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A New Sliding Mode Controller for TCP Congestion Control

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ABSTRACT

In this paper a new sliding mode controller for congestion problem in TCP networks has been proposed. Congestion occurs during high network loads then this congestion focuses on some aspect of network behavior under high load. In a congestion situation three things accrue in sequence. Congestion control is a set of mechanisms that prevent or reduce such as consumptions. Generally, to solve this problem with a systematic approach using control theory, closed loop data transfer processing structure in computer networks can be considered. Sliding mode controller is robust against modeling uncertainties and disturbances. In sliding mode control states should be reached a predefined surface (sliding surface), in a limited time and remain the same surface over time. Moving on the sliding surface is independent of the uncertainties, so this technique is one method of robust control. After applying controller to system, stability of the system with controller has been proven by Lyapunov stability criteria. Simulation result shows the efficiency of the sliding mode controller in different scenarios.
KEYWORDS: Sliding mode control, Congestion control, Robust, Uncertainties, Disturbances Lyapunov.

I. INTRODUCTION

Congestion collapse was identified as a possible problem as far back as 1984 [1]. It was first observed in the early days of Internet in October 1986, when the NSFnet phase-I backbone dropped three orders of magnitude from its capacity of 32 kbit/s to 40 bit/s, to solve the problem the end nodes started implementing Van Jacobson's congestion control between 1987 and 1988 [2].

Congestion occurs during high network loads then this congestion focuses on some aspect of network behavior under high load. In a congestion situation three things accrue in sequence. Firstly, the queuing delay of the data packets increases then there may be packet losses and, finally, the traffic is dominated by retransmissions, so the data rate decreases. Delay, loss and single-bit or multi-bit explicit signals from routers can be used as feedback for congestion control. Congestion control is a set of mechanisms that prevent or reduce such as consumptions. Generally, to solve this problem with a systematic approach using control theory, closed loop data transfer processing structure in computer networks can be considered.

Control theory shows good ways to solve this problem. The word control has a double meaning; first, controlling a system can be understood simply as testing or checking that its behavior is satisfactory. In a deeper sense, to control is also to act, to put things in order to guarantee that the system behaves as desired. Control theory is an interdisciplinary branch of engineering and mathematics, which deals with the behavior of dynamical systems. Control Theory shows systematic approach to analysis and designs a system, predict system response to some input and approaches to assessing system stability.

Active Queue Management (AQM) is the most famous congestion controller for TCP networks. While the rest of the components are altogether defined as a plant in figure 1 [3],[7], AQM is designed as a congestion controller to be implemented in network routers.

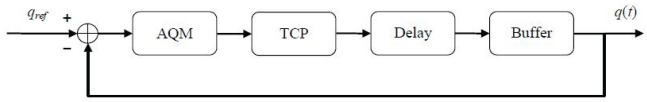

Figure 1: The feedback control system for TCP/AQM.

The routers are run on by AQM algorithms and they detect incipient congestion through typically monitoring the instantaneous or average queue size. AQM algorithms infer congestion on the link and notify the end systems to speed down their transmissions by proactively dropping some of the packets arriving at a router or by marking the packets when the average queue size exceeds a certain threshold. End systems that experience the marked or dropped packets reduce their transmission rates for relieving congestion and preventing the queue from overflowing. Congestion is prevented With AQM

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before it actually occurs. Therefore, the deployment of AQM could result in a high throughput, reduced packet loss and low queuing delay network. Random early detection (RED) is an active queue management algorithm.

The RED algorithm computes the average queue length when a packet arrives in the queue. Also, congestion does not exist and the packet is queued if length of average queue is lower than lower threshold, otherwise, congestion is serious and the packet is discarded. If length of average was between the two thresholds, this could indicate the onset of congestion. Next the probability of congestion is calculated [7]. In this paper tuning the RED has been discussed as a case study however authors have practices on other networks [4].

II. TCP MODEL

Three main components to TCP congestion control are as additive increase/multiplicative decrease, slow start, and fast retransmit and recovery. Based on these components, There are many models. Based on a stochastic differential equation which describes a sample path of each long-lived TCP connection (implementing an additive increase and multiplicative decrease (AIMD) strategy) has been derived in [3] and is given as:

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

$$\dot{q}(t) = \begin{cases} -C(t) + \dfrac{N(t)}{R(t)}W(t), & q > 0 \\ \max(0, -C(t) + \dfrac{N(t)}{R(t)}W(t)) & q = 0 \end{cases} \qquad (1)$$

where $\dot{x}$ denotes the time-derivative and *x(t)=(w(t),q(t)), u(t)=p(t);*
W: average TCP window size (packets);
Q: average queue length (packets);
R(t): round-trip time $= q/C + T_p$ (secs);
C: link capacity (packets/sec);
T_p :propagation delay (secs);
N: load factor (number of TCP sessions);
P: probability of packet mark.

