

## A Novel Parameter Tuning Algorithm for AQM-PI Controllers

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**Abstract:** AQM is recognized as an active queue management mechanism to solve network congestion. As an easily implemented algorithm, PI controllers can effectively control the queue length of router. Based on in-depth analysis of classical design methodologies towards PI controllers, this paper explicitly introduces a novel PI parameter tuning algorithm, which takes advantage of the relationship between PI parameters and control systems' damping ratios and employs recursive bisection searching approaches to achieve an optimum damping ratio in terms of both steady-state and accuracy; performances of controlled queue length, thereby obtaining the best parameters of PI controllers. An experimental study is carried out to demonstrate the effectiveness of the proposed algorithm

**Key words:** AQM, network congestion, parameter tuning, PI controller

### INTRODUCTION

Network provides highly reliable, high-bandwidth and highly stable platform for information transmission. However, with the amount of network services increase, network congestion may occur. Queue management algorithm is used by routers to determine when or how to drop the packets to alleviate network congestion. There are two categories (Misra *et al.*, 2000; Feng *et al.*, 1999): PQM, Passive Queue Management and AQM, active queue management. PQM drops the packets when the queue is full. AQM actively drops the packets before the queue are full, aiming to control the queue length to an expected value. AQM can guarantee better Qos performances, such as throughput, end to end delay, and delay jitter.

In this study, we propose a novel parameter tuning algorithm for AQM-PI controllers. The algorithm is based on the relationship between the PI parameters and control system damping ratio, using recursive bisection to search the damping ratio in terms of both steady-state and accuracy; performances of controlled queue length, thereby obtaining the best parameters of PI controllers.

### LINK CONGESTION CONTROL ALGORITHM

Literature (Misra *et al.*, 2000) regards the Internet data stream as a fluid flow model with continuous state, and gives the differential equation of the TCP congestion window of source host and queue change of router:

$$\frac{dW(t)}{dT} = \frac{1}{R(t)} - \frac{W(t)W(t-R)}{2R(t)} p(t-R(t))$$

$$\frac{dq}{dt} = \frac{N(t)}{R(t)} W(t) - C(t) \quad (1)$$

W is the size of congestion window, p is the packet drop probability, q is the instantaneous queue length, d is the propagation delay, C is the link bandwidth, N is the number of TCP connection, R is the round-trip time, RTT = q/C + d. After Linearization with classical control theory, Literature (Hollot *et al.*, 2001) obtains the AQM control system near the equilibrium point, the transfer functions are as follows:

- The transfer function of TCP congestion window and the queue of router are:

$$P_{tcp}(s) = (R_0 C^2 / 2N^2) / (s + 2N/R_0 C)$$

$$P_{queue}(s) = (N/R_0) / (s + 1/R_0)$$

- The transfer function of controlle dsystem is:

$$G_p(s) = k_p / ((T_1 s + 1)(T_2 s + 1)),$$

$$k_p = (R_0 C)^3 / (4N^2),$$

$$T_1 = R_0, T_2 = (R_0^2 C) / (2N)$$

- The transfer function of AQM control system is:

$$G_{PI}(s) = K_{PI} (s/\omega_g + 1) / s$$

and literature [14] points that when,

$$2N^- / (R^+)^2 C \ll 1/R^+ \text{ and } \omega_g = 2N^- / (R^+)^2 C,$$

$$\text{then } K_{PI} = \omega_g | (J \omega_g / P_{queue} + 1) / ((R^+ C)^3 / (2N^-)^2) |$$

C is the link bandwidth, N is the network load, R is the round trip time,  $\omega_g$  is the angular frequency. When  $N \geq N^-$  and  $R \geq R^-$ , The system is stable, the phase stability margin is about  $90^\circ - (180^\circ/\pi) \omega_g^2$ .

