Assessing the Quality of Experience of HTTP Video Streaming Considering the Effects of Pause Position

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***Abstract*—In order to assess the quality of experience (QoE) of HTTP video streaming, the model of three levels of quality of service (QoS): network QoS, application QoS and QoE, is employed in this paper. We mainly study the effects of pause position, and therefore propose two new application performance metrics: location of each pause and time interval of pauses. We first focus on the buffer behaviors of the video player, and correlate the application QoS with the network QoS, based on the analytical model and mathematical model. Then the subjective tests and experiments are carried out to assess how application performance metrics affect the QoE, and the Back Propagation Neural Net (BPNN) is established to map the application QoS to the QoE. This paper reveals that the pauses in the front part of the video, as well as the shorter time interval of pauses, have a higher negative effect on QoE of HTTP video streaming.**

Keywords—QoE; Video Streaming; HTTP; Pause; BPNN

I. Introduction

It's recently predicted that the sum of all forms of video will be in the range of 80 to 90 percent of global consumer network traffic by 2017. Due to this huge demand for video services, the study of assessing video quality is becoming important.

Modern Internet video services are predominantly based on HTTP via Transmission Control Protocol (TCP). This is because video services based on User Datagram Protocol (UDP) cannot guarantee the transmission quality of video streaming. In some cases, UDP-based streaming would be intercepted by firewalls or network address translation techniques (NATs). Additionally, most of video online is not live, so it's not necessary for the video streaming server and client to synchronize.

For a TCP stream, in order to mitigate the impact of delay caused by the packet loss, the video player stores the data in the buffer. However, if the network congestion lasts long enough, the buffered data run out, and it will lead to a rebuffering event, which reduces quality of experience (QoE). During rebuffering periods, no information is presented. Consequently, there is no spatial quality degradation, and therefore, we should consider temporal factors of video streaming.

Previous works [1] proposed a set of application performance metrics (APMs): initial buffering time, mean rebuffering duration and rebuffering frequency, to quantify the application quality of service (QoS) for HTTP video streaming. However, this paper mainly studies the effects of pause position on QoE. Taking into account the human psychology and memory characteristics, different pause location has different weights with the user-perceived quality. Therefore, when assessing QoE, pause location is a factor to be reckoned with. In addition, an online video service probably experiences several pauses, and each pause event is also affected by the others. Thus, the time interval of pauses also should be considered. In this paper, we propose two new application performance metrics: location of each pause and time interval of pauses, and correlate them with the network QoS. Then we perform subjective tests and experiments to assess how these metrics affect QoE.

The remainder of this paper is organized as follows. Section II first reviews the related works. Assessment model is described in section III, followed by the setup of the subjective tests and experiments in section IV. Section V presents results and analysis. Finally conclusions are made in section VI.

II. Related Works

Hossfeld T, Egger S, Schatz R, et al. [2] compared the influence of initial delays and interruptions during video streaming, then concluded that users were extremely sensitive to interruptions. Porter T, Peng X H. [3] investigated a new objective measurement for assessing the video quality via TCP and defined a new metric as pause intensity to characterize the video quality. Bailey C, Seyedebrahimi M, Peng X H. [4] presented a full analytic model for pause intensity (PI): a no-reference metric for video quality assessment. Mok R K P, Chan E W W, Chang R K C. [1] investigated the relationship among three levels of QoS of HTTP video streaming and mapped QoE to the application QoS. Unlike these works, we studied the assessment of QoE via HTTP, taking the effects of pause position into account. Whereas Rodriguez D Z, Abrahao J, Begazo D C, et al. [5] proposed impairment factors: number of pauses, their duration and temporal location, and defined a new metric named VsQM. However, the time interval of pauses was not considered.

III. ASSESSMENT MODEL

Fig.1 depicts an overview of video streaming via HTTP.

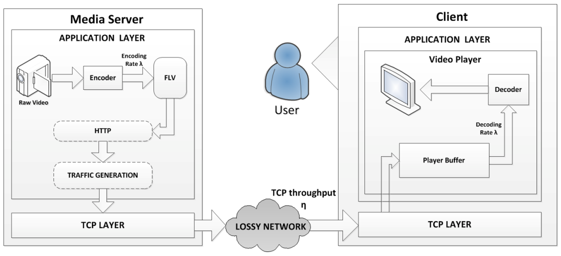


Fig. 1. The architecture of a video streaming over HTTP.

