International Journal of Mathematics and Soft Computing
Vol.5, No.1. (2015), 45 - 55.

ISSN Print : 2249 – 3328
ISSN Online: 2319 – 5215

Congestion control in high speed networks using fuzzy logic control

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Abstract

The tremendous growth of the internet and the advances of computer technology have been pushing forward computer networks for high speed and broad bandwidth. Congestion, being a non-linear and dynamic problem requires robust, possibly intelligent, control methodologies to obtain satisfactory performance. Fuzzy logic helps to increase throughput, reduction in packet drop and delays. In this paper, we illustrate the power of the methodology by the successful application of fuzzy based congestion control in the two diverse networking technologies of ATM and TCP/IP.

Keywords: Congestion control, Fuzzy Logic (FL), TCP, Computational Intelligence (CI), Available Bit Rate (ABR), Quality of Service (QoS), Explicit Rate (ER), Fuzzy inference engine (FIE).

AMS Subject Classification (2010): 60K30.

1 Introduction

Congestion is an important issue that can arise in packet switched network. Congestion is a situation in Communication Networks in which too many packets are present in a part of the subnet, performance degrades. Congestion in a network may occur when the load on the network (that is, the number of packets sent to the network) is greater than the capacity of the network (that is, the number of packets a network can handle).

1.1 Causing of Congestion

The routers are too slow to perform bookkeeping tasks (queuing buffers, updating tables, etc.) The routers' buffer is too limited. Congestion in a subnet can occur if the processors are slow. Slow speed CPU at routers will perform the routine tasks such as queuing buffers, updating table and the like slowly. As a result of this, queues are built up even though there is excess line capacity. Congestion is also caused by slow links. This problem will be solved when high speed links are used. But it is not always the case. Sometimes increase in link bandwidth can further deteriorate the congestion problem as higher speed links may make the network more unbalanced. Congestion can make itself worse [12]. If a router does not have free buffers, it starts ignoring/discarding the newly arriving packets. When these packets are discarded, the sender may retransmit them after the timer goes off. Such packets are transmitted by the sender again and again until the source gets the acknowledgement of these packets. Therefore multiple transmissions of packets will force the congestion to take place at the sending end.

1.2 Congestion Control in TCP/IP Networks

The congestion control schemes employed by the TCP/IP protocol have been widely studied. It has become clear [4] that the existing TCP congestion avoidance mechanisms, while necessary and powerful, are not sufficient to provide good service in all circumstances. Basically, there is a limit as to how much control can be accomplished from the edges of the network. Some mechanisms are needed in the routers to complement the end- point congestion avoidance mechanisms. Thus, Active Queue Management (AQM) mechanisms have been introduced to assist the TCP congestion control.

The AQM approach can be contrasted with the “Tail Drop” (TD) queue management approach, employed by common Internet routers, where the discard policy of arriving packets is based on the overflow of the output port buffer. Contrary to TD, AQM mechanisms [4] start dropping packets earlier in order to be able to notify traffic sources about the incipient stages of congestion. AQM allows the router to separate policies of dropping packets from the policies for indicating congestion. The use of Explicit Congestion Notification [23] was proposed in order to provide TCP an alternative to packet drops as a mechanism for detecting incipient congestion in the network. The ECN scheme requires both end-to-end and network support. An AQM-enabled gateway can mark a packet either by dropping it or by setting a bit in the packet’s header if the transport protocol is capable of reacting to ECN. The use of ECN for notification of congestion to the end-nodes generally prevents unnecessary packet drops. However, for ECN the adopted feedback scheme is based on a single bit, and thus it is not as rich as for ATM ABR. Given that, many AQM schemes have been proposed to provide high network utilization with low loss and delay by regulating queues at the bottleneck links in TCP/IP best-effort networks, including random early detection (RED) [9], adaptive RED (A-RED) [10], proportional-integral (PI) controller [11], and random exponential marking (REM) [1].

1.3 Congestion Control in ATM Networks

Congestion control in ATM based networks has been extensively researched. The complexity and immensity of the task was recognized early. Initially, there was a push for preventive control (that is, open loop type controls). This view was influenced by a predominant view that controls must reside at the edges of the network. Note that many researchers, even at the early stage, did not adopt that view [9]. Progressively, there was a shift from that view that feedback is essential for effective control, and finally that controls inside the network should not be precluded, at least to supplement preventive controls. Several feedback based control schemes were proposed for delay tolerant traffic, including: EPRCA [24], ERICA [13] and Predictive Adaptive control [19-20].

