Time Delayed Feedback Control of Internet Congestion Control Model with Compound TCP under RED

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Abstract—This paper is concerned with controlling of chaotic behavior in Internet congestion control model with Compound TCP under RED. Compound TCP (CTCP) is currently the default transport layer protocol in the Windows operating system. Firstly, this paper briefly analyzes the nonlinear dynamics of the CTCP under RED network with respect to system parameters. Bifurcation is shown to occur when parameters cross through the critical values. Then, in order to widen the stability domain of the system, the Time Delayed Feedback Control (TDFC) is added to the system. With the purpose of better reflecting the effect of TDFC, the paper analyzes the fixed point of congestion control system by theoretical analysis. By appropriately selecting the time delay feedback gain, the bifurcation is successfully delayed and the chaotic orbits are stabilized to the fixed point which indicates the performance of congestion control system is improved significantly. Finally, numerical simulations are provided to show the effectiveness of the theoretical results.

Keywords-Nonlinear system; Time Delayed Feedback Control; congestion control; CTCP; RED

I. INTRODUCTION

Transport Control Protocol (TCP) [1] has been widely used in the current Internet for reliable end-to-end transmission of data. As time goes, several variations of the basic congestion control mechanism of TCP have been proposed during the last several years for efficient transmission of data over high-speed long-distance networks. Compound TCP (CTCP) [2] is one of these proposals. In the class of transport protocols, CTCP is of particular interest as it is the default protocol in the Windows operating system, and its performance evaluation is relevant to current networks [3]. It is an important flavor of TCP, as its evaluation can help people understand the performance of transport protocols that are used in real networks.

For an analysable evaluation, one needs to have a model. The model we use for CTCP is the Internet congestion control model which is under the Random Early Detection (RED) [4] policy. The Random Early Detection (RED) policy [5] was proposed in order to overcome synchronisation among TCP flows. Synchronisation among TCP flows can be induced in a Drop-Tail policy when Drop-Tail drops all incoming packets and the router buffer is full [3]. And the TCP-RED system can be modeled as a first-order nonlinear map which exhibits a rich variety of irregular behaviors such as bifurcation and chaos [6], the possibility of controlling bifurcation and chaos in the TCP-RED system is investigated in [7]. In this paper, time delayed feedback control(TDFC) [8] [9] approaches are used to control the chaotic behavior in Internet congestion control model. It is one of the most efficient chaos control scheme which is first introduced by Pyragas [10] and later applied by many other authors [11]. As for the aim of this article is to study analytically the effect of applying a TDFC to the system. Finally, it can be seen that through numerical simulations, the TDFC can be a good solution for stabilizing the system when it is working out of its stability domain.

The rest of the paper is organized as follows: Section II introduces the model. Section III presents preliminary results about some properties of the nonlinear dynamics of the system without TDFC and analyses the fixed point. Section IV analyzes adding the control to the system, and gives the numerical simulations. Section V is the final conclusions.

II. DYNAMIC MODEL FOR CTCP UNDER RED

In this section, the author studies the Internet congestion control model with CTCP under RED. The nonlinear one-order discrete-time dynamic model of CTCP under RED is defined as follow:

$$\overline{q_{k+1}} = \begin{cases} (1-w)\overline{q_k}, & if\ \overline{q_k} > \overline{q_u} \\ (1-w)\overline{q_k} + wB, & if\ \overline{q_k} < \overline{q_u} \\ (1-w)\overline{q_k} + w\left(\dfrac{N}{\alpha^{\frac{1}{2-k}}(1-(1-\beta)^{1-k})p^{\frac{1}{2-k}}}\left[\dfrac{1-(1-\beta)^{\frac{1-k}{2-k}}}{2-k}\right]^{\frac{1-k}{2-k}} - \dfrac{Cd}{M}\right), & otherwise \end{cases} \quad (1)$$

The d second represents the same round-trip propagation delay. The long-lived uniform CTCP connections is N and their packet size is M bit/packer. A single bottleneck link is shared by multiple connections in simple network, and the capacity of the bottleneck link is denoted by C bit/s. k is the period. According to the exponential averaging rule, the queue size q_k is used to compute the average queue size $\overline{q_k}$. The average queue size $\overline{q_k}$ is used to calculate the packet drop probability at period k. p_k (packet drop probability) is defined as the feedback signal which is provided by the RED controller at the router, it also is a function of the average queue size q_k at period k according to [12]. Due to the feedback delay of round trip time, the packet drop probability p_k at period k (k ≥1) determines the throughput of connections and the queue size q_{k+1} at period $k+1$.