As shown in Fig. 2, a three-level protocol stack is built. In this model, the network QoS is the network path performance, including RTT, packet loss rate and network bandwidth; the application QoS reflects the temporal application performance, including five application performance metrics to quantify the application QoS: initial buffering time (T_{init}), mean rebuffering duration (T_{rebuf}), rebuffering frequency (f_{rebuf}), location of each pause (L_{rebuf}) and mean time interval of pauses (I_{rebuf}).

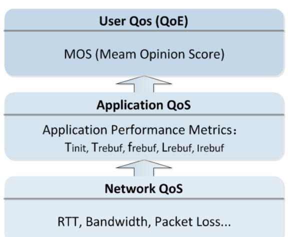


Fig. 2. The three-level protocol stack.

A. Characteristics of Buffer

The video player provides a buffer to store the data. However, the inefficiency in the network, caused by packet loss or limited bandwidth, may result in buffer underrun. Let R_r denote the rate at which the data are received from the Internet, V_r be the rate at which the data are extracted from the player buffer, and B(t) be the amount of data stored in the player buffer.

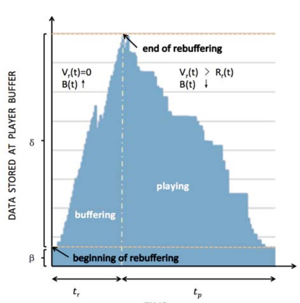


Fig. 3. The amount of data stored in the player buffer during rebuffering.

As illustrated in Fig. 3, B(t) rises as long as R_r is continuously higher than V_r during playback. However, if the available bandwidth is not sufficient, R_r drops below the encoding rate V_r, and then the player drains data from the buffer more rapidly than it is received from the Internet, and therefore, B(t) reduces. When the amount of buffered data B(t) falls below β, the playback is paused, and the player starts rebuffering. When the amount of data increases to β+δ, the rebuffering event ends. If R_r is still less than V_r, the next pause will occur. Here the rebuffering duration is denoted by t_r, and the time interval of pauses is denoted by t_p.

B. Application QoS and Network QoS

This paper focuses on the effects of pause position. As discussed before, pause position is related to the buffer behaviors, and we now pay attention to the time interval of pauses.

When the amount of buffered data reduces to b_{min} at time t_{min1}, playback is paused; when the amount of buffered data reaches b_{max} at time t_{max}, playback is resumed. The amount of buffered data during the playing-rebuffering period is computed by

$$\begin{cases} B_{buffering} - b_{\min} = \dfrac{\delta}{t_r}(t - t_{\min 1}), t_{\min 1} < t \le t_{\max} \\ b_{\max} - B_{playing} = \dfrac{\delta}{t_p}(t - t_{\max}), t_{\max} < t < t_{\min 2} \end{cases} \quad (1)$$

In the rebuffering period, there is no data consumed, so

$$\begin{cases} B_{buffering} = b_{\min} + \eta(t - t_{\min 1}), t_{\min 1} < t \le t_{\max} \\ B_{playing} = b_{\max} + (\eta - \lambda)(t - t_{\max}), t_{\max} < t < t_{\min 2} \end{cases} \quad (2)$$

From (1) and (2), the rebuffering duration t_r and time interval of pauses t_p can be expressed as

$$\begin{cases} t_r = t_{\max} - t_{\min 1} = \dfrac{b_{\max} - b_{\min}}{\eta} = \dfrac{\delta}{\eta} \\ t_p = t_{\min 2} - t_{\max} = \dfrac{b_{\max} - b_{\min}}{\lambda - \eta} = \dfrac{\delta}{\lambda - \eta} \end{cases} \quad (3)$$

From (3), the time interval of pauses depends on the average TCP throughput. To estimate it, we adopt the throughput model for a TCP Reno flow [6], given by

$$\eta = \frac{1}{R\sqrt{\dfrac{2bp}{3}} + T_0 \min(1, 3\sqrt{\dfrac{3bp}{8}})p(1 + 32p^2)} \quad (4)$$

where p is the packet loss rate, b is the number of packets that are acknowledged by an ACK, T_0 is the retransmission timeout, and R is the RTT.