The ATM community concentrated its efforts on a mechanism to allocate bandwidth dynamically within an ATM network, while simultaneously preventing data loss. This effort culminated in the introduction of a service category by the ATM Forum, called available bit rate (ABR). A feedback control framework was selected to achieve these aims [2]. The proposed framework allows downstream nodes to periodically send information to the traffic sources relating to maximum cell rates that they can handle. The cell rate information is carried by a stream of resource management (RM) cells. While these cells pass through the switching nodes, the cell rate information contents of these cells are dynamically updated by the intermediate systems. This introduces a framework for multivalued feedback, which can be quickly send back to the source (sent by congested switches, that is, where is sensed).

This paper is organized as follows. In Section 2, we present our Fuzzy Logic Methodology for congestion control applied in both TCP/IP and ATM. Section 3 presents some indicative simulation evaluation, and finally in section 4 we offer our conclusions future work.

2 Fuzzy Logic Control System

Fuzzy Logic Control has been considered for IC (Intelligence Control). It is a methodology used to design robust systems that can contend with the common adverse synthesizing factors such as system nonlinearity, parameter uncertainty, measurement and modeling imprecision. In addition, fuzzy logic theory provides a convenient controller design approach based on expert knowledge which is close to human decision making, and readily helps engineers to model a complicated non-linear system. In fact, fuzzy logic control has been widely applied in industrial process control and showed extraordinary and mature control performance in accuracy, transient response, robustness and stability. These control algorithms are explicit in nature, and they depend on absolute queue length (the maximum buffer size) instead of the TBO to adjust the allowed sending rate. Nevertheless, these early designs have various shortcomings including cell loss (even though cell loss is used as a congestion signal to compute the rate factor, queue size fluctuations, poor network latency, stability and low utilization. Later, FLC was used in RED (Random Early Detection) algorithm in TCP/IP networks, to reduce packet loss rate and improve utilization. However, they are still providing implicit or imprecise congestion signaling, and therefore cannot overcome the throughput fluctuations and conservative behavior of TCP sources. We would like to integrate the merits of the existing protocols to improve the current explicit traffic congestion control protocols (like XCP, RCP, APIRCP and their enhancements) and form a proactive scheme based on some prudent design ideas such that the performance problems and excessive resource consumption in routers due to estimating the network parameters could be overcome.

Fuzzy logic control system design essentially amounts to (1) choosing the fuzzy logic controller input(s) and output(s), (2) choosing the preprocessing that is needed for the controller input(s) and possibly postprocessing that is needed for the output(s) (that is, normalization of the input and output values), and (3) designing each of the four components of the fuzzy logic controller shown in Figure 1.

A fuzzy logic control system is a nonlinear mapping between its inputs and output(s). The inputs and output(s) are crisp – real numbers. The fuzzification block converts the crisp inputs to fuzzy sets, the inference mechanism uses the fuzzy rules in the rule base to produce fuzzy conclusions and the defuzzification block converts these fuzzy conclusions into crisp output(s).

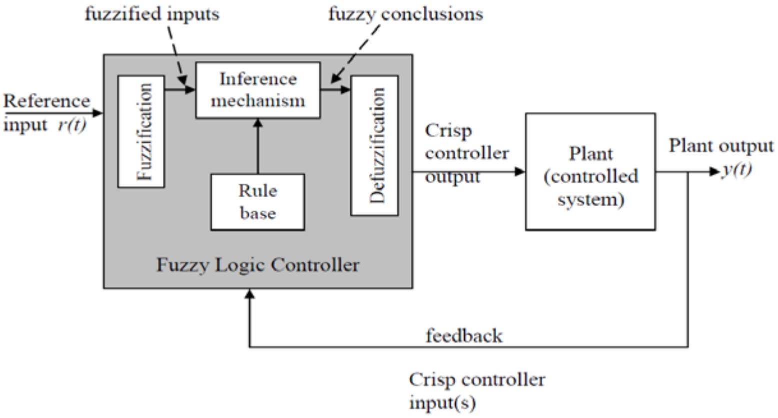

Figure 1: Fuzzy logic controller.

