# CONGESTION CONTROL SYSTEM WITH PID CONTROLLER USING FUZZY ADAPTATION MECHANISM

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Keywords: Congestion control, fuzzy inference system, PID controller, adaptation mechanism.

Abstract: The congestion control in computer network is a problem of controlling a specific object such as a computer network. The paper provides an adaptation mechanism designed to prevent unstable behavior of the system, with fuzzy rules, and with an inference mechanism that identifies the possible sources of nonlinear behavior. The adaptation mechanism can be designed to adjust PID controller tuning parameters when oscillatory behavior is detected. Tests in nonlinear and uncertainty process are performed.

## 1 INTRODUCTION

The congestion control is essential for ensuring the appropriate quality of service for network users. This problem plays a significant role in designing and using computer networks. At the same time, the congestion control constitutes a current research issue, with a constantly growing number of publications (Imer and Basar 2001; Misra, Gong and Towsley; Turowska 2004; 2007).

The paper provides an adaptation mechanism designed to prevent unstable behavior, with fuzzy rules, and with an inference mechanism that identifies the possible sources of nonlinear behavior of computer network. The adaptation mechanism can be designed to adjust PID controller tuning parameters when oscillatory behavior is detected.

## 2 MODEL OF THE CONTROL SYSTEM

TCP congestion control dynamics with an AQM (*Active Queue Management*) can be modelled as a feedback system (Figure 1). This system consists of a desired queue length at a router, denoted by $y^*$; a queue length at a router as a controlled variable $y$; a plant that represents a combination of subsystems such as TCP sources, routers, and TCP receivers that send, process, and receive TCP packets, respectively; an AQM controller, which controls the packet arrival rate to the router queue by generating packet drop probability as a control signal $u$; and a feedback signal $y$ (the queue length) used to obtain the control error term $\varepsilon = y^* - y$.

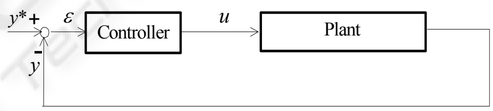


Figure 1: A feedback control model of TCP/AQM.

In Misra, Gong and Towsley 2000 a dynamic model for TCP congestion control, delays, and queues is expressed by the transfer function:

$$K_P(s) = \frac{\beta}{(\alpha s+1)(ds+1)} e^{-sd} \tag{1}$$

where $d$ is the round-trip delay, $\beta = \dfrac{C^3}{4N^2}$, $\alpha = \dfrac{d^2 C}{2N}$, $C$ is the bottleneck link capacity, and $N$ is the number of TCP connections.

To regulate the queue length at a router around a desired value $y^*$ a controller having the ability to predict and adjust control performance is required. This can be achieved by using the PID controller (Fan, Ren and Lin 2003). The transform function of PID controller has a form



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$$K_C(s) = k_P + \frac{k_I}{s} + k_D s\,. \tag{2}$$

To tune parameters $k_P$, $k_I$, and $k_D$ of the PID controller we analyse the stability of the closed loop system with the plant (1) and the controller (2).

Using frequency response techniques it can be established that marginal stability is obtained when

$$|K_{OL}(i\omega)| = 1 \quad \text{and} \quad \arg K_{OL}(i\omega) = \pm\pi$$

where $K_{OL}(s) = K_P(s)K_c(s)$ is the open loop transfer function. For the system (1), (2) the solution for marginal stability is given by

$$\left| \frac{\beta(k_P i\omega + k_I + k_D(i\omega)^2)}{(\alpha i\omega + 1)(di\omega + 1)} e^{-i\omega d} \right| = 1 \tag{3}$$

and

$$\arg\left( \frac{\beta(k_P i\omega + k_I + k_D(i\omega)^2)}{(\alpha i\omega + 1)(di\omega + 1)} e^{-i\omega d} \right) = \pm\pi\,. \tag{4}$$

If the controller tuning is fixed and the degrees of freedom are granted to parameter $\alpha$ from (3) and (4) we can calculate $\alpha_u$ and $\omega_{\alpha,u}$, the value of parameter $\alpha$ that leads the closed loop response to marginal stability and the frequency of such oscillations. If similar analysis are performed, granting degrees of freedom to $\beta$ calculating its frequency, and next to $d$, the set of values $\omega_{\alpha,u}$, $\omega_{\beta,u}$ and $\omega_{d,u}$ will be obtained for a given controller tuning. This frequencies can be called as the characteristic ultimate frequencies for a given process parameter.

The parameters that can be identified from the observed oscillatory behavior of the system response are the damped natural frequency, $\omega$, and the damping ratio, $\zeta$. These parameters will indicate how oscillatory the response is and what is cause of such oscillation, and can be calculated from a dynamic analysis of the closed-loop system response, like the one presented in Figure 2.