Based on (4), the average TCP throughput is affected by packet loss rate. The network condition is not always perfect. If network congestion occurs, the probability of packet-discarding at the network nodes will increase. This effect is alleviated by the retransmission, which implies a longer transmission delay. It also reduces the transmission data rate at the TCP layer.

C. QoE and Application QoS

As previously stated, the application performance metrics affect the QoE; however, the relationship between them is complicated. This paper designs the BPNN model and maps the QoE to application QoS. We adopt the well-adapted three-layer BPNN, as depicted in Fig 4.

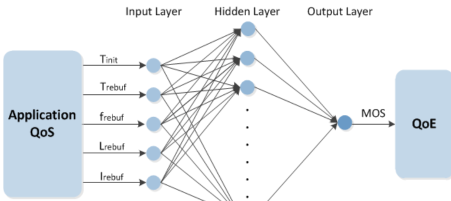


Fig. 4. A three-layer BPNN.

There are five neural nodes in the input layer of BPNN to receive selected application performance metrics: initial buffering time, mean rebuffering duration, rebuffering frequency, location of each pause and mean time interval of pauses. The output layer contains a single neural node: the average MOS. Since the number of hidden layer nodes has significant influence on the BPNN, based on the error convergence rate and the mean square error, we choose 10 hidden layer nodes to construct the BPNN. The performance of the BPNN will be shown in section V.

IV. Subjective Tests and Experiments

This paper performed experiments and subjective tests twice.

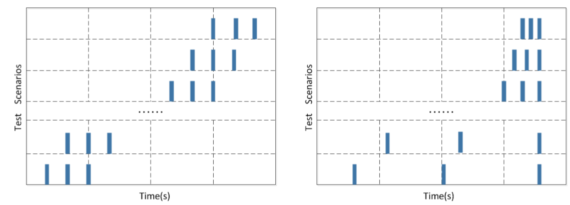
First, subjective tests 1 mainly studied the effects of pause position on QoE, and therefore, three groups of test scenarios were constructed to analyze the location of each pause and time interval of pauses. Second, we used ns-2 to simulate a TCP Reno flow, varying the RTT and packet loss rate, and then, subjective tests 2 were carried out to assess how application performance metrics affect the QoE quantitatively. Table I summarizes the characteristics of the video clip.

TABLE I. Characteristics of Video Clip

Items	Parameters
Video Length	60s
Video Format	H.264
Audio Format	ACC
Resolution	1280 * 720
File Format	FLV
Frame Rate	29.97fps

A. Subjective Tests 1

In the first subjective tests, pause position was considered a consequence. In order to assess how the location of each pause and the time interval of pauses affect the QoE, three groups of test scenarios were built, ensuring the same number of pauses and mean rebuffering duration, as shown in Fig. 5. These scenarios have three pauses, however, the pauses are arranged at different locations of the video clip: Group 1, the time interval of pauses is 5s, and the pauses are distributed across several locations (front, middle, tail - 9 scenarios); Group 2, the location of the last pause is fixed, while the time interval of pauses is changing (1s, 3s, 5s, 7s, 9s, 11s, 13s, 15s, 17s, 19 - 10 scenarios); Group 3 of scenarios, the location of the first pause is fixed, and the time interval of pauses is changing as Group 2.



(a) Test scenarios of Group 1 (b) Test scenarios of Group 2

Fig. 5. Test scenarios used as reference.

B. Simulation and Subjective Tests 2

TABLE II. Specifications of Simulation

Items	Parameters
Packet Loss Rate	0,2,4,6,8%
RTT	20,40,60,80,100,120s
T0	3*RTT
Packet Size	2000B
Window Size	20

The experiments were constructed using the ns-2 simulator to simulate a TCP Reno flow. A separate module was added to acquire the buffer behaviors. There was only one video stream and no background traffic. We varied the RTT and packet loss rate, which affect the buffer behaviors and TCP throughput. The packet loss occurrence timing, with an element of randomness, was varied regarding the level of buffer occupancy. The buffer size δ was set to 2 seconds, and β was set to 0.5 seconds. Table II shows the specification of the simulation.

