Active Queue Management in TCP NetworksBased on fuzzy-PID Controller

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***Abstract-* We introduce a novel and robust active queue management (AQM) scheme based on a fuzzy controller, called hybrid fuzzy-PID controller. In the TCP network, AQM is important to regulate the queue length by passing or dropping the packets at the intermediate routers. RED, PI, and PID algorithms have been used for AQM. But these algorithms show weaknesses in the detection and control of congestion under dynamically changing network situations. In this paper a novel Fuzzy-based proportional-integral derivative (PID) controller, which acts as an active queue manager (AQM) for Internet routers, is proposed. These controllers are used to reduce packet loss and improve network utilization in TCP/IP networks. A new hybrid controller is proposed and compared with traditional RED based controller. Simulations are carried out to demonstrate the effectiveness of the proposed method and show that, the new hybrid fuzzy PID controller provides better performance than random early detection (RED) and PID controllers.**

Keywords- AQM, Fuzzy controller, Fuzzy PID controllers, PID controllers, adaptive hybrid controllers.

I. INTRODUCTION

Internet is the fundamental part for running many new applications such as Web, multimedia, etc. However, due to unpredictability in interference and number of users who may access Internet in a given time congestion may result. This brings about long delays in data transmission and frequently makes the queue length in the buffer of intermediate routers to overflow, and even may lead to total network collapse. An active queue management (AQM) scheme is one of the efficient tools which detects inceptive congestion and gives early notice of current Internet situation by dropping (or marking) the incoming packets before router queues become full. Recently, many active queue management (AQM) schemes have been proposed to increase network utilization by regulating queues at the bottleneck links in TCP/IP networks, including Random early detection (RED) [1], Adaptive RED (A-RED) [2], proportional-integral (PI) controller [3], and Random exponential marking (REM)[4]. Random early detection (RED) algorithm, the earliest well-known AQM scheme, was proposed and is now used in the Internet routers for reducing the flow synchronization problem and calming the traffic load via the measurement of average queue length..

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Unfortunately, RED causes oscillations and instability in the network due to the parameter variationsTherefore, some modified RED schemes have been introduced in the literature. Proportional-integral-derivative (PID) feedback control is a practical and simple control approach for controller design. This approach has been used to design and analyze various present AQM schemes in Internet congestion control.Based on linearized fluid TCP/AQM model, a proportional-integral (PI) controller was developed [5] to regulate the queue length, round trip time and packet loss. The virtual rate control (VRC) algorithm for AQM in TCP networks has been proposed in [6]. Additionally, a saturated nonlinearity of the control input usually exists in such a control problem due to the property of packet-dropping probability. Therefore, the effect of a saturated actuator should also be considered; otherwise it may cause serious degradation and instability of the network especially in large-scale, complex ones.In this paper, a PID controller for a time-delayed TCP/IP network with input saturation is developed to achieve a stable and desired queue length, low packet loss and high link utilization. Numerical simulations show that the proposed scheme is of good stability and is robust with respect to variations in number of TCP sessions.

II. AQM MECHANISMS

AQM mechanisms aim to provide high link utilization with low loss rate and queuing delay while reacting to load changes quickly. Several schemes have been proposed to provide congestion control in TCP/IP networks. RED, which was the first proposed AQM algorithm, simply sets some minimum and maximum marking thresholds in the router queues. In case the average queue size exceeds the minimum threshold, RED starts randomly marking packets based on a probability which depends on the average queue length, whereas if it exceeds the maximum threshold every packet will be dropped. The properties of RED have been extensively studied in the past few years. Here issues of concern are: problems with performance of RED under different scenarios of operation and loading conditions [7], the correct tuning of RED parameters which implies a ―global" parameterization which itself is a very difficult job if not impossible, as is shown in [9]. Some researchers have advocated against using RED, in part because of its tuning difficulty [8]. Linearity of the dropping function has also been questioned by some number of researchers.

