

# Admission Control for Wireless Adaptive HTTP Streaming: An Evidence Theory Based Approach

Zhisheng Yan  
The State University of New  
York at Buffalo

Chang Wen Chen  
The State University of New  
York at Buffalo

Bin Liu  
University of Science and  
Technology of China

## ABSTRACT

In this research, we propose an evidence theory based admission control scheme for wireless cellular adaptive HTTP streaming systems. This novel scheme allows us to effectively address the uncertainty and inaccuracy in QoE management and network estimation, and seamlessly grant or deny the access requests. Specifically, based on recent work of QoE continuum model and QoE continuum driven adaptation algorithm, we utilize Dempster-Shafer evidence theory to assign proper degree of belief to admission, rejection and an uncertainty decision for each user's evidence. We then can strategically combine the weighted evidence of multiple users and make the final decision. The evaluation results show that the proposed scheme can provide satisfactory QoE for both existing and new users while still achieving comparable bandwidth efficiency.

## Categories and Subject Descriptors

H.5.1 [Multimedia Information Systems]: Video

## General Terms

Algorithms; Human Factors

## Keywords

Adaptive streaming; admission control; QoE continuum; evidence theory

## 1. INTRODUCTION

In the past few years, video streaming over wireless Internet has been rapidly booming, thanks to the development of high-performance smart phones, tablets, and laptops, as well as the growing demand of watching videos anywhere and anytime. In an effort to improve the bandwidth efficiency of HTTP streaming in wireless environment, adaptive HTTP streaming has recently been standardized [1]. The source video is encoded in several quality versions and is split into small segments. At each switching point, the client requests

the most appropriate segment based on the network conditions. That way, the user can enjoy the video with highest possible quality while still efficiently utilizing the bandwidth.

Many rate adaptation schemes have been proposed to enhance the Quality of Experience (QoE) of users [2–5]. They all assume that the number of users in the system is fixed and the available bandwidth of a client is always larger than the lowest video bit-rate. However, the number of users changes dynamically in reality. When the number of streaming flows is so large that the total bandwidth requirement is beyond the system capacity, users would experience QoE degradation. To overcome such challenges, proper network regulation policy is critically needed to grant or deny the service requests from new users.

One challenge of designing such an effective admission control scheme is to appropriately assess users' QoE in order to make a QoE-driven decision. Although reasonable QoE modeling improves system design, such objective QoE assessment cannot adequately reflect subjective human feeling. This is especially true when mobile users are watching video under time-varying environment. Another crucial challenge is how to handle the system uncertainty introduced in network estimation and admit/reject the new user accordingly. Due to the time-varying fading and path loss, estimating network status of wireless networks is generally of uncertainty and dynamics. The probability of different network status is also not known accurately. Thereby, both uncertainty and inaccuracy need to be effectively captured during the admission control.

Admission control in wireless networks was originally studied for cellular networks with general data services. A comprehensive survey on admission control in wireless networks was presented in [6]. Admission control schemes for wireless video services have been recently proposed. They usually formulate admission constraints by considering available bandwidth [7, 8], objective QoE metric [9] or QoE distribution [5], and multiple QoS parameters using cross-layer notion [10]. However, most of the existing works are not targeted at adaptive HTTP streaming, where both the initial request of the new user and the current service of existing users can be adjusted in order to accommodate the new user. More importantly, all of them adopt an on-off decision-making logic, as illustrated in Fig. 1. The admission probability would be 1.0 as long as certain decision scores are larger than the thresholds and vice versa. Considering the various types of system uncertainty, such deterministic logic lacks flexibility and could cause inaccurate decisions when the estimated decision score (e.g., 0.21) is close to the thresh-

Permission to make digital or hard copies of all or part of this work for personal or classroom use is granted without fee provided that copies are not made or distributed for profit or commercial advantage and that copies bear this notice and the full citation on the first page. Copyrights for components of this work owned by others than ACM must be honored. Abstracting with credit is permitted. To copy otherwise, or republish, to post on servers or to redistribute to lists, requires prior specific permission and/or a fee. Request permissions from [permissions@acm.org](mailto:permissions@acm.org).