2.1 Fuzzy Explicit Rate Marking in ATM Networks

The proposed FERM scheme [21] is compliant with the ATM Forum Traffic Management Specification, version 4. Cell rates of data sources are adjusted by Explicit Rate (ER) information carried by Resource Management cells. The scheme, in the calculation of ER, monitors both the current queue length and its growth rate.

Based on these two inputs, the fuzzy controller computes the Flow Rate Correction (FRC -values between -1 and 1), and an Explicit Rate ERnext = ERcurrent+(FRC*Link Cell Rate) for the sources feeding the ATM switch. Periodical ER calculations are performed by the Fuzzy Logic Controllers located in each ATM switch. If, within the current control interval, the ATM switch receives an RM cell travelling to the upstream nodes, it examines the ER field of the cell and if this rate is greater than the calculated flow rate, it modifies the ER field with the calculated value and retransmits the RM cell.

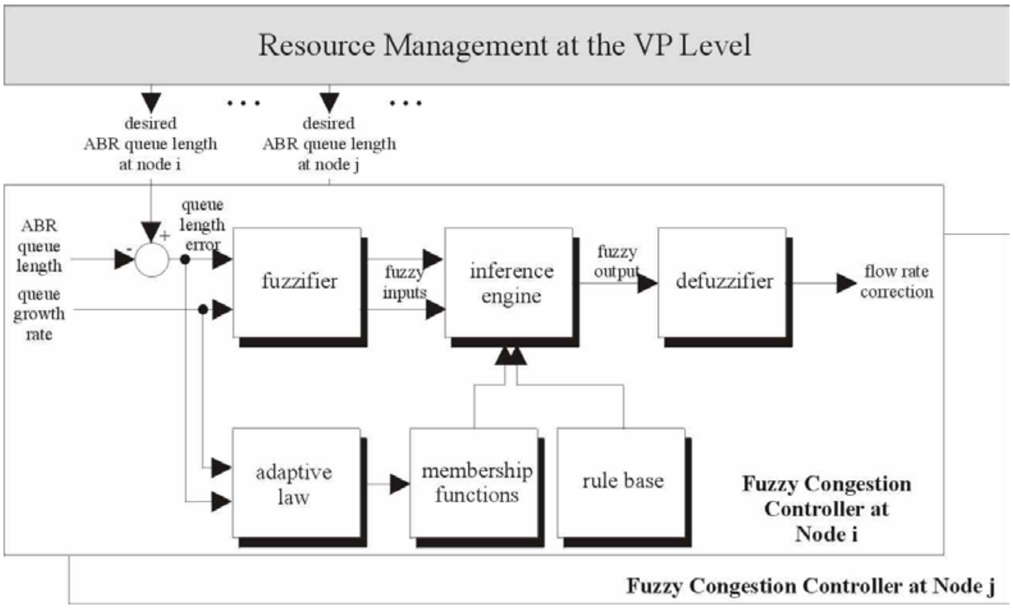

Figure 2: Block Diagram of FERM scheme.