### CONTROLLER PARAMETER TUNING METHOD

**Controller design:** The controlled object is:

$$G_p(s) = K_p / (T_1 s + 1)(T_2 s + 1)$$

and the PI controller is:

$$G_c(s) = (T_1 s + 1)(n K_p T_2 s)$$

The open-loop transfer function of TCP/AQM control system is:

$$G_0(s) = G_c(s)G_p(s) = 1 / ((n T_2) s (T_2 s + 1))$$

The closed-loop damping rate is as follow:

$$\xi = 1 / 2 \left( \sqrt{(1/n T_2) * T_2} \right) = 1(2\sqrt{1/n}) = \sqrt{n} / 2 \quad (2)$$

after the z-transform:

$$G_c(z) = T_1 / n K_p T_2 + (1/n K_p T_2)(z/z-1) = [T_1 + 1]z - T_1 / [n K_p T_2(z-1)]$$

We get the following equation:

$$p(z)(z-1) = \delta q(z) \left( \frac{(T_1 + 1)z}{n K_p T_2} - \frac{T_1}{n K_p T_2} \right) \quad (3)$$

when  $t = kT$ ,  $T = 1/f$ , the differential Equations is as follow:

$$P(kT) - p(k-1)T = \frac{(T_1+1)}{nK_p T_2} \delta q(kT) - \frac{T_1}{nK_p T_2} \delta q((k-1)T) \quad (4)$$

The drop probability is calculated as follows:

$$p = a * (q - q_{ref}) - b * (q_{old} - q_{ref}) + p_{old} \quad (5)$$

p is drop probability, q,  $q_{old}$  and  $q_{ref}$  are the current value, old value and the reference value of queue length. Then, we can get the relationship between parameter a or b between damping ratio  $\xi$ :

$$a = (T_1 + 1) / 4\xi^2 K_p T_2, \quad b = T_1 / 4\xi^2 K_p T_2 \quad (6)$$

The open-loop frequency feature of control system is as follow:

$$\begin{aligned} G(j\omega) &= \frac{K}{s(Ts+1)} \Big|_{s=j\omega} = \frac{K}{\omega \sqrt{(T^2\omega^2+1)}} A(\omega) e^{j\varphi(\omega)} \\ &= A(\omega) e^{j\varphi(\omega)} \\ \varphi(\omega) &= -\frac{\pi}{2} - \arctan T\omega \\ &= \frac{-k + jKT\omega}{w(1+T^2\omega^2)} \\ &= \text{Re}(\omega) + j\text{Im}(\omega) \end{aligned}$$

when  $\omega = 0^+$ ,  $G(j\omega) = 8 < -\pi/2$ , and when  $\omega = 8$ ,  $G(j\omega) = 0 < -\pi$ .  $G(j\omega)$  is symmetrical about the real axis. The system has no open-loop poles, so the system is open-loop stable. The  $G(j\omega)$  does not include the critical point  $(-1, j_0)$ , so the system is closed-loop stable. At frequency:

$$\omega_c = \left( \sqrt{-2\xi^2 + \sqrt{4\xi^4 + 1}} \right) / 2T\xi, A(\omega_c) = 1$$

The phase margin

$$\gamma = \arctan \left( 2\xi / \sqrt{-2\xi^2 + \sqrt{4\xi^4 + 1}} \right)$$

when  $\xi$  changes from 0.1 to 1, the phase stability margin will change from 11.42060 to 76.34540 accordingly.

**Parameter tuning algorithm:** Based on the Equation (6), we draw the relationship between the damping ratio and the parameter a and b, as shown in Fig. 1. Then we propose a novel parameter tuning algorithm for AQM-PI controller. First, the classical PI algorithm gives the initial value of the damping ratio, and then adjust damping ratio according to the congestion degree of network. When the network traffic is heavy, the damping ratio is adjusted to a smaller value to strengthen the controlment, when the network traffic is light, the damping ratio is adjusted to a bigger value to weaken the controlment. When the controlment is adapted to the congestion situation of network traffic, a suitable damping ratio is searched, which ensure the smooth and accurate response of the controller. The algorithm steps are as follows: Calculate  $K_{pi}$ ,  $\omega_g$ , and the initial value of parameter a; With the parameter a, the initial value of damping ratio  $\xi_0$  will be calculated according to formula (6). In Fig. 1, the blue line and the curve a will intersect, the point of intersection falls within the interval  $[\xi_1 \xi_2]$ .

Assign the parameter a to PI controller, calculate the historical average length of the router queue, and the difference and variance between the historical average length and threshold.