MM'14, November 3–7, 2014, Orlando, Florida, USA.

Copyright 2014 ACM XXX-X-XXXX-XXXX-X/XX/XX ...\$15.00.

old (e.g.,  $\theta = 0.2$ ). Besides, the decision score in existing work is usually obtained by averaging the individual score of each user. Such simple combination logic fails to recognize the different contribution of each individual user.

The major contribution of this research is in the development of an admission control scheme for adaptive HTTP streaming within one wireless cell. It can guarantee the QoE of both new and existing users, and minimize the negative effects of system uncertainty while efficiently utilizing the bandwidth. Specifically, we first adopt a *QoE continuum* driven rate adaptation algorithm to effectively improve the playback quality and smoothness of users. By exploiting *Dempster-Shafer evidence theory*, we recognize the adaptation results as the evidence for the usual admission and rejection decision, as well as an additional ‘‘uncertainty’’ decision in order to address the inflexibility in on-off decision logic. We then derive the overall belief for each decision from multiple user evidences by using differential trust weighting. This way, the proposed scheme is able to handle system uncertainty and most efficiently regulate the network access.

## 2. SYSTEM MODELS

### 2.1 System Architecture

In the proposed streaming system, the source video is split into segments with the same length  $T$ . Each segment is encoded into multiple levels of quality. Since modern internet videos are usually variable-bit-rate video, a single-value representation using average bit-rate may not accurately reflect the actual size of each individual segment to be downloaded. Hence, we propose to adopt fine-grained video representations and characterize the video segment by a tuple represented by quantization parameter and file size, i.e.,  $(\mathbf{QP}, \mathbf{FS})$ , in order to capture video characteristics in a segment scale and execute more efficient adaptation.

In this research, we consider a wireless adaptive HTTP streaming system under cellular environments. The proposed admission control scheme targets at one cell, where  $\mathcal{U}$  is the set of users and each user is indexed by  $i, i = 1, 2 \dots N$ . For simplicity of discussion, we assume that one user can only establish one streaming flow with the server.

Under the wireless shared bandwidth, individual adaptation and admission control using local information by each client could lead to unfair and inefficient performance. For instance, even though two clients have the same channel condition and priority, the client with an initial request for higher quality tends to continuously request a high-quality video and vice versa for the client with low-quality initial request. This is because the two clients remain a high and low local throughput measurement, respectively. In fact, if the second client knows the condition and priority of the first client, it could have requested a better video such that two users achieve a relatively fair experience, e.g., a medium-quality video. Therefore, we propose to move the intelligence of adaptation and admission control to base station (BS) while not intervening the standard adaptive HTTP streaming architecture. Thus we can explore the collective knowledge and constraints of multiple streams. The proposed system works as follows. The video server initially sends out the Media Presentation Description so that video representation information is available to the users and BS. At each adaptation period whose length equals to the segment length, a user requests a segment based on throughput calculation that needs very low complexity. This request can be recog-

nized as a *naive suggestion* and thereby no corresponding local client’s operating system or hardware optimization is operated, which indicates there would be no conflict if the client request is modified. Instead of relaying the request directly, BS in the proposed system will intercept the request and may revise the client request based on the cell-wide adaptation strategy. Notice that information feedback from the clients is used for the BS adaptation. This is feasible under current adaptive HTTP streaming framework because 3GPP has standardized the quality metrics reporting process for clients [1]. If there is a new user request before the current switching point, BS would proceed to the admission control, wherein the current QoE and estimated QoE are regarded as the evidence for the decision-making process to ensure the QoE provision for both existing users and new user. This way, all users are able to enjoy the video with optimized QoE while neither the user nor the video server is aware of the adaptation and admission control done by BS.

