An Effective Controller Design for Active Queue Management Scheme Assisting TCP Flows

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Abstract

In this study, a control theoretical approach is brought to design and examine different flow controllers for congestion control in communicating networks. First, an Effective controller is planned for explicit rate congestion control in individual chokepoint network. The controller ensures constancy Effectiveness with respect to ambiguous time varying multiple time delays in different channels brings the queue length of the chokepoint client to a desirable value asymptotically and fulfills a weighted fairness condition. The use of the outgoing link capability is further investigated to improve functioning. As well, a few variations on a linear model of Active Queue Management assisting TCP flows are used to design an Effective AQM controller and to examine the functioning and stableness of Multilevel ECN and Traffic load based AQM strategies.

Keywords: Congestion, TCP, Queue, router buffer, AQM.

1 Introduction

We focus on end to end congestion control. It has been shown recently [2, 3, 4] that the Active Queue Management (AQM) schemes implemented in the routers of communication networks assisting Transmission Control Protocol (TCP) flows that can be modeled as a feedback control system. Based on the delay differential equations model of TCP's congestion-avoidance modes different control schemes have been proposed[3]. Here an Effective controller is designed base on the known techniques for H Infimum controls of systems with time delays.

2 Mathematical Model for an AQM scheme assisting TCP flows

We consider in this research work, the network configurations consisting of a single router receiving N TCP flows, we assume that the AQM scheme implemented at the router marks packets using ECN [1] to inform the TCP sources of impending congestion. In the following, we ignore the TCP SlowStart and timeout mechanisms, thus providing a model and analysis during the congestion avoidance mode. In TCP, the congestion window size(W(t)) is increase by one every round trip time, if no congestion is detected, and is halved upon a congestion detection. This additive-increase multiplicative-decrease behavior of TCP has been model in [2] by the following difference equation (case of one TCP flow interacting with a single router)

$$dW(t) = \frac{dt}{R(t)} - \frac{W(t)}{\beta} dN(t) \qquad (1)$$

with $\beta = 2$, $R(t) = q(t)/C + Tp$ where Tp is the propagation delay, q(t) is the queue length at router, C is the router's transmission capacity, thus q(t)/C is the queuing delays and R(t) is the round trip time delays, and dN (t) is the number of marks the flow suffers. In a network topology of N homogeneous TCP sources and one router a model relating to the average value of these variables and the router's queue dynamics becomes [3]

$$W(t) = \frac{1}{R(t)} - \frac{W(t)W(t-R(t))}{2\,R(t-R(t))} p(t - R(t)) \qquad (2)$$

$$q(t) = \begin{cases} \frac{N(t)}{R(t)} W(t) - C & \text{if } q(t) > 0 \\ max\left\{0, \frac{N(t)}{R(t)} W(t) - C\right\} & \text{if } q(t) = 0 \end{cases} \qquad (3)$$

where p(t) is the probability of packets mark due to the AQM mechanism at the router.
The linearization in (2) and (3) about the operating point is carried out in [3] and the perturbed variables about the operating point satisfy

$$\delta W(t) = -\frac{N}{R_0^2 C}\left(\delta W(t) + \delta W(t - R_0)\right) - \frac{1}{R_0^2 C}\left(\delta q(t) + \delta q(t - R_0)\right) - \frac{R_0^2 C^2}{2N^2}\delta q(t - R_0) \tag{4}$$

$$\delta q(t) = \frac{N}{R_0} - \frac{1}{R_0}\delta q(t) \tag{5}$$

where the operating point is defined by

$$R_0 = \frac{q_0}{C} + T_p \tag{6}$$

$$W_0 = \frac{R_0 C}{CN} \tag{7}$$

$$p_0 = \frac{2}{W_0^2} \tag{8}$$

For the linearization time-varying nature of the round-trip time delay in the terms "t − R(t)" is ignored and these terms are approximated by "t − R0". The queue length is still depends upon the round-trip time in the dynamic equation (3).
From (4) and (5) we derive the transfer function from δp to δq:

$$\frac{\delta q(s)}{\delta p(s)} = -\frac{NW_0^3}{2}\left(\frac{e^{-R_0 s}}{W_0 (R_0 s)^2 (W_0+1) R_0 s+2}\right)\left(\frac{1}{1+\frac{R_0}{W_0 (R_0 s)^2 (W_0+1) R_0 s+2}}\right) \tag{9}$$

Considering a negative feedback control system with the AQM being the controller, the system to be controlled is given by

$$p(s) = \frac{NW_0^3}{2}\frac{e^{-R_0 s}}{W_0 (R_0 s)^2 (W_0+1) R_0 s+2}\cdot\frac{1}{1+\frac{R_0}{W_0 (R_0 s)^2 (W_0+1) R_0 s+2}} \tag{10}$$

$$= \frac{NW_0^3}{2}\frac{e^{-R_0 s}}{\frac{R_0 C}{N}R_0^2 s^2 + \left(\frac{R_0 C}{N}+1\right)R_0 s + 2 + R_0 s e^{-R_0 s}} \tag{11}$$

