Robust Congestion Control for TCP/AQM over Wireless Networks

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Abstract. This paper presents the robust congestion control for TCP/AQM over Wireless Networks. The proposed controller shows a robust control for wireless networks environments in the given varying wireless link.

Keywords: Congestion Control, LQ-servo, TCP/AQM, Wireless Networks

1 Introduction

Computer networks have increased congestion collapse problems according to growth of wired or wireless network. So, some researches [1] ~ [2] proposed the end-to-end congestion control algorithm for Active Queue Management (AQM).

In order to obtain a behavior of AQM, Misra et al. [3] developed a non-linear mathematic model and Hollot et al.[4] approximated its linearized model to convert to control problem based on feedback control theory. More recently, Yang and Suh[5] proposed the robust PID controller based on LQ approach for AQM system. And Lee and Yang [6] proposed the LQ-Servo controller structure, and then Yang et al, [7] developed the tuning method of controller parameter based on Loop-Shaping [8]. But, they did not apply the wireless networks environment.

For applying TCP/AQM over wireless networks, this paper an extension version of previous works [6] and [7] in order to apply wireless networks environments.

2 Model of TCP/AQM

A nonlinear dynamic model for TCP/AQM is presented using fluid-flow and stochastic differential equation in [3]. In order to linearize, it is assumed that the number of TCP sessions and the link capacity are constant, and then a linearized

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constant model can be approximated by small-signal linearization about an operating point (W_0, q_0, p_0), see [4] for linearization details. The linearized model can be presented in (1)

$$\delta\dot{W}(t) = -\frac{2N}{R_0^2 C}\delta W(t) - \frac{R_0 C^2}{2N^2}\delta p(t - R_0)$$
$$\delta\dot{q}(t) = \frac{N}{R_0}\delta W(t) - \frac{1}{R_0}\delta q(t) \quad \textbf{(1)}$$

where $\delta W(t) \doteq W - W_0$, $\delta q(t) \doteq q - q_0$, $\delta p(t) \doteq p - p_0$, $\dot{W}(t)$ denotes the time-derivative of $W(t)$, $\dot{q}(t)$ denotes the time-derivative of $q(t)$, $W \doteq$ Expected TCP window size (packets), $q \doteq$ Expected queue length (packets, $R_0 \doteq$ Round-trip time (seconds), $C \doteq$ Link capacity (packets/second), $N \doteq$ Load factor (number of TCP sessions), $p \doteq$ Probability of packet mark/drop, and $t =$ Time. And also, the probability of packet mark (drop) p takes value only in $0 \le p \le 1$.

For the state space model with an augmented state variable $z_p(t)$, equation (1) can be represented as following:

$$\dot{x}(t) = Ax(t) + Bu(t - R_0)$$
$$y(t) = Cx(t) \quad \textbf{(2)}$$

where $x(t) = \begin{bmatrix} x_r(t) & y_p(t) & z_p(t) \end{bmatrix}^T = \begin{bmatrix} x_p(t) & z_p(t) \end{bmatrix}^T = \begin{bmatrix} \delta W(t) & \delta q(t) & \int_0^t q(\tau)\, d\tau \end{bmatrix}^T$ is state variable included the augmented state variable, $y(t) = \delta q(t)$ is an output variable, $u(t - R_0) = \delta p(t - R_0)$ is an input control variable,

Also, the system matrix, input matrix and output matrix of (2) can be expressed as:

$$A = \begin{bmatrix} A_p & 0 \\ C_p & 0 \end{bmatrix}, B = \begin{bmatrix} B_p \\ 0 \end{bmatrix}, C = \begin{bmatrix} C_p & 0 \end{bmatrix} \quad \textbf{(3)}$$

where $A_p = \begin{bmatrix} -\frac{2N}{R_0^2 C} & 0 \\ \frac{N}{R_0} & -\frac{1}{R_0} \end{bmatrix}, B_p = \begin{bmatrix} -\frac{R_0 C^2}{2N^2} \\ 0 \end{bmatrix}, C_p = \begin{bmatrix} 0 & 1 \end{bmatrix}$.