### 2.2 QoE Continuum Driven Adaptation

QoE at a certain moment should be assessed in a temporally continuous manner by considering both the previously displayed frames and currently displayed frame. Hence, we adopt a QoE continuum model [11], which has been extensively validated by using various types of tests and videos. The QoE continuum experience  $E$  at frame  $j$  can be derived as the weighted sum of instantaneous experience over all displaying moments until the measuring moment, i.e.,

$$E_j = \lambda E_{j-1} + (1 - \lambda)e_j \quad (1)$$

where  $E_{j-1}$  is the QoE continuum experience at the previous frame,  $\lambda$  is the memory constant that characterizes the importance of previous viewing experience, and  $e_j$  is the instantaneous experience at frame  $j$ .  $E_j, |e_j|$  and  $\lambda$  all belong to  $(0,1]$ . Details on how to calculate  $e_j$  that is decided by  $QP$  can be found in [11].

To guarantee the QoE continuum among multiple clients, we adopt the same adaptation algorithm in [4]. BS can find the optimal level of video segment, indicated by  $(QP, FS)$ , for each user  $i$  at time  $t$  by solving an optimization problem, where the objective is to maximize the average QoE continuum of all possible users at next switching point  $t + T$ , subjective to the cellular resource constraint, i.e.,

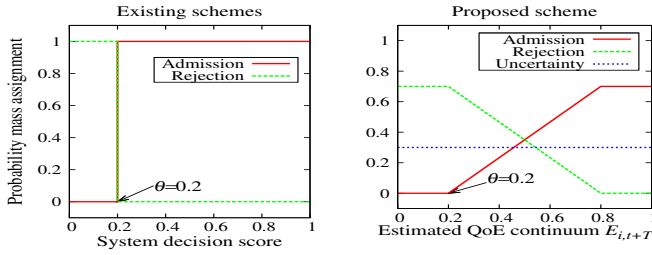
$$\begin{aligned} \max_{(\mathbf{QP}, \mathbf{FS})} \quad & \frac{1}{N} \sum_{i \in \mathcal{U}} E_{i,t+T} \\ \text{s. t.} \quad & \sum_{i \in \mathcal{U}} \frac{FS_i}{TB_{i,max}} \leq 1 \end{aligned} \quad (2)$$

where  $B_{i,max}$  is the maximum bandwidth of user  $i$  that can be mapped from channel quality indicator using 3GPP standard table. Based on the current buffer status feedback from the users and a given quality level,  $E_{i,t+T}$  can be calculated using (1). The adaptation wisdom behind (2) is to assign higher quality level to those users who are experiencing lower QoE continuum and a better channel status. The optimization problem can be efficiently solved by using a greedy algorithm [4].

## 3. PROPOSED ADMISSION CONTROL

### 3.1 Applying Evidence Theory

Recall that the criterion for admission control is whether or not admitting the new request would undermine the QoE continuum of existing users or the new user in the near future. How to make a system-level decision based on estimated QoE of multiple users is non-trivial due to the system



**Figure 1: Probability mass assignment in existing schemes and the proposed scheme ( $\theta = 0.2$ ).**

uncertainty. Here we propose to exploit Dempster-Shafer evidence theory (DST) [12], wherein the degree of belief for different decisions can be obtained from the evidence of estimated QoE. We prefer DST because it allows for assigning support to not only single hypothesis but also to union of hypotheses. Here we introduce an uncertainty decision  $U$ , which means either admitting ( $AD$ ) or rejecting ( $RJ$ ) the new user is acceptable. In other words, we can assign degree of belief to  $U$  if certain part of evidence provides no support to either  $AD$  or  $RJ$ . This is especially more plausible than on-off decision logic, where only the definitive decisions (i.e.,  $AD$  and  $RJ$ ) are supported. Moreover, unlike existing schemes that acquire the system decision score by averaging individual user scores, we propose a DST-based weighting method to combine the estimated QoE of multiple users.