III. SLIDING MODE CONGESTION CONTROLLER FOR TCP

One of the famous control techniques is sliding mode control, because this technique has been robust against modeling uncertainties and disturbances. In sliding mode control states should be reached a predefined surface (sliding surface), in a limited time and remain the same surface over time. Moving on the sliding surface is independent of the uncertainties, so this technique is one method of robust control.

The motion along these boundaries and the geometrical locus consisting of the boundaries are called a sliding mode the sliding surface respectively. An example trajectory of a system under sliding mode control is shown in figure 2. When system trajectories have reached the surface, the sliding surface is described by s = 0 and the sliding mode along the surface commences after the finite time. The system states "slides" along the line s = 0 after the initial reaching phase. As it has desirable reduced-order dynamics when constrained to it, the particular s = 0 surface is chosen [5]. Here, the $s(t) = x_1 + \dot{x}_1 = 0$ surface corresponds to the first-order LTI system $x_1 = -\dot{x}_1$, which has an exponentially stable origin.

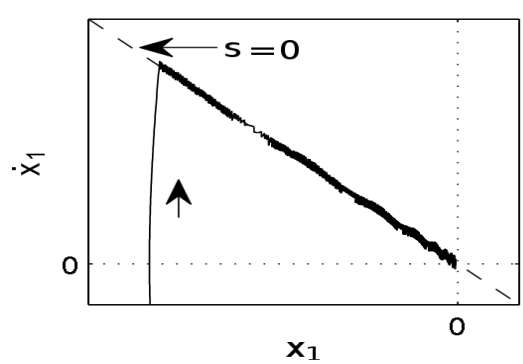

Figure 2: Phase plane trajectory of a system being stabilized by a sliding mode controller.

Consider nonlinear model of TCP in equation (1), by defining $x_2 = \dot{x}_1, x_1 = q(t) - q_0$ the SMC surface is as follow:

$$s(t) = x_1 + \dot{x}_1 = 0 \tag{2}$$

to prove stability and finding control signal the Lyapunov function V(t) has been defined as follows:

$$V(t) = \frac{1}{2}s^2(t)\ ,\ \dot{V}(t) < 0 \Rightarrow s(t)\dot{s}(t) < 0 \tag{3}$$

For designing and robustness of the controller assume that:

$$\dot{s}(t) = -k_1 s - k_2 \operatorname{sgn}(s) \tag{4}$$

Where k_1 and k_2 are designing parameter. Now, by derivative of equation (2) we have:

$$\ddot{x}_1 = -\dot{x}_1 - k_1 s - k_2 \operatorname{sgn}(s) \Rightarrow \ddot{x}_1 = \ddot{q} = -\dot{x}_1 - k_1 s - k_2 \operatorname{sgn}(s) \tag{5}$$

By replacing $\dot{q}(t)$ from equation (1):

$$\Rightarrow \ddot{q}(t) = -\dot{C}(t) + \frac{\dot{N}(t)}{R(t)}W(t) - \frac{N(t)\dot{R}(t)}{R^2(t)}W(t) + \frac{N(t)}{R(t)}\dot{W}(t) \tag{6}$$

By replacing $\ddot{q}(t)$ from equation (5):

$$\frac{N(t)}{R(t)}\dot{W}(t) = \dot{C}(t) - \frac{\dot{N}(t)}{R(t)}W(t) + \frac{N(t)\dot{R}(t)}{R^2(t)}W(t) - \dot{x}_1 - k_1 s - k_2 \operatorname{sgn}(s)$$

By replacing $\dot{W}(t)$ from equation (1):

$$\frac{1}{R(t)} - \frac{W(t)}{2}\frac{W(t-R(t))}{R(t-R(t))}p(t-R(t)) = \tag{7}$$

$$\frac{R(t)}{N(t)}\dot{C}(t) - \frac{\dot{N}(t)}{R(t)}W(t) + \frac{N(t)\dot{R}(t)}{R^2(t)}W(t) - \dot{x}_1 - k_1 s - k_2 \operatorname{sgn}(s)$$

$$p(t-R(t)) = -\frac{2(R(t-R(t))}{W(t)W(t-R(t))}\Big(-\frac{1}{R(t)} + \frac{R(t)}{N(t)}\dot{C}(t)$$

$$-\frac{\dot{N}(t)}{R(t)}W(t) + \frac{N(t)\dot{R}(t)}{R^2(t)}W(t) - \dot{x}_1 - k_1 s - k_2 \operatorname{sgn}(s)\Big)$$

(8)

$\dot{N}(t), \dot{R}(t), \dot{C}(t)$ are uncertainties and upper bound of this parameter should be defined or considered negligible like other researches[3].