A. Random Early Detection: RED

The RED active queue management algorithm allows network operators to simultaneously achieve high throughput and low average delay. However, the resulting average queue length is quite sensitive to the level of congestion and to the RED parameter settings, and is therefore not predictable in advance. Delay as a major component of the quality of service delivered to customers, is used by network operators to give a rough a-priori estimate of the congestion in routers. To achieve such predictable average delays, RED would require constant tuning of the parameters to current traffic conditions. Since the RED-based algorithms control the macroscopic behavior of the queue length (average), they often cause sluggish response and fluctuations in the instantaneous queue length. As a result, an important change in end to end delays is observed. As a consequence, RED and its variants provoke dramatic consequences on sensitive flows.

B. Control-Theoretic to Flow Control

The control theoretic techniques have been lately introduced in flow control and congestion avoidance. These recently developed mechanisms outperform the existing works by presenting formal proofs. Whereas classical approaches are rather informal, they give the necessary means to explicitly specify multi criterion performance. These alternative methods model the AQM algorithm as a feedback control system that tunes the router queue length as a plant variable.

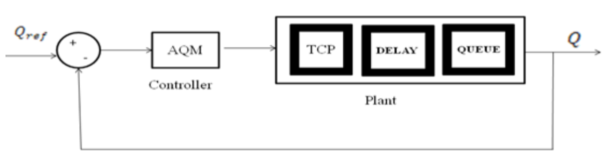

Figure 1. Feedback control modeling of congestion control with AQM

In the system above, Qref represents the reference value of the queue length. The *Plant* represents a combination of subsystems such as TCP sources, TCP receivers, routers ... and others.

Among the contributors to control-theoretic flow control, [10],[11] proposed use of the PID controller which is widely used in automatic control systems. In [12] a feedback compensation element was introduced in order to provide a more robust controller under time-varying network conditions. Beside that, in a variable structure based control scheme was used to take into account the model uncertainties and the number of active TCP connections. These controllers permit better performance in compared with REDs. For instance, the PID controller adds to the integral control, a proportional control for a faster response, and a derivative control for anticipated congestion avoidance.

The theoretic control in the network management domain brings some new alternatives which permit good performance in router throughput and better management in queue length. Note that the plant model is strongly uncertain and nonlinear. This leads to some parameterization problems under realistic traffic environment which is characterized by its intrinsic bursty nature and time-variable structure. Based on this fact, it is much more suitable to deploy an adaptive/auto-tuned control to tackle the changing network conditions

III. FUZZY – BASED PID CONTROLLER STRUCTURE

PID is regarded as the standard control structures of the classical control theory, and fuzzy controllers have positioned themselves as a counterpart of classical PID controllers with the same dominant role at the knowledge rich spectrum. PID controllers are designed for linear systems and provide a preferable cost/benefit ratio. However, the presences of nonlinear effects limit their performances. On the other hand Fuzzy controllers are successfully applied to non-linear systems because of their knowledge based nonlinear structural characteristics. Hybridization of these two controllers brings to ones mind immediately to exploit the advantages of both categories.

The objective of this study is to design a new hybrid fuzzy PID controller for congestion control in TCP/IP networks so as a further improvement can be achieved in response performance , both the transient and steady states, in compared with the system response obtained from each individually [13],[14].

A. Proposed Controller

The proposed hybrid controller which is shown in Figure 2 consists of two main parts: the classical PID controller and fuzzy PID controller.

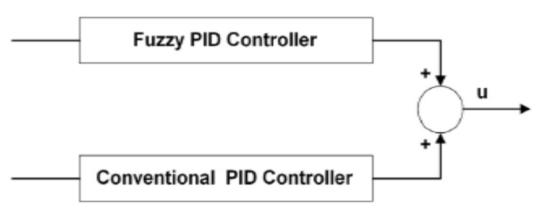

Figure 2. Block diagram of hybrid type fuzzy PID controller

Transfer function of a PID is generally written as

$$Gpid(s) = K(1 + \frac{1}{T_I s} + T_D s)$$

where K is the proportional gain, K_I the integral gain, K_D the derivative gain, T_I the integral time constant and T_D the derivative time constant[15].