Then we carried out the second subjective tests to assess how application performance metrics affect the QoE. Five APMs (T_{init}, T_{rebuf}, f_{rebuf}, L_{rebuf}, I_{rebuf}) were calculated by buffer behaviors obtained from the simulation, and the scenarios of video used in the subjective tests were built in accordance with these AMPs.

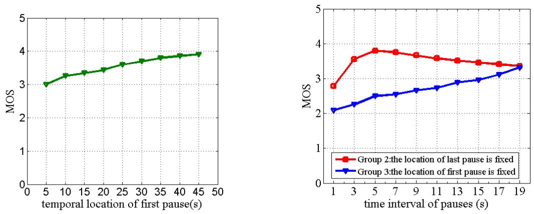
V. Results and Analysis

We selected 54 assessors from different background with no experience in assessing video quality. We processed the sample data, according to ITU P.910 [7] and ITU-R BT.500-13 [8].

A. Effects of Pause Position

Fig. 6(a) depicts the average MOS of Group 1 in subjective tests 1. MOS increases while the pause locations move backward.

It is demonstrated that pauses in the front part of the video have a higher negative effect, compared with in the final parts. This is probably because pauses in the early period may leave an annoying first impression on users allowing for the human psychology, and it is very likely to affect the quality of user experience throughout the whole video. So the location of each pause plays an important role in assessing video quality.



(a) Group 1 (b) Group 2 & 3

Fig. 6. The average MOS in subjective tests 1.

The red curve in Fig. 6(b) represents the average MOS of Group 2, in which the location of last pause is fixed. At this point, longer time interval of pauses makes pause locations moving forward. If the location of each pause was the only factor considered, this average MOS should degrade all the time. On the contrary, it increases at first. This is because each pause is also affected by other pauses, especially the adjacent ones. Consequently, time interval of pauses should also be taken into account. As the red curve in Fig. 6(b) illustrated, when occurrence timings of pauses are closer, time interval of pauses is the main factor. Therefore, MOS rises while time interval of pauses gets long. However, when time interval reaches a certain value (5s in this paper), the location of each pause becomes the main factor, and an inflexion point of MOS appears. MOS begins to decline owing to the effects of location of each pause. If pause locations move backward, with time interval of pauses becoming longer, the average MOS increases without doubt. The blue curve in Fig. 6(b) shows this tendency of MOS.

B. BPNN for QoE and Application QoS

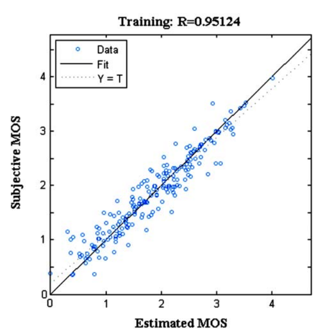


Fig. 7. Correlation coefficient of estimated MOS and subjective MOS.

We normalized the samples, which were collected from subjective tests 2, and then trained them with BPNN. Regression R values - the correlation coefficient of estimated MOS and subjective MOS - were calculated to illustrate the performance of BPNN, which was designed in section III, as shown in Fig. 7.

VI. CONCLUSION

In this paper, we assessed the QoE of HTTP video streaming considering the effects of pause position, and therefore proposed two new application metrics: location of each pause and time interval of pauses.

Subjective tests were performed to study how pause position factors affect the QoE. Results showed that pauses in the front part have a higher negative effect, and the negative effect gradually weakened when the locations of pause move backward. Also, it was proved that the shorter time interval of pauses would make a higher negative effect as well. Then we carried out subjective tests and experiments to assess five application performance metrics (initial buffering time, mean rebuffering duration, rebuffering frequency, location of each pause and mean time interval of pauses) and established Back Propagation Neural Net to map the application QoS to the QoE.

Future work will be focused on the improvements of the QoE based on the network QoS and the application QoS management.

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