### 3.2 Making Admission Decision

The admission control scheme starts by estimating user  $i$ 's QoE continuum,  $E_{i,t+T}$ , at the next switching point. This is accomplished by running the adaptation algorithm with the assumption that the new user is admitted using (2). In DST, the probability mass assignment  $m_i$  is a value in  $[0,1]$  indicating how much support that user  $i$  provides to a certain decision and the total  $m_i$  of all possible decisions is 1.0. Here we use the simple yet effective piecewise linear assignment [12]. Furthermore, we apply a weight factor for each user using differential trust scheme [12] in order to account for their different level of uncertainty and trustiness. The  $m_i$  for  $AD$ ,  $RJ$ , and  $U$  decision can be expressed as

$$m_i(AD) = \begin{cases} 0 & E_{i,t+T} \leq \theta \\ \omega_i \left( \frac{1}{1-2\theta} E_{i,t+T} - \frac{\theta}{1-2\theta} \right) & \theta < E_{i,t+T} < 1 - \theta \\ \omega_i & E_{i,t+T} \geq 1 - \theta \end{cases} \quad (3)$$

$$m_i(RJ) = \omega_i - m_i(AD) \quad (4)$$

$$m_i(U) = 1 - m_i(AD) - m_i(RJ) = 1 - \omega_i \quad (5)$$

where  $\omega_i$  is the weight factor of user  $i$  and  $\omega_i \in [0,1]$ . The illustration of the probability mass assignment is shown in Fig. 1. The rationale behind such assignment is that although  $E_{i,t+T}$  going over and under certain thresholds ( $1 - \theta$  and  $\theta$ ) leads us towards a quite certain decision, our beliefs should be treated with an increased support in between. Furthermore, by applying the differential trust scheme, the probability mass assigned to the uncertainty decision of the relatively untrusted users is effectively raised. That way, we can take into account the trustiness of each user and accordingly enhance the accuracy of the assignment.

The weight factor is dictated by the user evidence's historical impact to the system decision. Provided that the new user is eventually admitted, user  $i$ 's evidence is considered as

**Table 1: Encoding Parameters of Source Video**

	$l_1$	$l_2$	$l_3$	$l_4$	$l_5$
Seg 1 (bytes)	11924	23399	46128	92394	124772
Seg 2 (bytes)	11098	22067	42383	84770	115719
Seg 3 (bytes)	9300	20041	40242	82783	113240
Seg 4 (bytes)	11715	23217	44488	89569	121986
Seg 5 (bytes)	15619	30158	56136	106233	140522

positive if user  $i$  provides more support to  $AD$  than  $RJ$  and all users can indeed enjoy satisfactory watching experience during the next period. However, if user  $i$  supports more to  $RJ$  or any user experiences unacceptable video, the evidence is regarded as negative. If the new user is ultimately rejected, the rationale is similar. Hence, the weight factor is given by

$$\omega_i(t) = (1 - \rho) \sum_{g=1}^{\infty} c_i(t - gT) \rho^g \quad (6)$$

where  $\rho$  is the remnant factor that indicates how rapidly the past performance would be disregarded,  $c_i(t) = 1$  when the user evidence at  $t$  is positive and  $c_i(t) = 0$  otherwise.

By using the Dempster's rule of combination, we can then infer the system decision in a collaborative fashion based on individual support from the users. The combined probability mass assignment of user  $i$  and  $j$  for  $AD$  is given by

$$m_{i,j}(AD) = \frac{1}{1 - K} \sum_{H_i \cap H_j = AD \neq \emptyset} m_i(H_i) m_j(H_j) \quad (7)$$

where  $K = \sum_{H_i \cap H_j = \emptyset} m_i(H_i) m_j(H_j)$ .  $H_i$  and  $H_j$  is the hypothesis of user  $i$  and  $j$ , respectively (i.e.,  $AD, RJ$  or  $U$ ). Since the Dempster's rule of combination is associative, we can combine the individual support from more than two users accordingly. Finally, the belief and plausibility of  $AD$  can be expressed as follow.

