aware (Profile A)	0.00	0.00	0.00	0.04	0.02	0.94
QoE-aware (Profile B)	0.00	0.02	0.00	0.04	0.56	0.38

TABLE III
MULTI-USER APPROACH IMPROVEMENT

	QoE_{min}	$\bar{I}$
High Quality Case	2.8	72
QoE-aware Case	4.59	10
Interruption Case	4.47	3.6
Distributed Interruption Case	4.38	4.1

the experiment, more than 90 percent of the users add a very high value of perceived quality (MOS of 4 or 5) in the QoE-aware case, while in High Quality case almost 80 percent of the users were very unsatisfied.

B. Multi-User Approach

This experiment was performed by streaming the video file continuously with 1080p resolution on ten simultaneous video players (devices). The players were randomly and equally assigned to Profile A and Profile B. In order to introduce resource limitations, the average data-rate of the backbone was set to 25 percent less than the overall data-rate requirement (2) to stream 10 simultaneous playbacks with 1080p Quality ($\mu^{tot} \approx 4500KB$, backbone $\approx 3600KB$).

Table II shows the cumulative distribution function of QoE_{min} for all the cases in Multi-User approach. The results from the experiments show that we could significantly increase the QoE_{min} and decrease the $\bar{I}$ by performing QoE-aware resource allocation in the network. The QoE_{min} improvement represents that we could increase the minimum satisfaction in the network more than 41 percents.

V. CONCLUSION

QoE-aware resource management scheme has the potential to improve the quality of experience (QoE) for the video streaming services as the highest traffic share in the current mobile networks. According to the results gained from the experiments, it is possible to improve users' QoE while watching video streams more than 41 percent and decrease the length and time of the interruption by more than 6 times (Fig. 5) by applying the QoE-aware resource management scheme.

Fig. 5. Interruption Distribution for Multi-user Approach

Fig. 6. Video Quality Distribution for Multi-User Approach

Fig. 6 and Table III show that by applying a smart resource management scheme we can not only improve the users' QoE but also we can consume less capacity of the network while playing videos in lower qualities.

VI. FUTURE WORK

The QoE model in this paper considered only both total duration of video stream interruption during the playback and the served video resolution. This QoE model can include other aspects in video streaming services like place of interruption, content type and start-up delay. Combination of the adaptive quality approaches such as [8][5][3][7] with the QoE-aware case discussed in this paper can be a future work.

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