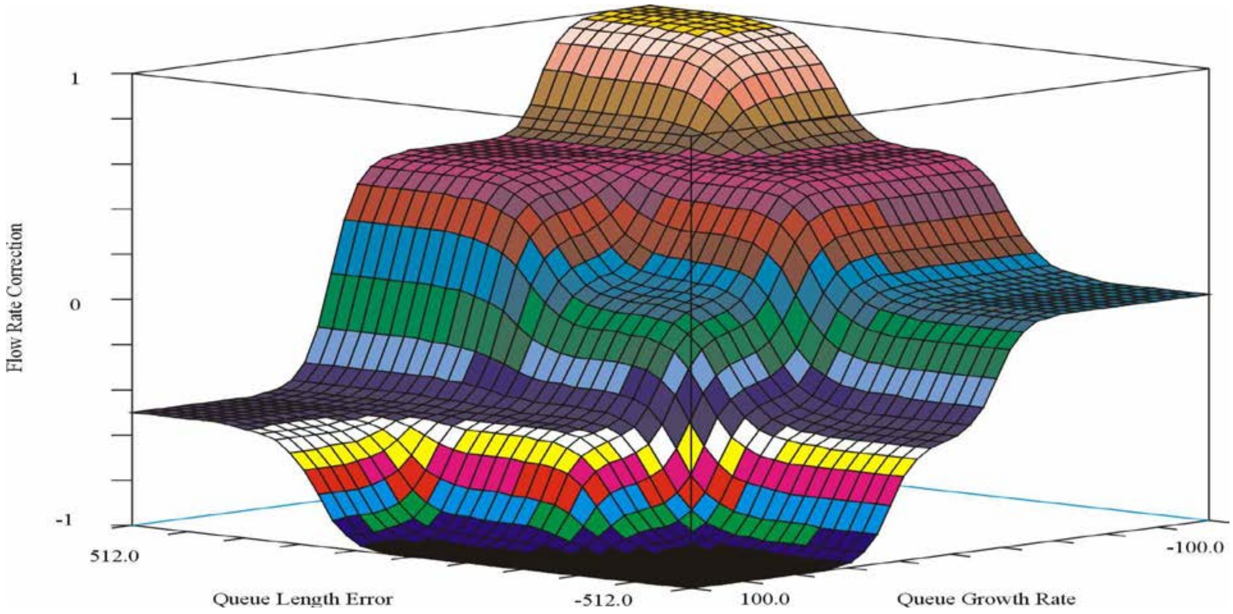

Figure 3: Control Surface of FERM scheme.

Figure 2 shows the block diagram of FERM. As can be observed from the control surface of FERM (Figure 3), it is a non-linear controller. For a certain queue length, it calculates different flow rate limits depending on the rate at which queue length varies.

2.2 Fuzzy Rate Marking (FEM) in TCP/IP networks

Our design of a fuzzy control system in TCP/IP networks [5-6, 8] is based on a fuzzy logic controlled AQM scheme to provide congestion control in best-effort networks. The system model of FEM is shown in Figure 4, where all quantities are considered at the discrete instant kT, with T the sampling period, e(kT) = qdes – q is the error on the controlled variable queue length, q at each sampling period, e(kT – T) is the error of queue length with a delay T (at the previous sampling period), p(kT) is the mark probability, and SGi and SGo are scaling gains.

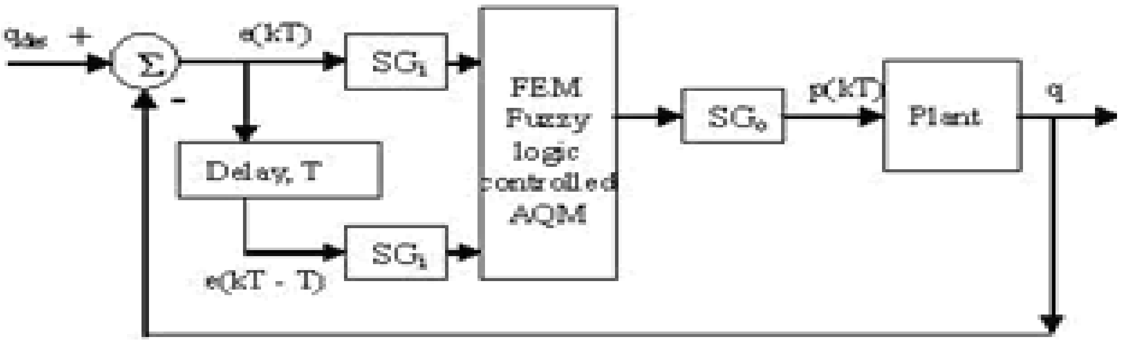

Figure 4: Fuzzy logic controlled AQM (FEM) system model.