The structure of the fuzzy PID controller, which has two inputs and one rule base, is shown in Figure 3.

The inputs are the conventional error (e) and the rate of the change of error ($\dot{e}$).

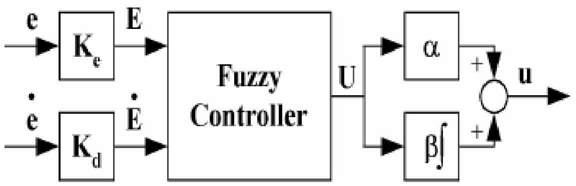

Figure 3. The Fuzzy PID Controller structure

Triangular membership functions are used for input variables and the output as is shown in Figures 4 and 5.

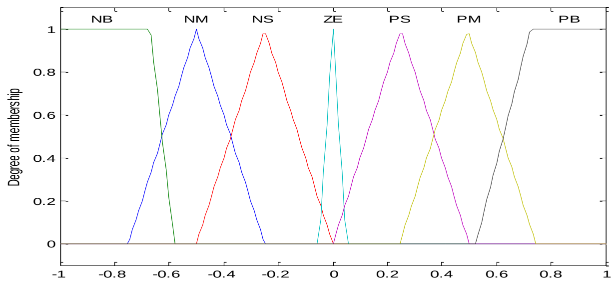

Figure 4. The membership functions of e and $\dot{e}$.

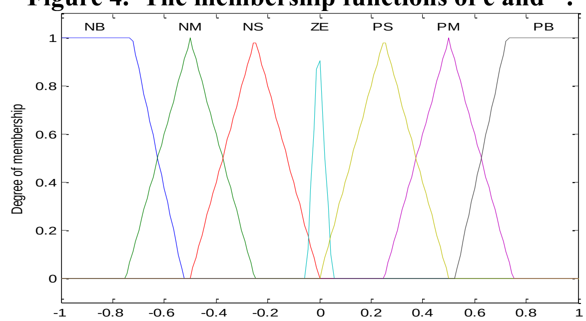

Figure 5. The membership functions of u.

In this paper, the classical PID and fuzzy PID controller are combined by a blending mechanism which depends on a certain function of actuating error [16]. Moreover, an intelligent switching scheme is induced on the blending mechanism that makes a decision based on the priority of the two controller parts. The Matlab/Simulink simulation model of the proposed intelligent hybrid PID controller is shown in Figure 6. The parameters of the PID controller are denoted by K, T_I, and T_D. These stand for proportional gain, integral and derivative time constants respectively. The parameters of the fuzzy controller are defined as K_e, K_d, α, and β.

Figure 6. Due to lack of space, it is shown At the end of the paper.

The fuzzy PID controller rule base is composed of 49 (7x7) rules as shown in Table 1.

Table 1: PID type Fuzzy Controller Rule Base

E \ CE	NB	NM	NS	Z	PB	PB	PB
NB	NB	NB	NB	NM	NS	NVS	Z
NM	NB	NB	NM	NS	NVS	Z	PVS
NS	NB	NM	NS	NVS	Z	PVS	PS
Z	NM	NS	NVS	Z	PVS	PS	PM
PS	NS	NVS	Z	PVS	PS	PM	PB
PM	NVS	Z	PVS	PS	PM	PB	PB
PB	Z	PVS	PS	PM	PB	PB	PB

IV. Performance Evaluation

A. Simulation Model

In order to evaluate the performance and robustness of our proposal, we performed some simulations using the topology depicted in figure 7. The bottleneck is located at the central router level which implements one of the three AQM algorithms: RED, PID or Adaptive Hybrid Fuzzy (our proposal). Its capacity is 10 Mbps (2621 packets/s, default packet size is 500 bytes), and delay is 20 ms. Each queue may contain up to 400 packets.[17]

However, the most performing queue length is of 80 packets.