Where p_k is defined as follow:

$$p_k = \frac{p_{\max}(\overline{q_k} - q_{\min})}{q_{\max} - q_{\min}}$$

w is the exponential averaging weight that determines how fast the RED mechanism reacts to a time-varying load. Parameters α , β and k are tunable, therefore, they are given to desirable stability, smoothness and responsiveness. $q_{\min}$ and $q_{\max}$ are the lower and upper threshold values. $p_{\max}$ is the drop probability when $\overline{q} = q_{\max}$. $\overline{q_u}$ and $\overline{q_l}$ are the average queue size and the corresponding average queue size.

$$\overline{q_u} = \begin{cases} \dfrac{p_u(q_{\max} - q_{\min})}{q_{\max}} + q_{\min}; & if p_u \le p_{\max} \\ q_{\max}; & otherwise \end{cases} \quad (2)$$

$$\overline{q_l} = \frac{p_l(q_{\max} - q_{\min})}{q_{\max}} + q_{\min} \quad (3)$$

III. Fixed point of the model

In order to get the fixed point of the Eq.(1), we let

$$\overline{q_{k+1}} = Q(\overline{q_k}, \delta) \quad (4)$$

Where δ is the system parameter such as exponential averaging weight w. The fixed point of mapping $Q^{(*)}$ is an average queue size q^* such that $q^* = Q(q^*, \delta)$. The fixed point remains between $q_{\max}$ and $q_{\min}$ when parameters are configured.Solving $q^* = Q(q^*, \delta)$, one derives that the fixed point of the system is given as a solution to the following polynomial:

$$y - e \cdot (y - q_{\min})^{\frac{-1}{2-k}} - \frac{Cd}{M} = 0 \quad (5)$$

where

$$e = N\left[\frac{1-(1-\beta)^{\frac{1-k}{2-k}}}{2-k}\right]^{\frac{1-k}{2-k}} \left(\alpha^{\frac{1}{2-k}}(1-(1-\beta)^{1-k})\left(\frac{p_{\max}}{q_{\max} - q_{\min}}\right)^{\frac{1}{2-k}}\right)^{-1}$$

For Eq.(5) is a transcendental equation, Matlab is used to calculate its numerical solution,parameters are defined as follows:

$q_{\max} = 750\,packets$, $q_{\min} = 250\,packets$, $p_{\max} = 0.1$, $C = 15Mbit/s$, $B = 3750\ packets$, $M = 4000\ bit$, $d = 0.1\ s$, $N = 1$, $k = 0.75$, $\alpha = 1/8$, $\beta = 1/2$.

Then, get the fixed point q^* . And q^* = 338.3 .

IV. Controlling chaos

Firstly, according to Sec.2, a figure can be got. as it can be seen from Fig.1, there is a fixed point which is equal to the value of analysis in Sec.3. Also, from the figure, the critical value of w is $w_c =$ 0.269. As for $w > w_c$, the system loses its stability. When $w < w_c$, the system is stable. Then, this paragraph above talks about adding TDFC approaches to control the chaos of the system.

Using control signal to Eq.(4):

$$\overline{q_{k+1}} = Q(\overline{q_k}, \delta) + u_k \quad (6)$$

Where u_k is the control signal .From the article [13], we can get:

$$u_k = \left[g\left(\overline{q_k} - (1-r)\sum_{j=1}^{\infty} r^{j-1}\overline{q_{k-j}}\right)\right] \quad (7)$$

Therefore ,

$$u_k = g(\overline{q_k} - \overline{q_{k-1}}) + ru_{k-1} \quad (8)$$

Where g is feedback gain and $r \in [0,1)$, it will be the standard TDFC when r = 0.

Define the control signal u_k :

$$u_k = \begin{cases} g\left(\overline{q_k} - \overline{q_{k-1}}\right) + r u_{k-1}, |u_k| < \theta \\ 0 \qquad\qquad\qquad\qquad , \text{otherwi} \end{cases} \quad (9)$$

Where θ is a small positive quantity. From Eq.(9) and $r \in$[0,1), get $g \in$(0.44,1.64).

For all of these analysis above, the eigenvalue of the controlled system is described as:

$$\varphi = \frac{\partial \ (Q(\overline{q_k}, \delta) + u_k)}{\partial \overline{q_k}} \bigg|_{\overline{q_k} = q^*} \quad (10)$$

If the controlled system is stable at the fixed point, the nonlinear stability criterion should be satisfied, i.e.

$$|\varphi| < 1 \quad (11)$$

Substituting Eq.(11) into Eq.(11) yields

$$\left| \frac{\partial (Q(\overline{q_k}, \delta) + u_k)}{\partial \overline{q_k}} \bigg|_{\overline{q_k} = q^*} \right| < 1 \quad (12)$$

The critical value w_{cg} is calculated in Eq.(12). As Eq.(12) is a transcendental equation, Matlab is used to calculate its numerical solution and the value of w_{cg}.

As an example, we choose r =0.3, g =1.The control signal is added to the system at time 200. From the numerical simulations, Fig.2 and Fig.3 are got, they are average queue size and the control signal, and q^* =314 is got.