Lemma 1 The plant P defined in (10) is stable for all positive values of R0, C and N .
Proof: The poles of transfer function A defined by

$$A(s) = \frac{1}{W_0 (R_0 s)^2 + (W_0+1) R_0 s + 2}$$

are in left-half part of the complex plane for all values of the parameters W0 and R0 positive, thus A is always stable. We also have

$$\left|\frac{R_0 s e^{-R_0 s}}{W_0 (R_0 s)^2 + (W_0+1) R_0 s + 2}\right|_{s=j\omega} = \frac{R_0 \omega}{\sqrt{(2 - W_0 R_0^2 \omega^2)^2 + (W_0+1)^2 (R_0 \omega)^2}} < 1$$

for all positive values of the parameters, W0 and R0 . So according to the Nyquist stability test the transfer function

$$\frac{1}{1+\frac{R_0 s e^{-R_0 s}}{W_0 (R_0 s)^2 + (W_0+1) R_0 s + 2}}$$

is stable for all positive W0 and R0 . We can thus conclude that the plant P defined in (10) stable for all positive values of R0 , C and N .
In the following we design an AQM scheme based on H Infimum control techniques that improves the system's transient response while stabilizing plant, and ensures Effectiveness with respect to uncertainties in the values of system's parameters.

3 An H Infimum optimization problem

We design the controller to minimize the following H Infimum cost function

$$inf \left\| \begin{bmatrix} W_1 (1 + P_n C)^{-1} \\ (W_2 P_n C)^{-1} \end{bmatrix} \right\|_\infty =: \gamma_{opt} \tag{12}$$

where the Infimum is taken over all the C stabilizing Pn , and W1 (s) = 1/s for good tracking of step like reference inputs (desired queue size). Applying the formula given in [7] and [6], the optimal solution to (12) is found as (a similar derivation can be found in[5]):

$$C_{opt}(s) = \frac{2\gamma}{CNnW_{0n}^3}\frac{W_{0n} R_{0n}^2 s^2 + (W_{0n}+1) R_{0n} s + 2 + R_{0n} s e^{-R_{0n} s}}{s^2}\cdot\frac{1}{1+\frac{\alpha 2C2\gamma^2}{s}+F(s)} \tag{13}$$

where F is finite impulse response filter defined as

$$f(t) = \begin{cases} (b_2 + a_2 - a_2 c_2 \gamma^2) \cos\left(\frac{t}{\gamma}\right) + \gamma\left(c_2 + a_2 b_2 - \frac{1}{\gamma^2}\right) \sin\left(\frac{t}{\gamma}\right) & for\ t < R_{0n} \\ 0 & otherwise \end{cases} \quad (14)$$

4 Simulations

The simulations are carried out by using ns2, the nonlinear model defined by equations (2) and (3) representing the dynamic of N TCP flows loading a router. The router implement the AQM scheme defined in (13). The following scenario is considered:
Nominal values known to controller: $N_n = 50$ TCP sessions, $C_n = 300$ packets/sec, $Tp = 0.2$ sec, so $R_{0n} = 0.533$ seconds and $W_{0n} = 3.2$ packets (we assume that here a fluid model and thus we do not consider the packetization issues).

Real values for the plant: N = 40 TCP sessions, C = 250 packets/sec, Tp = 0.3 sec, so $R_0 = 0.7$ seconds, $W_0 = 5.375$ packets.
The controller design parameters are considered: $\Delta N^+ = 10$, $\Delta R_0^+ = 0.1$, $\Delta C^+ = 50$, which implies $\Delta W_0^+ = 2.3417$.

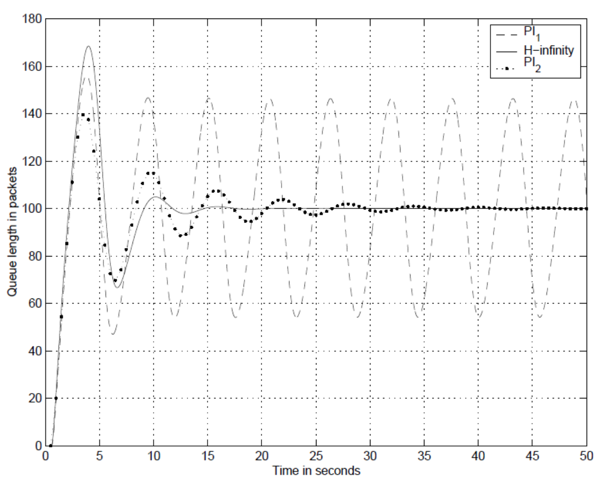

Figure 1: Comparison between H Infimum and PI controllers

For comparison, we also simulate the PI AQM scheme proposed in [3]. The parameters of the controller PI1 are computed as suggested by the author of [3] using the above known nominal values. We can see in Figure 1 that H Infimum controller performs significantly better than PI controller for this set of parameters. However, if the PI controller is designed in a conservative way, assuming that the number of TCP flows are lower than what is known to the controller, it is possible to approach a similar performance than the H Infimum controller, as seen in Figure 1 for PI2 designed with N = 40.