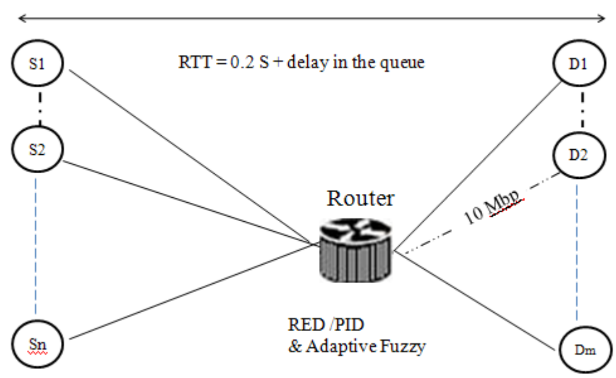

Figure 7. Simulation Network Topology

Note that the parameters of RED and PID are set as recommended respectively in [18] and in [19]. The controller parameters of the classical PID controller are set to K=2, T_I = 0.25, T_D = 0.025 in order to have a small rise time. On the other hand, the fuzzy PID controller has the following parameters: α = 0.05, β = 4.5, Ke = 1, Kd = 0.56.

In our simulation, the number of TCP connections changes in accordance with the curve in Figure 8.

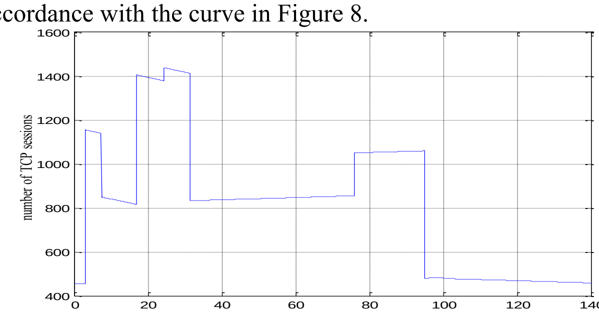

Figure 8. Variations in time of TCP sessions number

B. Experimental Results

Figure 9 presents the queue evolution, which shows that the Hybrid Fuzzy controller regulates the queue to the reference value very quickly in spite of the work-load variations. Contrary to Hybrid Fuzzy , the PID controller converges slowly and is very disturbed with the variations of the number of TCP sessions. The statistics in Table 2 show that, in the case of the PID controller, the static error decreases and the queue length converges to the referenced value asymptotically with the stabilization of the work-load. Figure 9 shows that RED doesn‘t guarantee the stability of the queue; it only permits good performance with respect to the throughput (see Table 2). As It can be seen from Figure 10, all three controllers permit good performance. However, Hybrid Fuzzy gives a constant and maximal throughput value by stabilizing of the queue size as is shown in Figure 9.

Note that the maximal throughput of the router is 10 Mbps, which means that any excessive traffic will cause a buffering at the router queue, and even higher drop rate when the buffer queue length is reached (figure 9).

