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# A hybrid model of the Akamai adaptive streaming control system[☆]

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ABSTRACT

Video streaming is the application generating the largest fraction of the Internet traffic. Adaptive video streaming adds to classic video streaming the possibility of dynamically adapting the video bitrate to track the time-varying network available bandwidth, avoid playback interruptions and ensure the delivery of the best video quality. This work focuses on the adaptive video streaming control system employed by Akamai, a major Content Delivery Network operator whose video delivery system is used by several video streaming platforms, including Livestream. Differently from the typical client-side control, Akamai employs an interesting and unique hybrid client/server control architecture. In this paper we propose and experimentally validate a closed loop mathematical model of the control system in the form of a hybrid automaton. The model is analyzed to derive key properties which can be used to properly tune the controller parameters.



## 1. Introduction

Today, multimedia applications produce an ever increasing fraction of the Internet traffic [1]. Video streaming is the most important application driving this trend. Examples such as YouTube and Netflix, which together account for more than half of US traffic during peak hours,[1] give evidence of the wide diffusion such applications have reached.

Adaptive video streaming represents a key innovation with respect to classic progressive download streaming. In fact, adaptive streaming systems can change the video bitrate to match the time-varying and unpredictable available bandwidth. Moreover, start-up latency can be minimized and video playback interruptions can be avoided.

Today, the leading approach to implement adaptivity, which is used – among the others – by YouTube, Netflix, and Akamai, is the *stream-switching*: the server encodes the video content at different bitrates, namely the video levels, and a control algorithm dynamically selects the video level to be sent based on measurements such as the available bandwidth and the player buffer length.

From the control architecture point of view, the mainstream approach is the one employed by the *Dynamic Adaptive Streaming over HTTP* (DASH) standard, which places the controller at the client and streams the video through standard HTTP (HyperText Transfer Protocol) servers [2].

In this paper, which is an extended version of [3], we focus on the proprietary adaptive streaming control system employed by Akamai, which is used by several video streaming services to implement a massive video distribution platform.

☆ This is an extended version of the paper De Cicco et al. (2014) [3] presented at the IFAC World Congress 2014.

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[1] Sandvine, "Global Internet Phenomena Report, 2014", 2014, https://www.sandvine.com/trends/global-internet-phenomena/.

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Since its source code is not available and cannot be inspected, in De Cicco and Mascolo [4] an experimental testbed has been used to investigate its control system. It has been shown that the Akamai control system employs an interesting and unique hybrid architecture that is distributed at the client and the server. In De Cicco and Mascolo [4] the key features of the Akamai adaptive video streaming algorithm were identified and experimentally validated. However, a rigorous mathematical model of the control system was missing. In this paper we make the following contributions: (1) we propose a model of the client playout buffer; (2) we design a hybrid automaton rigorously modeling the Akamai control system, which shows a tight interaction between time-discrete and time-continuous dynamics; (3) we derive several control system properties that can be used for tuning the controller parameters; (4) an experimental validation of the proposed hybrid automaton is given.

By analyzing the model we are able to provide tuning rules for the controller parameters to ensure that: (1) the optimal video level can be reached; (2) the playout buffer does not grow unbounded; (3) the interruption of the video reproduction due to the presence of an actuation time-delay is avoided.

The paper is organized as follows. Section 2 contains a review of the literature studying adaptive video streaming systems and an overview of the related work on hybrid models for computer network applications; Section 3 introduces the stream-switching approach; in Section 4 the dynamics of the playout buffer is derived; the model of the Akamai control system is proposed in Section 5 and several properties of the system are derived in Section 6; finally, Section 7 provides the validation of the model.

## 2. Related work

The study of client-side adaptive streaming algorithms is a hot topic in the networking community. Recently, several authors have analyzed the issues of client-side adaptive streaming systems. Typically, such systems produce an on–off traffic pattern [5,6]: the video segments are downloaded during an ON phase and then, during the OFF phase, the player is kept idle until the next download is started. In Akhshabi et al. [7] it is shown that such on–off traffic pattern is the key factor causing unfair bandwidth utilization, server bandwidth underutilization and oscillation of the player requested video level. To tackle these issues, several adaptive streaming algorithms have been proposed so far. In Jiang et al. [8] FESTIVE has been proposed to address the fairness issues arising in a multi-client scenario. In Li et al. [9] the algorithm PANDA is proposed: a controller dynamically computes the segment inter-request time to address fairness issues and video bitrate oscillations. A different approach has been taken in Akhshabi et al. [10], where authors place a traffic shaper at the server with the purpose of ruling out the OFF phases when the player is in steady-state. In Huang et al. [11] a heuristic control approach to control the playout buffer avoiding OFF phases is taken at the client. The proposed algorithm does not require any bandwidth estimate. An extensive experimental section is presented, in which performance obtained by Netflix clients employing the proposed algorithm is shown. In Zhu et al. [12] a PI controller is employed to control the playout buffer. Instead, by using a feedback linearization approach De Cicco et al. [13] have designed a stream-switching controller which is able to avoid OFF phases without requiring server cooperation. Experimental results carried out in a controlled testbed are provided. In Yin et al. [14] an optimization problem is formulated to take a Model Predictive Control approach to control the playout buffer. The objective function to maximize expresses the user perceived Quality of Experience, which is related to the number of times the playout buffer gets empty.

Regarding the topic of hybrid modeling for computer networking applications, in Lee et al. [15] a hybrid model of both the buffer routers and the TCP (Transmission Control Protocol) congestion control algorithm is provided in the form of a hybrid automaton. The model is validated by comparing simulations of the hybrid models against packet-level simulations. Another relevant application is considered in Hespanha [16], which proposes a stochastic hybrid framework to model the TCP congestion control. Both the congestion-avoidance and slow-start modes for on–off TCP flows are considered in the model, which takes into account the distribution of the transmitted bytes. It is shown that, for transfer-size distributions reported in the literature, the standard deviation of the sending rate is much larger than its average and that the average sending rate varies slightly with the probability of packet drop. In Savkin et al. [17] the Medium Access Control (MAC) of a class of wireless communication networks is modeled through a hybrid framework. Some stabilizability conditions, which guarantee that any data packet in the wireless network will reach its destination within finite time, are provided. In Albea-Sanchez et al. [18] a hybrid model of a cluster of three servers has been proposed to design a load balancing hybrid controller. In particular, the controller aims at adapting the number of active servers to the total load of incoming requests in order to minimize energy consumption.

This paper enriches the state of the art by proposing, at the best of our knowledge, the first hybrid model of a real adaptive video streaming system.

## 3. The stream-switching approach

A video streaming system allows a client to reproduce the video that is sent by a remote server through an Internet connection. The client employs a playout buffer to absorb the instantaneous mismatches between the encoding bitrate and the network available bandwidth, which in best effort Internet is unpredictable and time-varying. However, if the bandwidth gets below the video bitrate for a sufficiently long time, the buffer will eventually get empty and a buffering phase will be triggered: the player gets paused for a time interval, the *buffering time*, allowing the buffer to reach a safety threshold before the playing can be resumed again.