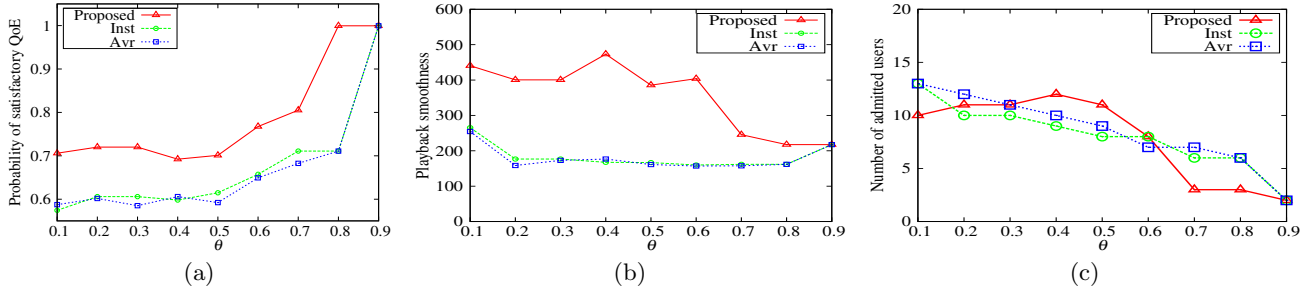
$$bel(AD) = \sum_{H \subseteq AD} m_{combo}(H) \quad (8)$$

$$pl(AD) = \sum_{H \cap AD \neq \emptyset} m_{combo}(H) \quad (9)$$

Similarly, the belief and plausibility of rejection and uncertainty decision can be calculated and then the final decision can be made by comparing the belief and plausibility of  $AD$  and  $RJ$  decision. The decision with larger belief or larger plausibility (when beliefs for two decisions are equal) is considered as the final system decision.

## 4. PERFORMANCE EVALUATIONS

In this section, we compare the performance of streaming systems with different admission control schemes using ns-2. We implement two reference schemes (referred as *Inst* and *Avr*) that use instantaneous quality and average quality as the decision metric, respectively. Both reference schemes combine the scores from multiple users by averaging and make the decision using on-off logic. Here we focus on a 3G High-Speed Downlink Packet Access (HSDPA) network as the underlying cellular network using the simulation model in [13] with typical network settings. We encode the "Stefan" test sequence into 5 levels H.264/AVC video with  $QP \in \{47, 42, 37, 32, 30\}$  using JM 18.4 encoder. The segment length  $T$  is 2 seconds and the frame rate is 25 fps. The test sequence has 250 frames and these 5 segments are repeatedly streamed. The file size  $FS$  of each segment for each level  $l$  is shown in Table 1. We set  $\lambda$  to be 0.71 [11] and  $\rho$  to be 0.5. The initial  $E_{i,t}$  and  $\omega_i$  are both 1. Initially, two



**Figure 2: Evaluations results: a) Probability of satisfied QoE versus  $\theta$ ; b) Expected length of one playback round without level change versus  $\theta$ ; c) Number of admitted users after the evaluations versus  $\theta$ .**

users are enjoying the video services. The service request rate is one user per ten seconds. Note that we assume users will not end services during the evaluations.

We compare the performance of different systems under various  $\theta$ , whose significance was introduced in Fig. 1. We disregard the cases where no admission ( $\theta = 1$ ) or no rejection ( $\theta = 0$ ) is allowed. We show the probability of satisfactory QoE (i.e.,  $E_{i,t} > 0.5$ , which corresponds to  $MOS > 3$ ) in Fig. 2a. We observe that a user is more likely to be satisfied with the video by using the proposed system since new request is admitted only if the QoE continuum of both the new and existing users can be ensured. When  $\theta$  increases to 0.9, all new requests turn out to be rejected in three systems, which brings the equal 1.0 probability of QoE satisfaction. Note that the satisfaction is not accomplished at the expense of bandwidth utilization, which we will discuss later.