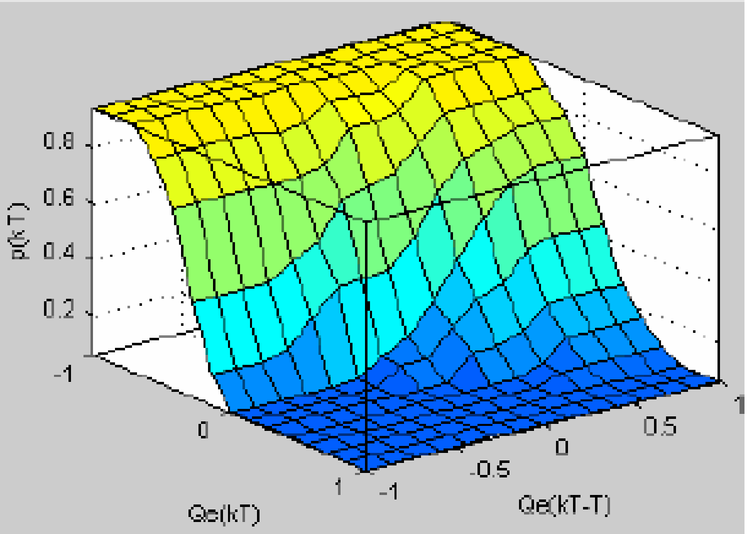

Figure 5: Control Surface of FEM Scheme

The proposed fuzzy control system is designed to regulate the queues of IP routers by achieving a specified desired TQL, qdes, in order to maintain both high utilization and low mean delay. A fuzzy inference engine (FIE) is designed to operate on router buffer queues, and uses linguistic rules to mark packets in TCP/IP networks. As shown in Figure 4, the FIE dynamically calculates the mark probability behavior based on two network-queue state inputs: the error on the queue length (that is, the difference between the desired (TQL) and the current instantaneous queue length) for two consecutive sample periods (which can be interpreted as a prediction horizon). We have implemented FEM with marking capabilities, so that FEM routers have the option of either dropping a packet or setting its ECN bit in the packet header, instead of relying solely on packet drops (for the rest of the paper, by marking a packet it is meant setting its ECN bit). The decision of marking a packet is based on the mark probability, which is dynamically calculated by the FIE.

The FIE uses linguistic rules to calculate the mark probability based on the input from the queues. Usually multi-input FIEs can offer better ability to linguistically describe the system dynamics. We expect that we can tune the system better, and improve the behavior of the queue, by achieving high utilization, low loss and delay. The dynamic way of calculating the mark probability by the FIE comes from the fact that according to the error of queue length for two consecutive sample periods, a different set of fuzzy rules, and so inference apply. Based on these rules and inferences, the mark probability is calculated more dynamically than other AQM approaches [9-11,1].

This point can be illustrated by observing the visualization of the decision surface of the FIE used in the FEM scheme (see Figure 5). An inspection of this decision surface provides hints on the operation of FEM. The mark probability behavior under the region of equilibrium (that is, where the error on the queue length is close to zero) is smoothly calculated. On the other hand, the rules are aggressive about increasing the probability of packet marking sharply in the region beyond the equilibrium point. These rules reflect the particular views and experiences of the designer, and are easy to relate to human reasoning processes and gathered experiences.

The design of FEM aims to provide better congestion control and better utilization of the network, with lower losses and delays than other AQM schemes [9-11,1], especially by introducing additional input variables and on-line (dynamic) adaptivity of the rule base (self-tuned).

The FEM controller has been evaluated in [5-6] considering both a single congested AQM router [8], and more realistic scenarios like a tandem network with multiple congested routers. Based on these results, the FEM scheme outperforms a number of representative AQM schemes in terms of regulated queues, packet losses, and link utilization.

3 Simulation Results of the Proposed Mechanism

3.1 Evaluation of Fuzzy Explicit Rate Marking

Extensive simulations, using OPNET Modeler [16], on a representative ATM network have been done [21], and a comparison is made between FERM and EPRCA. The results have been reported in [21]. Due to lack of space, we show here an indicative simulation result (see Figure 6 and 7), where we can observe the transient responses of ATM LAN under FERM and EPRCA control, respectively. FERM offers excellent transient behavior with good rise time, good settling time, and insignificant, if any, oscillations. Its transient behavior is much better than EPRCA, in the sense that FERM attains steady-state much faster, and that it offers “smooth” control (no or negligible oscillations present).

FERM is also shown [21] to exhibit many desirable properties, like robustness, fairness, and scalability.

