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# A fuzzy logic-based AQM for real-time traffic over internet

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**Abstract**

Autonomic networking has been proposed as an approach to reduce cost and complexity of managing communication functions. An autonomic system is self-configuring, self-optimizing, self-healing and self-protecting. Such a system requires the minimum of administration, primarily involving policy-level management and AI-cognitive models. On the other hand, numerous Active Queue Management (AQM) algorithms have been proposed in the literature to address the problem of congestion in the Internet. Their performance is highly dependent on parameters' setting and tuning. Besides that, most of the AQM algorithms focus on throughput optimization and fail to provide bounded transmission delay while providing high link utilization to popular TCP-based radio/video streaming applications. Tackling the aforementioned concerns, in this paper we propose and evaluate a novel self-configuring AQM algorithm based on fuzzy logic. The proposed approach simplifies significantly the deployment and management of such complex QoS control mechanisms in the Internet providing at the same time a good tradeoff between link utilization and queuing latency. The introduced algorithm is compared with the most efficient adaptive AQM algorithms proposed to date such as ARED, REM, BLUE, PID and LRED. The performance analysis demonstrates that the proposed "Fast and Autonomic Fuzzy Controller" (FAFC): (1) minimizes queue fluctuation, (2) optimizes the throughput regardless of the traffic load variation and the presence of unresponsive UDP/RTP based voice and video communications, and (3) suggests the best compromise between link utilization and queuing delay.


*Keywords:* Internet; TCP-based streaming; Quality of Service; AQM; Self-configuring

## 1. Introduction

Today's Internet traffic is dominated by TCP flows. TCP uses several mechanisms to handle network congestion such as Additive Increase and Multiplicative Decrease (AIMD), Slow Start, Congestion Avoidance, Fast Retransmit and Fast Recovery. These mechanisms, while essential and powerful, are not sufficient to avoid congestion since it is detected only after changes in throughput, changes in end-to-end delay or packet drops. Moreover, TCP streaming is presently well accepted and widely used in commercial streaming systems. In fact, a recent measurement study has shown that a significant fraction of commercial streaming traffic uses

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TCP (with more than a two-to-one margin over UDP) [22]. There are also more and more multimedia applications with integrated congestion control behavior known as "TCPFriendly" (e.g., TFRC, DCCP) which underlines a new challenge for efficient handling of delay-sensitive TCP-like real-time traffic. Especially, there is a growing need to fairly regulate competing network flows in the Internet while maintaining a restricted end-to-end latency. This means that the network must participate more efficiently in controlling its own resource utilization [1]. Thereby, to mitigate such problems, Active Queue Management (AQM) has been introduced recently.

The basic philosophy of AQM is to trigger packet dropping (or marking, if explicit congestion notification (ECN) is enabled), at the routers' level, before buffer overflow occurs. For instance, RED [2] randomly drops the arriving packets with a probability that is proportional to its average queue length in order to detect baseline congestion. However, it is known that RED's algorithm is not sufficient to detect incipient congestion effectively. Furthermore, it presents many weaknesses and open issues [27], such as: (1) accurate parameter configuration and tuning, (2) short- and long-term queue behavior mismatch, (3) sensitivity to network-load variation, and (4) provisioning of quality of service guarantees.

Hence, recently many advanced forms of router queue management with adaptive behavior were proposed not only to avoid congestion but also to control it and to reach many other objectives such as: high link utilization, low drop rate and low packet queuing delay. However, the two main objectives of queue management: high link utilization and low packet queuing delay are often in conflict. Indeed, the AQMs minimizing the queuing delay such as REM [3], GREEN [4] or AVQ [5] suffer from packet loss and low link utilization. Besides, the AQMs maximizing the link utilization such as BLUE [6] suffer from large queuing delays.

New alternative AQMs address the tradeoff between link utilization and queuing delay. Hence, some AQMs try to maintain the queue length between a minimum and a maximum threshold, for instance: SC-RED [25], ARED [11], PD-RED [12] and H-RED [13]. Others AQMs try to stabilize the queue length at a certain reference value to decouple congestion measurement from performance measurement such as: loss ratio, queue length or delay. Examples of such approaches are PI [7], PD [8], PIP [9], SFC [10], DRED [14], FIPD [31], PAQM [15] and APACE [16].

Those mechanisms present a good tradeoff but do not avoid buffer overflow and buffer emptiness except from the new robust approaches like R-PI [17], ST-PI-PP [18], PID [19], SMVS [29], LRED [20] and FAFC [21] that minimize them.

Avoiding buffer overflow is an important issue in transporting QoS sensitive traffic. In fact, buffer overflow implies: (1) unnecessary consecutive packet drops and (2) an increase of the end-to-end delay, that often have perceptible nasty effects on delay sensitive application such as VoIP or video/radio streaming over HTTP. Moreover, avoiding buffer emptiness eliminates throughput drop and permits optimal link utilization. In addition, stable queuing delays are beneficial for real-time applications, such as voice transmission, and for reliable transport protocols, since they need to be able to estimate retransmission timeouts.

In light of the above observations, the present work proposes an autonomic, self-configuring and stateless robust AQM; and explains how it achieves all these features. The proposed AQM presents a new implementation of earlier work [21], incorporating several substantial changes to the original FAFC proposal while retaining its basic intuition and spirit. Indeed, the new proposal introduces: (1) a novel approach to set up the default parameters values, (2) a new design of the fuzzy controller outperforming the classical scheme, and (3) a new adaptation mechanism reducing the complexity of the FAFC algorithm. The adoption of FAFC tackles avoiding buffer overflow and buffer emptiness and in that way allows the controller to maximize the throughput and manage buffering delay. Besides, the proposed AQM algorithm is intended to be applied to: best effort traffic or differentiated-services better than best effort traffic class that does not have end-to-end bandwidth guarantees.

The remainder of the paper is organized as follows: Section 2 gives an overview of related work on AQM. Section 3 is devoted to the specification and analytical evaluation of the proposed "Fast and Autonomic Fuzzy AQM Controller" (FAFC). Section 4 presents the performance evaluation and results analysis through simulation. Finally, conclusions follow in Section 5.

## 2. Background on AQM approaches

Research activities on Internet dynamics show TCP congestion avoidance mechanisms, while essential and powerful, are not sufficient to avoid