To evaluate the video consistency, we employ the playback smoothness metric in [3]. The metric is defined as the expected length of one playback round without level change, i.e.,  $\sqrt{\sum_{p=1}^P (n_p^2)/P}$ . Here the continuous playback of one level is defined as one round and it consists of  $n_p$  frames. There are  $P$  rounds in total. As shown in Fig. 2b, the proposed scheme attains a significant better playback smoothness, which in turn contributes to its higher QoE continuum.

We also show the number of admitted users after the evaluation ends to evaluate the bandwidth utilization. Such user number can be treated as stable since we found that the evaluation time (200 seconds) is long enough and all systems keep a constant user number after 165th second. In Fig. 2c, we observe that the proposed system achieves a comparable bandwidth utilization as the reference systems.

## 5. CONCLUSION

In this paper, we propose an evidence theory based admission control scheme to address the issues caused by inaccurate QoE and network measurement in cellular adaptive HTTP streaming. By assigning degree of belief to the uncertain decision and combining the weighted individual user support, we can derive a system decision that guarantees QoE continuum and bandwidth utilization. Future work shall be focused on extending the linear user request model to more general cases. Besides, the termination of services needs to be dynamically considered in developing future admission control schemes.

## 6. ACKNOWLEDGMENTS

This research is supported by NSF Grant 1405594 and NSF Grant 0915842.

## 7. REFERENCES

- [1] Progressive download and dynamic adaptive streaming over http. 3GPP TS 26.247 v12.1.0, 2013, Available: <http://goo.gl/4EJbvd>.
- [2] T. Wirth, Y. Sánchez, B. Holfeld, and T. Schierl. Advanced downlink lte radio resource management for http-streaming. In *ACM MM*, pages 1037–1040, Nara, Japan, October 2012.
- [3] S. Xiang, L. Cai, and J. Pan. Adaptive scalable video streaming in wireless networks. In *ACM MMSys*, pages 167–172, Chapel Hill, USA, February 2012.
- [4] Z. Yan, J. Xue, and C. W. Chen. Qoe continuum driven http adaptive streaming over multi-client wireless networks. In *IEEE International Conference on Multimedia and Expo (ICME)*, Chengdu, China, July 2014.
- [5] C. Chen, X. Zhu, G. de Veciana, A. C. Bovik, and Jr. R. W. Heath. Rate adaptation and admission control for video transmission with subjective quality constraints. *IEEE Journal of Selected Topics in Signal Processing*, 2014, early access.
- [6] M. H. Ahmed. Call admission control in wireless networks: A comprehensive survey. *IEEE Communications Surveys and Tutorials*, 7(1):50–69, 2005.
- [7] P. Koutsakis. Using traffic prediction and estimation of provider revenue for a joint geo satellite mac/cac scheme. *Wireless Networks*, 17(3):797–815, April 2011.
- [8] M. Halldórsson and P. Mitra. Wireless capacity and admission control in cognitive radio. In *IEEE INFOCOM*, pages 855–863, Orlando, March 2012.
- [9] K. Piamrat, A. Ksentini, C. Viho, and J. Bonnin. Qoe-aware admission control for multimedia applications in iee 802.11 wireless networks. In *IEEE VTC-Fall*, pages 1–5, Orlando, USA, September 2008.
- [10] R. Balakrishnan and B. Canberk. Traffic-aware qos provisioning and admission control in ofdm hybrid small cells. *IEEE Transactions on Vehicular Technology*, 63(2):802–810, February 2014.
- [11] J. Xue, D.-Q. Zhang, H. Yu and C. W. Chen. Assessing quality of experience for adaptive http video streaming. In *IEEE ICME Workshop on Emerging Multimedia Systems and Applications*, 2014.
- [12] H. Wu. *Sensor Data Fusion for Context-aware Computing Using Dempster-Shafer Theory*. PhD thesis, Carnegie Mellon University, 2003.
- [13] A. M. Mutairi and U. A. Baroudi. Ns-2 enhancements for detailed hsdpa simulations. In *Proc. of 3rd VALUETOOLS*, Brussels, Belgium, October 2008.