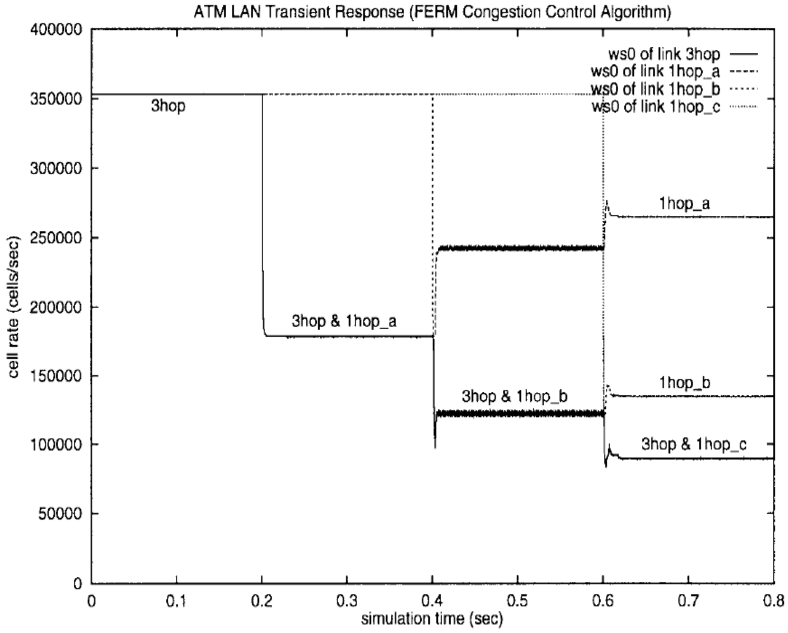

Figure 6: Cell rate transient response under FERM congestion control.

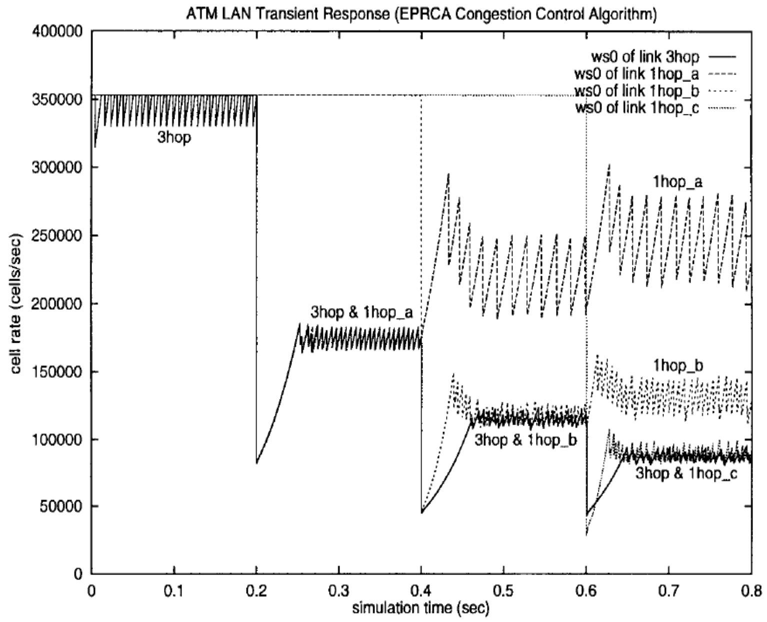

Figure 7: Cell rate transient response under EPRCA congestion control.

3.2 Evaluation Fuzzy Rate Marking

We have evaluated the performance and robustness of the recently proposed fuzzy logic based scheme, namely FEM AQM [5-7, 8], in a wide range of environments, and compare with other published results by taking some representative AQM schemes, namely A -RED [10], PI controller [11] and REM [1], using NS-2 [15] simulator. The performance evaluation examines the influence of both network and AQM parameters. In particular, the following have been examined: dynamic traffic changes, traffic load factor, heterogeneous propagation delays, introduction of short-lived TCP connections, different types of data streams, like FTP and