In this paper $p(t-R(t))$ is control signal, by applying the above control signal can be expected that the system reached stable equilibrium and its states move on the predefined sliding surface. But moving speed and the amount of control signal toward equilibrium point are unknown.

IV. SIMULATION AND RESULTS

To compare the proposed method with previous methods, a scenario is presented in this paper. In this scenario the network parameters are considered N = 60, C = 3750 Packets / s and $R_0 = 0.246\ s$ s. The proposed controller has been applied under these conditions and the results will be compared with sliding mode controller [6], P and PI controllers [3].

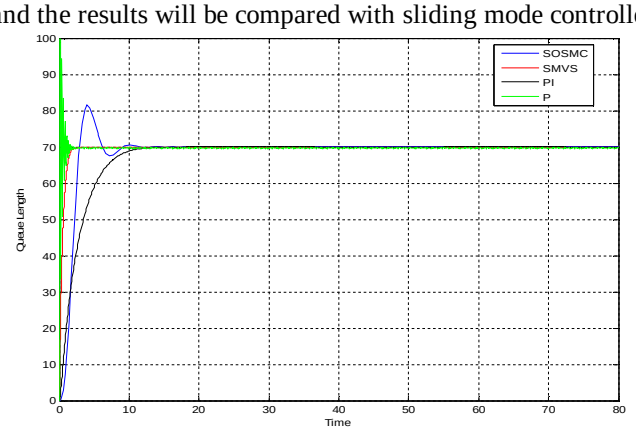

Figure. 3: Network responses to different controllers

It can be observed:

P controller has the fastest response with more fluctuations. The sliding mode controller has fast response without overshoot.

Both P and sliding mode controller in less than 5 seconds reach to steady state but their response have the steady state error. Second order sliding mode controllers (SOSMC) and PI have slower response and reach steady state with no error. SOSMC controller has 15 percent overshoot. Control signal for mention controllers is as follows:

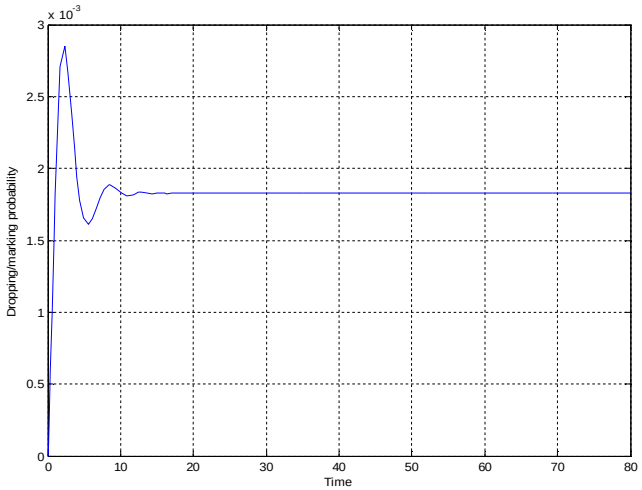

Figure4: SOSMC Control signal

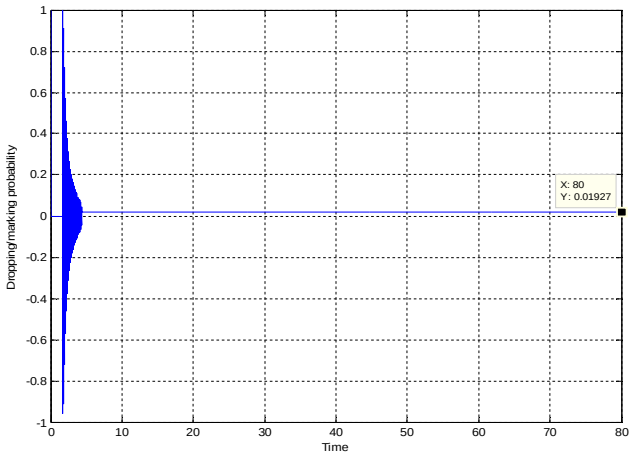

Figure5: SMVS Control signal

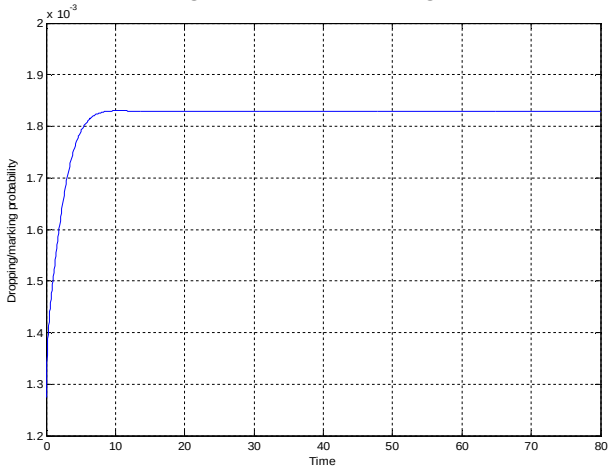

Figure6: PI Control signal

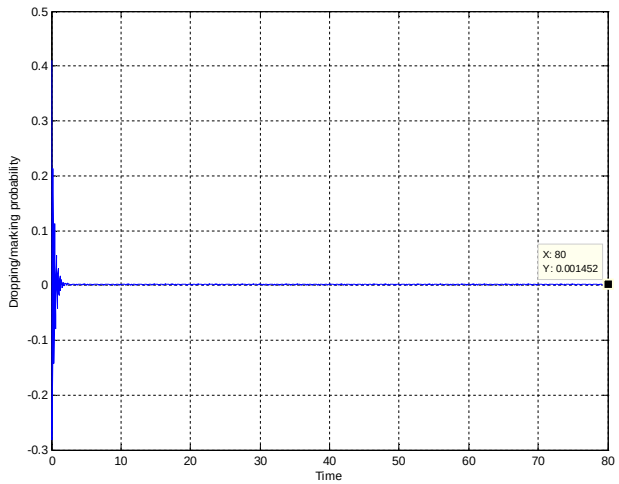

Figure7: P Control signal

Lowest oscillation control signal related to the PI controllers and SOSMC. The final value of the two signals is approximately 0.002. Sliding mode controller and P control signal have negative part then these controllers are not acceptable. Also, the final value of sliding mode controller and P controllers are about 0.02 is about 0.002 respectively. Then SOSMC with appropriate control signal has rapid response with no steady state error.

For evaluating proposed method, all parameters considered with 10% deviation. Then in this scenario the network parameters are considered $N = 60 \pm 6$, $C = 3750 \pm 375$ Packets/s and $R_0 = 0.246 \pm 0.02\,s$ s. In the next step our proposed sliding mode controller has been investigated in these conditions and results have been shown in Figure (8). It can be observed this controller is fast and less than 3 seconds queue length reaches the desired queue length.

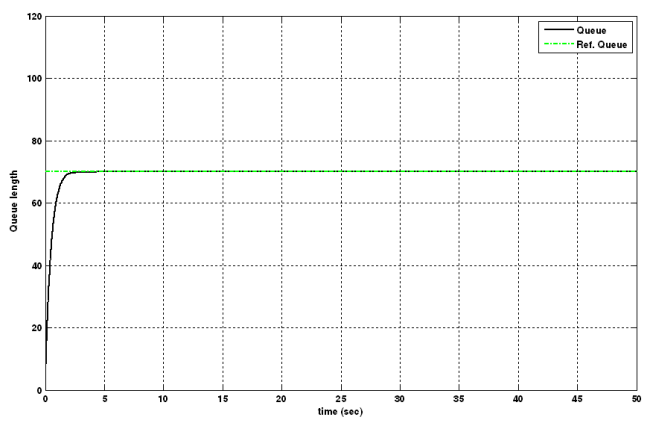

Figure 8: Network responses to SMVS controller

Sliding mode Control signal is shown in the figure (9). In some moments control signal is fluctuated.

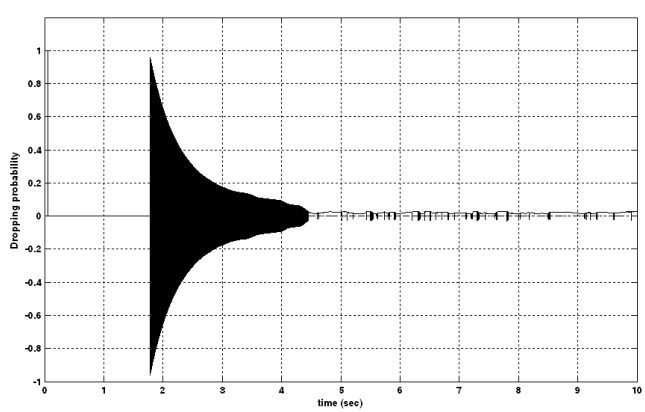

Figure 9: SMVS Control signal

V. CONCLUSION

In this paper a new sliding mode controller for a TCP congestion control was presented. Sliding mode control has good efficiency against uncertainties. After applying controller to system, stability of the system with controller has been proven by Lyapunov stability criteria. For evaluating the proposed method, results with different controllers have been compared.The results of this comparison prove the efficiency of the above the proposed sliding mode controller.

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