If the difference is greater than the threshold of the queue, indicating that controlment is weak, the controller's

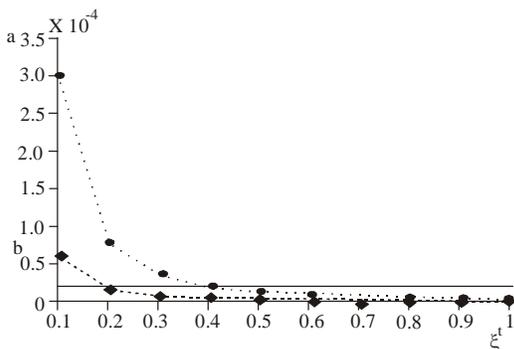


Fig. 1: The relationship between damping rate and parameters

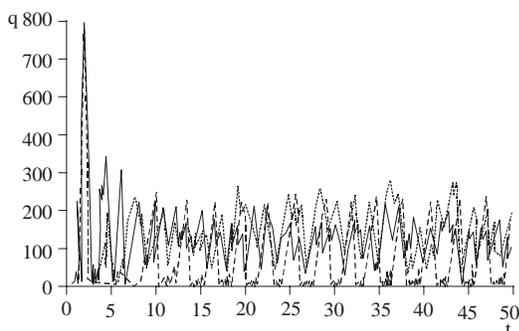


Fig. 2: The queue length of router

damping ratio should be reduced. The recursive bisection search is used to find the suitable damping ratio  $\xi$  within the interval  $[\xi_1 \xi_0]$ , which makes the variance of the control objective become smaller. If the difference is smaller than the threshold of the queue, indicating that controlment is strong, the controller's damping ratio should be increased. The recursive bisection search is used to find the suitable damping ratio  $\xi$  within the interval  $[\xi_0 \xi_2]$ , which makes the variance of the control objective become smaller.

With the new value of damping ratio  $\xi$ , the new value of parameter a will be calculated according to formula (6).

Return to step (2), repeat these procedures to adjust the parameters of PI controller, until the variance is not significantly reduced. The final damping ratio is suitable for the current status of network traffic congestion situation;

Parameter b of the PI controller is updated according to the same procedure as parameter a.

### CASE STUDY

The simulation environment is created in NS-2. In the topology, the bottleneck link is located between routers r1 and r2, link capacity is 15 Mbps; the other link capacity

between the end hosts and routers is 100 Mbps. Packet size is 512 bytes, round-trip time for the entire network 246 ms. The capacity of router buffer is 800 packets, and the reference queue length is 175 packets. Thus,  $N = 60$ ,  $R+ = 0.246$ ,  $C = 3750$  packets/sec.

At time  $t = 0$  second, 60 ftp streams are created from the source host s1 to s60, through the router r1 and r2 of the bottleneck link, to reach the destination host d1 to d60. The simulation time is 100 sec, Active Queue Management AQM-PI algorithm is implemented on the router r1, the length of router queue is shown in Fig. 2.

For the same topology, the PI controller parameters calculated in literature (Hollot *et al.*, 2001) are:  $a = 1.849 \times 10^{-5}$ ,  $b = 1.843 \times 10^{-5}$ , and the output parameter curve is the blue one. The parameters calculated in Literature (Liu *et al.*, 2005) are:  $a = 6.0427 \times 10^{-6}$ ,  $b = 1.1930 \times 10^{-6}$ , and the output parameter curve is the red one. The new proposed algorithm calculates the PI controller parameters as follows: parameter a and b adjust the values within the interval  $[2.99 \times 10^{-5}, 3.18 \times 10^{-5}]$  continually. The output parameter curve is the black one.

The simulation results show that, the average queue length of router controlled under the new algorithm is closer to the threshold. The accuracy of the controller is improved. At the same time, the variance is smaller than other algorithms, so the stability of the controller is significantly improved. Through the difference between the historical average queue length and threshold, the controller can analyze the controlment effect. By fine-tuning the damping ratio of the controller, the parameters are adjusted to the improve the performance of the controller.

### CONCLUSION

Based on the linear model of TCP/AQM and classic control theory, the paper proposes A novel parameter tuning algorithm for AQM-PI controllers. The algorithm employs recursive bisection searching approaches to achieve an optimum damping ratio in terms of both steady-state and accuracy; performances of controlled queue length, thereby obtaining the best parameters of PI controllers.

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