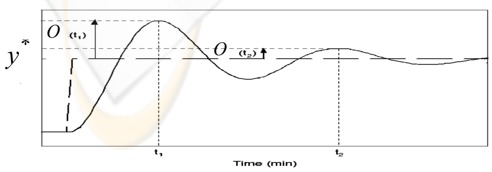


Figure 2: A response of the system under consideration.

The damping ratio $\zeta$ can be calculated as (Marlin, 2000):

$$\zeta = \frac{\ln(A)}{\sqrt{4\pi^2 + \ln^2(A)}}, \tag{5}$$

where $A = \dfrac{O(t_2)}{O(t_1)}$ and $\omega = \dfrac{2\pi}{t_2 - t_1}$.

By measuring $O(t_1)$, $t_1$, $O(t_2)$ and $t_2$ as indicated in Figure 2 we can calculate $\omega$ and $\zeta$.

An oscillatory behavior is obtained for $\zeta \in [-1, 1]$. The damping ratio equal to 1 is a critically damped system, with no oscillatory behavior, $\zeta$ equal to 0.7071 is a system with approximate 5% overshoot, which we will consider an optimal response, 0 leads to a marginally stable response (sinusoidal behavior), less than 0 leads to unstable behavior.

## 3 FUZZY ADAPTATION MECHANISM

When a PID controller operates with non-optimal tuning and in nonlinear environment two different behaviors can occur: slow compensation for disturbances or setpoint changes, or presence of undesired oscillatory behavior. The presence of such oscillations is usually more damaging since not only diminishes the computer network (the control system) performance but also causes the network degradation.

Additional information may be used to gradual improving of basic control algorithm (PID). The improving is needed in order to adapt the basic control algorithm to the control plant. The structure of the system with adaptation is presented in Figure 3.

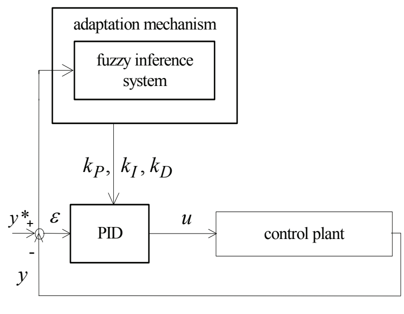


Figure 3: Block diagram of the closed-loop system with adaptation mechanism.

The proposed adaptation mechanism uses a two-input-three-output fuzzy inference system. The input linguistic variables are damping ratio and damped natural frequency. The output linguistic variables are the change factors $g_P$, $g_I$ and $g_D$ of control algorithm (PID regulator). We have used triangular shaped membership functions for damping ratio $\zeta$ and the damped natural frequency $\omega$, and for the change factors.

Figure 4, 5 and 6 show the membership functions of the input and output variables.

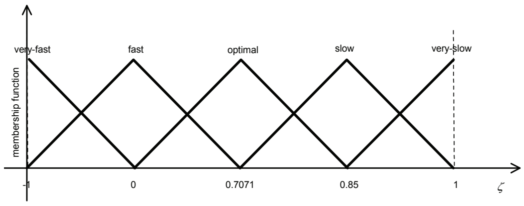


Figure 4: Membership function of the linguistic representing the damping ratio $\zeta$.

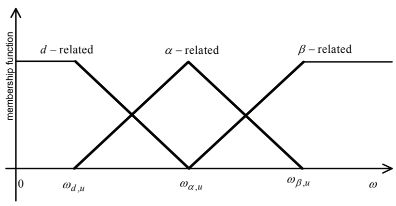


Figure 5: Membership function of the linguistic representing the damped natural frequency $\omega$.

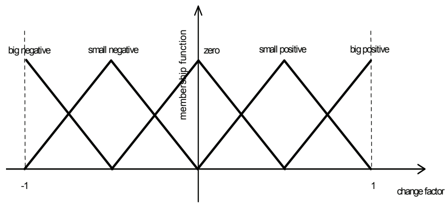


Figure 6: Membership function of the linguistic representing the output variables $g_P$, $g_I$ and $g_D$.

A fuzzy inference is designed to operate on damping ratio $\zeta$ and the damped natural frequency $\omega$, and uses linguistic rules to determine the change factors. The proposed rules are shown in Table 1.

For the implementation of the fuzzy inference system we have used the computationally simple and most widely chosen methods: singleton fuzzification, Mamdani's product rule of implication, and the centroid of area (CoA) method of defuzzification.

Once the fuzzy inference system has calculated the change factors, based on the nonlinear behavioral pattern that was identified, such value is used to obtain the new set of controller parameters $k_P$, $k_I$, and $k_D$.

The new values of controller parameters are set as $k_P = k_{P,pr}(1+g_P)$, $k_I = k_{I,pr}(1+g_I)$ and $k_D = k_{D,pr}(1+g_D)$, where $k_{P,pr}$, $k_{I,pr}$, $k_{D,pr}$ are the previous values of controller parameters.