When r is stable, Fig.4 and Fig.5 will be got. When keeping g stable, changing the value of r , Fig.6 and Fig.7 are got as follow:

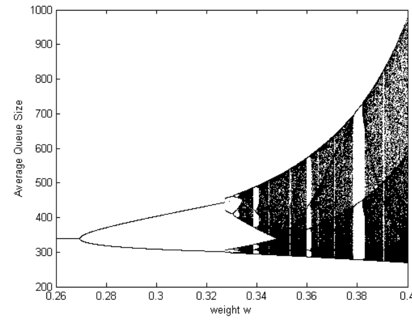

Figure 1. Bifurcation diagram

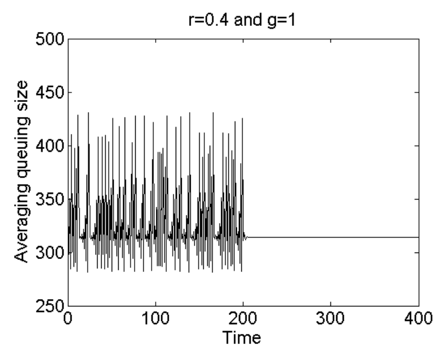

Figure 2. Average queue size (r =0.4 and g =1)

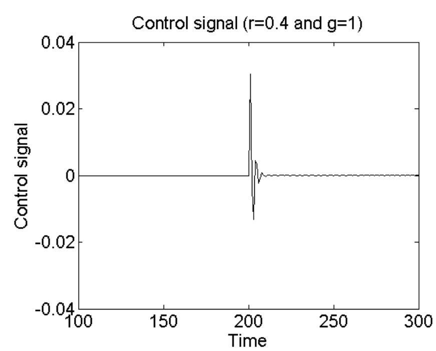

Figure 3. Control signal (r =0.4 and g =1)

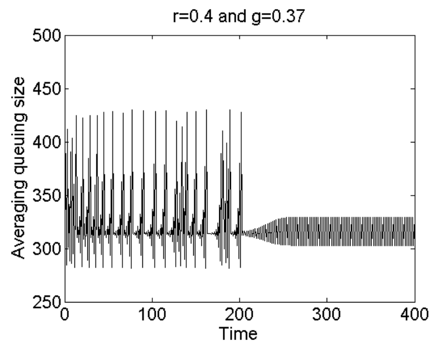

Figure 4. Average queue size (r =0.4 and g =0.37)

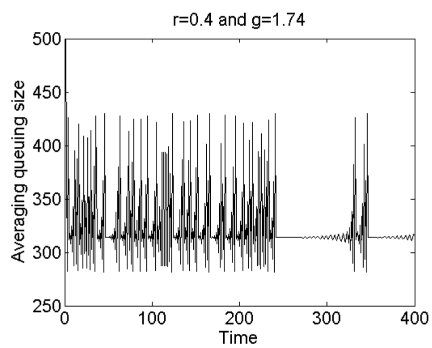

Figure 5. Average queue size(r =0.4 and g =1.74)

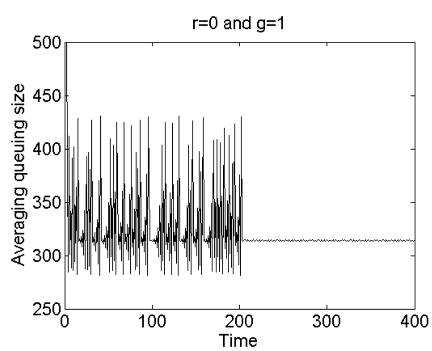

Figure 6. Average queue size (r =0 and g =1)

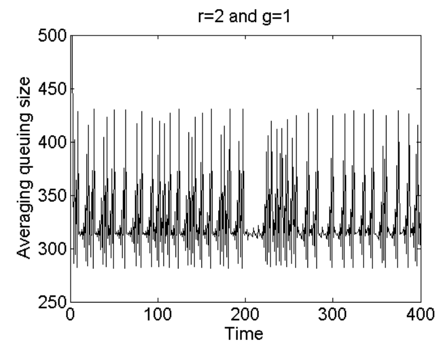

Figure 7. Average queue size (r =2 and g =1)

As for all of these analysis above, it can be seen that different h and r can lead to different control results. When the value of h and r is not in their own range($r \in [0,1)$, $g \in (0.44,1.64)$), there is no fixed point at their figures of average queue size which indicates that the system is unstable.

V. Conclusions

In this paper, the author first analyzes the system description. Among the flavors of TCP and RED, the author focuses on Compound TCP as it is widely deployed in the Internet congestion control model. Then, the fixed point of the system is determined and the nonlinear stability criterion is obtained. TDFC is used to control the system state parameter in order to stabilize the chaotic behavior of average queue size of Compound TCP under RED congestion system. Finally, simulation results indicate that the proposed approach provides a reliable and rather simple technique for controlling chaos behaviors in CTCP under RED congestion control model.

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