3 LQ-Servo controller

Without loss of generality, the optimal servo problem is to fine the optimal law $\boldsymbol{u(t)}$ for the linear system (2) by minimizing the cost functions

$$J = \int_0^\infty \{x^T(t) \cdot Q \cdot x(t) + u(t) \cdot \rho \cdot u(t)\} dt \quad \textbf{(4)}$$

where a weighting matrix Q is symmetric and positive semi-definite, and a weighting factor ρ is positive value. And, we use the general control law $u(t) = -G\,x(t)$ where $G = -\rho^{-1}B^T K$ and $K = K^T$ is a solution matrix of the algebraic Riccati's equation:

$$KA + A^T K + Q - \frac{1}{\rho} KB\ B^T K = 0 \qquad (5)$$

Suppose the gain matrix G is decomposed into $G = \lfloor g_r \quad g_y \quad g_z \rfloor$, the optimal control input can be expressed by the augmented state-variable $x(t)$ as following:

$$u(t) = -g_r x_r(t) - g_y y_p(t) - g_z z_p(t) \qquad (6)$$

Therefore, the LQ-Servo structure [6] of TCP/AQM is shown in Figure 1 to ensure that zero steady state error is robustly achieved in response to a constant reference commands

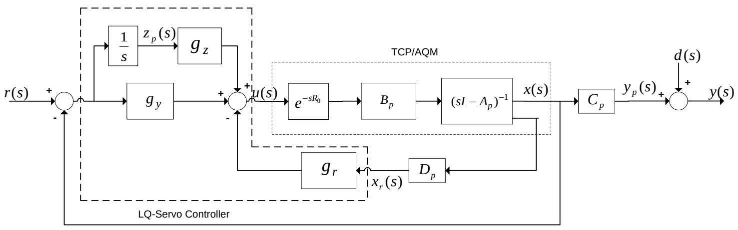


Fig. 1. LQ-Servo control structure for TCP/AQM

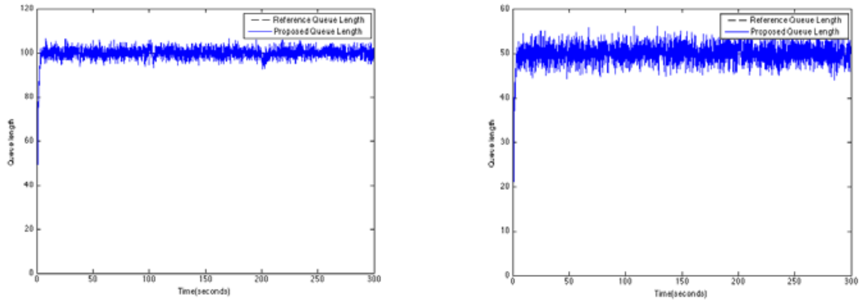
4 Simulation

In wireless networks environment, it should be noted that the system parameters are sensitive to varying channel conditions and data rates. This means that an adapting congestion controller is an important issue in the given varying wireless link. For simulations in this paper, the system parameters have 3-modes taken in Table 1.

Table 1. System parameters of 3-mode for Wireless Networks

Mode 1	Mode 2	Mode 3
$N = 100$	$N = 50$	$N = 20$
$C = 1875\, packets/\sec$	$C = 950\, packets/\sec$	$C = 1500\, packets/\sec$
$R_0 = 0.2$	$R_0 = 0.1$	$R_0 = 0.5$

At every 100 seconds, the mode is changed ((a) reference queue length: 100 (b) reference queue length: 50) from Mode 1 to Mode 3. The results are shown in Fig. 2. The proposed LQ-Servo controller is robust against the 3-modes, and the queue length does not fluctuated.



(a) (b)

Fig. 2. Simulation results

5 Conclusion

This paper proposes the robust controller for TCP/AQM over Wireless Networks. And, the simulation result shows that the proposed controller has the robust performance in wireless networks environments.

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