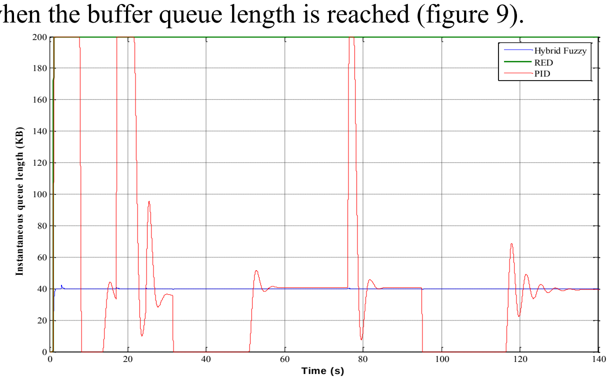

Figure 9. Instantaneous queue length

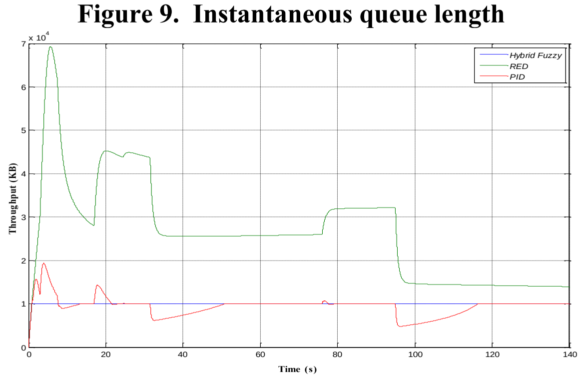

Figure 10. *Throughput*

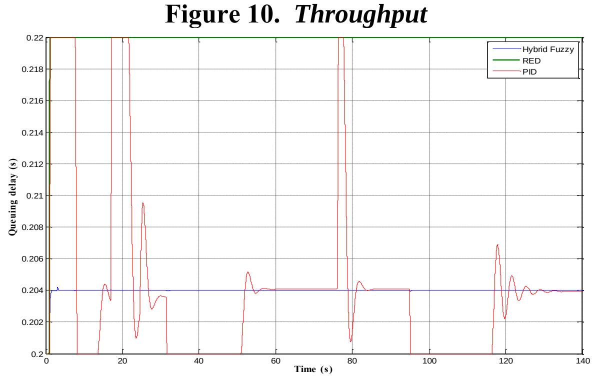

Figure 11. Queuing delay

From figure 10 and 11, it can clearly seen that queuing delays in Hybrid Fuzzy are constant. RED and PID controllers are sensitive to the number of session‘s variations. In addition, fluctuations in queuing delay implies a deep deterioration of multimedia communications which have strict requirements in term of end to end delay. So, in order to provide quality of service (QoS) guarantees, the elimination of the queuing delay fluctuation is a must. Our controller achieves this objective.

Furthermore, from the statistics tables, it can be seen that Hybrid Fuzzy induces a maximum delay of 0.004 s, while the RED and PID controllers have 0.0200 s each.

By looking at figure 12, it can be observed that the dropping probability in Hybrid fuzzy is not regular. Moreover, it is clearly seen that the dropping probability value in Hybrid Fuzzy is better than PID.

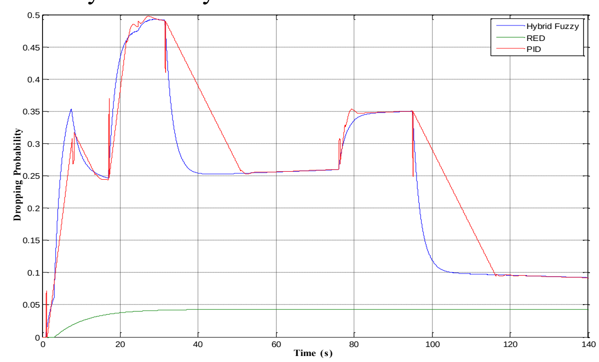

Figure 12. Dropping probability

The Hybrid Fuzzy algorithm shows much better performance than RED and PID controllers. In fact, the performances of RED and PID are sensitive to network fluctuations. In addition, RED and PID can make a buffer overflow in a transient period which itself can result in packets loss. All these remarks are summarized in Table 2, which briefly describes advantages and disadvantages of each of the AQM algorithm considered in this paper.

Table 2. A classification of AQM algorithms in terms of objectives.

Characteristics	Hybrid fuzzy	RED	PID
Router Throughput	good	good	good
Sensitivity to network parameters	no	yes	yes
Response	very fast	slow	fast
Queue stability	stable	not stable	stable
Delay	small	very large	variable
Buffer overflow/underflow	no/no	yes/yes	yes/yes

V. CONCLUSIONS

We have presented a new AQM scheme using fuzzy logic techniques, which we refer to as Hybrid Fuzzy PID controller. It can be implemented in TCP/IP networks to provide effective congestion control for high utilization, low losses and delays which are very important for multimedia applications.

Hybrid Fuzzy controllers behave better than other AQM schemes in terms of queue fluctuations and delay, loss and link utilization of packets in TCP/IP networks. Obtained results show that Hybrid Fuzzy Control methodology will offer significant improvements on controlling congestion in TCP/IP networks. It permits a very fast response in compared with the classical adaptive controllers, RED and PID.