Table 1: Fuzzy rules used in the inference system.

| | **IF** | **AND** | **THEN** | | |
|---|---|---|---|---|---|
| | the damping ratio $\zeta$ | the damped natural frequency $\omega$ | $g_P$ | $g_I$ | $g_D$ |
| 1 | very fast | $\alpha$ – related | BN | Z | Z |
| 2 | very fast | $\beta$ – related | BN | BP | SP |
| 3 | very fast | $d$ – related | BN | BP | BP |
| 4 | fast | $\alpha$ – related | SN | Z | Z |
| 5 | fast | $\beta$ – related | SN | SP | Z |
| 6 | fast | $d$ – related | SN | Z | SP |
| 7 | optimal | $\alpha$ – related | Z | Z | Z |
| 8 | optimal | $\beta$ – related | Z | Z | Z |
| 9 | optimal | $d$ – related | Z | Z | Z |
| 10 | slow | $\alpha$ – related | SP | Z | Z |
| 11 | slow | $\beta$ – related | SP | SN | SN |
| 12 | slow | $d$ – related | SP | Z | Z |
| 13 | very slow | $\alpha$ – related | BP | Z | Z |
| 14 | very slow | $\beta$ – related | BP | SN | SN |
| 15 | very slow | $d$ – related | BP | SN | BN |

# 4 SIMULATIONS RESULTS

In order to evaluate the performance of the fuzzy adaptation mechanism under consideration we carried out the number of simulation in Matlab 6.0 and Simulink 3.0. We compare the control performance of the system that use the PID controller and fuzzy adaptation mechanism with that of the PID controller only. In the PID controller, we use the parameters $k_P$, $k_I$, and $k_D$ calculated in Fan, Ren and Lin 2003.

We used the network topology shown in Figure 7.

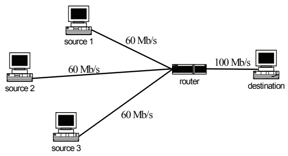


Figure 7: Network topology used for the simulation.

The results of simulations for conventional PID and fuzzy PID (PID with fuzzy adaptation) algorithms are shown in Figures 8 and 9.

The goodput presented in Fig. 8 is the ratio of the total number of nonduplicate packets received at all destinations per unit time to link capacity. System with fuzzy adaptation of PID achieves a higher goodput than conventional PID.

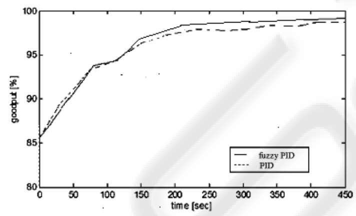


Figure 8: Goodput versus simulation time for both fuzzy PID and conventional PID.

As can be seen from Fig. 9 the queue length is regulated around the target value 100 packets for both fuzzy PID and PID algorithms. For conventional PID we have observed the higher magnitude of overshoots.

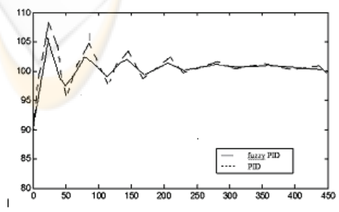


Figure 9: Queue length versus simulation time for both fuzzy PID and conventional PID.

The performance specification of system with fuzzy adaptation mechanism is better than the performance of system with conventional PID controller.

# 5 CONCLUSIONS

This paper presents the problem of fuzzy adaptation in the congestion control system with PID controller in TCP network.

The fuzzy mechanism has been tested in simulations. Simulation results show that the system with the proposed fuzzy inference system has better performance and queue length behavior than system with the conventional PID. The future work can include the design of mechanism, which can tune the parameters of membership functions on line, using measurements from the network, to obtain even better behaviour.

# REFERENCES

Fan, Y., Ren, F., Lin C., 2003. Design a PID Controller for Active Queue Management, Proceedings of the Eight IEEE International Symposium on Computers and Communication, pp. 985-990.

Imer, O., Basar, T., 2001. Control of congestion in high speed networks, *Eur. J. Contr.*, 7, pp. 132-144.

Marlin, T., 2000. Process Control. Designing Processes and and Control Systems for Dynamic Performance . McGraw-Hill, New York, USA.

Misra, V., Gong, W., Towsley, D., 2000. Fluid-based analysis of a network of AQM routers supporting TCP flows with an application to RED, Proceedings of ACM SIGCOMM, pp. 151-160.

Sanjuan, M., Kandel, A., Smith., C. A., 2006. Design and implementation of a fuzzy supervisor for on-line compensation of nonlinearities: An instability avoidance module. *Engineering Applications of Artificial Intelligence,* 19, pp. 323-333.

Turowska, M., 2004. Application of uncertain variables to stability analysis and stabilization for ATM ABR congestion control systems, *Proceedings of the International Conference on Enterprise Information Systems*. INSTICC Press, Porto, 2, pp. 523-526.

Turowska, M., 2007. Fuzzy congestion control in Internet, *Proceedings of the 16th International Conference on Systems Science*, Wroclaw, Poland, 2, pp. 347-354.