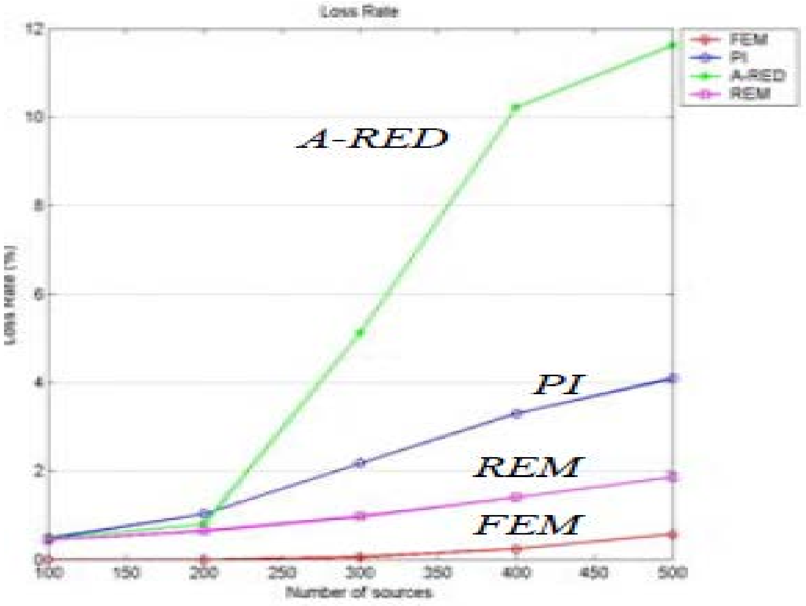

Figure 8: Loss Rate vs Traffic Load (for total traffic load of 250, 650, and 800 flows).

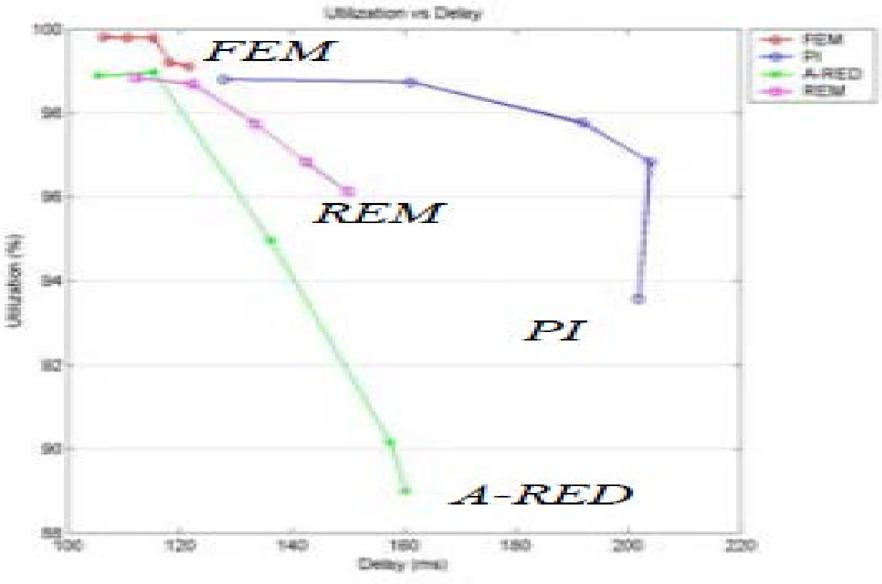

Figure 9: Utilization vs Mean Delay (for total traffic load of 250, 650, and 800 flows).

Web-like, as well as unresponsive UDP traffic, use of single- and multiple- bottleneck links, and various target queue lengths in order to examine the sensitivity of the AQM algorithms. The performance metrics used to compare the AQM schemes are the useful throughput, loss rate, and the mean queuing delay and its standard deviation. Schemes show a poor performance as the number of total traffic load increases, achieving much lower link utilization, and large queuing delays, far beyond the expected value. FEM also has the lowest variance in queuing delay, resulting in a robust behavior. On the other hand, the other AQM schemes exhibit very large queue fluctuations with large amplitude that inevitably deteriorates delay jitter.

4 Conclusion

In this paper we have presented a fuzzy logic control methodology that is applied in two various technologies: ATM and TCP/IP networks for congestion control. The design of the fuzzy knowledge base is kept simple, using a linguistic interpretation of the system behavior. We have successfully used the reported strength of fuzzy logic and have addressed limitations of existing alternative mechanisms. This is clearly shown from the extensive simulative evaluation [21, 5- 8]. From the results presented, using simple designs, we are optimistic that the Fuzzy Control methodology can offer significant improvements on controlling congestion in computer networks. Various enhancements of the proposed fuzzy based congestion control designs, such as adaptively, as well as the formal evaluation of the properties of the controllers are currently being investigated

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