VI. References

1) S. Floyd, V. Jacobson, ―Random Early Detection gateways for congestion avoidance", IEEE/ACM Trans. On Networking, Aug. 1993.
2) S. Floyd, R. Gummadi, S. Shenker, ―Adaptive RED: An Algorithm for Increasing the Robustness of RED's Active Queue Management", Technical report, ICSI, August 2001.
3) Hollot, V. Misra, D. Towsley, W.-B. Gong, ―Analysis and Design of Controllers for AQM Routers Supporting TCP Flows" IEEE Transactions on Automatic Control, vol. 47, no. 6, pp. 945-959, June 2002.
4) S. Athuraliya, V. H. Li, S. H. Low, Q. Yin, ―REM: Active Queue Management", IEEE Network Magazine, 15(3), pp. 48-53, May 2001.
5) Hollot C V, Misra V, Towsley D and Gong W B 2001 On Designing Improved Controllers for AQM Routers Supporting TCP Flows in: Proc. of IEEE INFOCOM (Alaska, USA) pp.1726.
6) H. Lim, K.J. Park, E.C. Park, and C.H. Choi, "Virtual rate control algorithm for active queue management in TCP networks," IEEE Electron. Lett., vol.38, no.16, pp.873–874, Aug. 2002.
7) Iannaccon G, Brandauer C, Ziegler T, Diot C, Fdida S, ―Tail Drop and Active Queue Management Performance for bulk-data and Web-like Internet Traffic", 6th IEEE Symposium on Computers and Communications, Hammamet, 2001.
8) M. May, T. Bonald, and J.C. Bolot, ―Analytic Evaluation of RED Performance", Tel Aviv, IEEE Infocom 2000.
9) Yanfei, and F.L. Chuang: ―Design a PID Controller for Active Queue Management". ISCC 2003 (July 2003)
10) Yanfei, and Chuang: ―Design a PID Controller for Active Queue Management". ISCC 2003 (July 2003)
11) Ryu, S., Rump, C., and Qiao, C.: ―A Predictive and Robust Active Queue Management for Internet Congestion Control". ISCC 2003 (June 2003).
12) Z. Heying, L. Baohong, and D. Wenhua: ―Design of Robust Active Queue Management Algorithm Based on Feedback Compensation". ACM/SIGCOMM 2003 (August 2003).
13) I Erenoglu, I. Eksin, E. Yesil, M. Guzelkaya, ―AN INTELLIGENT HYBRID FUZZY PID CONTROLLER " , European Conference on Modelling and Simulation, Wolfgang Borutzky, Alessandra Orsoni, Richard Zobel © ECMS, 2006
14) Akbiyik, B., Eksin I., Guzelkaya M., Yesil, E., 2005. "Evaluation of The Performance of Various Fuzzy PID Controller Structures on Benchmark Systems", ELECO '2005, 4rd International Conf. on Electrical and Electronics Engineering, Bursa, Turkey, 388-393.
15) N. Matsunaga,S. Kawaji, 1991. ―Fuzzy hybrid control for DC servomotor." Trans. Inst. Electrical Eng. Japan D (111), 195-200.
16) Yesil, M. Guzelkaya,I. Eksin, 2003. "Fuzzy PID Controllers: An Overview." The Third Triennial ETAI International Conference on Applied Automatic Systems, Skopje, Macedonia, 105-112.
17) Y.H.Aoul, A. Nafaa, D. Negru, A. Mehaoua, ―FAFC: fast adaptive fuzzy AQM controller for TCP/IP networks" , Global Telecommunications Conference, 2004. GLOBECOM apos;04. IEEE, Dec. 2004
18) S. Keshav: ―Congestion Control in Computer Networks". PhD Thesis, published as UC Berkeley TR-654 (September 1991)
19) Bitorika, A., and al. ―A Comparative Study of Active Queue Management Schemes". ICC 2004 (June 2004).