In Figures 2 and 3 we analyze the Effectiveness of two schemes with respect to variations in the network parameters. The outgoing link capacity C is a normal
distributed random signal with mean of 250 packets/s and variance 50 added to a pulse of period 60s, amplitude 60 packets. The number of TCP flows N is normally distributed random signal with mean 45 and variance 30 added to a pulse period 20s and amplitude 10. The propagation delay Tp is normally distributed random signal with mean of 0.8s and variance 0.05s added to a pulse of period 20s and amplitude 0.2s. Controllers have the following value known to them: C = 300 packets/s, N = 50, Tp = 0.7 and desired queue length is q0 = 100 packets. In addition the H Infimum controller uses the following design parameter: $\Delta N+ = 10$, $\Delta R+ = 0.1$ and $\Delta C+ = 50$. RED has following parameters: pmax = 0.1, $min_{th} = 80$, $max_{th} = 150$, Queue averaging weight = 0.0001.
It can be seen that both the PI and the H Infimum

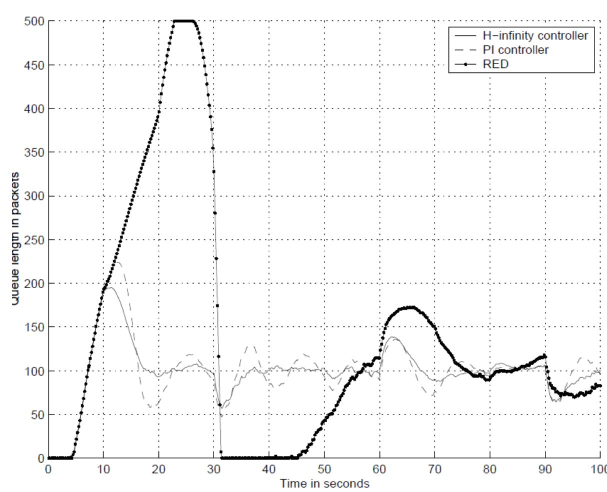

Figure 2: Comparison between H Infimum, PI controllers and RED

controllers perform better than RED as the initial overshoot is reduced, and the system oscillate lesser under parameter variations. The wide oscillations of RED can cause the queue to become empty, thus decreasing utilization of the outgoing link.

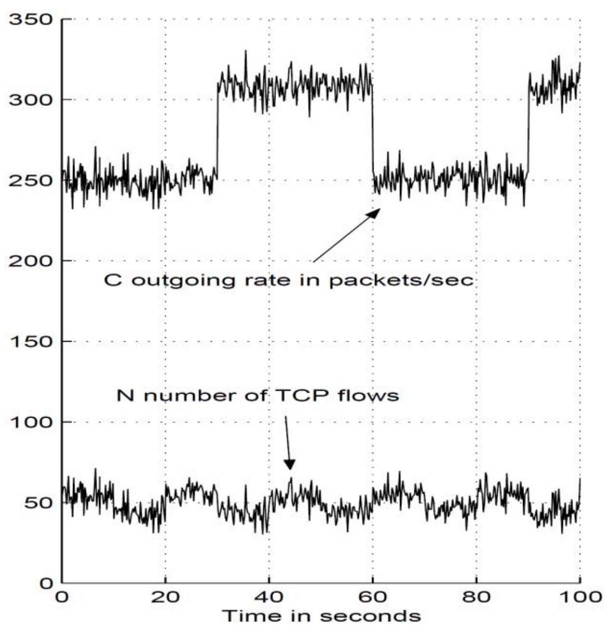

Figure 3: Values of C and N corresponding to Figure 2

However, the PI controller generally need more tuning than H Infimum controller to achieve the same performance, as expected from the Effective controller design.

5 Conclusions:

In this study, a control theoretical approach is accepted to design and examine various flow controllers for congestion control in communicating networks.

In this work, an explicit rate feedback controller is planned for flow control in rate supported networks. The controller ensures stability robustness with respect to changeable time varying multiple time delays in dissimilar channels. It also brings the queue length at the chokepoint client to the desirable changeless state value asymptotically and fulfills a weighted fairness condition. Lower bounds for constancy edges for uncertainty in the time delays and for the rate of modification of the time delays are calculated.

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