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Robust AQM Controller Design for DiffServ Network Using Sliding Mode Control

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Abstract: For DiffServ network, an AQM controller is designed based on the nonlinear fluid flow model and the Integrated Dynamic Congestion Control (IDCC) scheme. Due to modeling uncertainties, time varying parameter fluctuations and external disturbances, we adopt a robust controller based on sliding mode control. The controller is designed for premium traffic service and ordinary traffic service respectively. Especially for ordinary traffic, a sliding mode control algorithm is designed to compensate the input delay. Simulation results demonstrate that this method enables the queue length trace the reference value quickly. Consequently the proposed scheme gets good control effect.

1. INTRODUCTION

The rapid growth of Internet and increasing demand to use Internet for time-sensitive voice and video applications necessitate the design and utilization of new Internet architectures. As a result, the Differentiated Services (DiffServ) architecture was proposed (Blake *et al.*, 1998) to deliver Quality of Service (QoS) in networks. This architecture enables IP networks to offer different QoS levels for different users and applications, locating traffic classification and conditioning functions at the edge routers, thus relieving core routers from complex tasks. Core routers discriminate between packets exclusively on the basis of the information impressed at the network edge.

But even for the present Internet architecture, network congestion control remains a critical and high priority issue, and is unlikely to disappear in the near future. The DiffServ network is a development of present TCP/IP networks, so it needs more effective congestion control algorithms in addition to the TCP based congestion control. For present TCP/IP networks, several control algorithms have been proposed. Random Early Detection (RED) (Hollt *et al.*, 2001), the most famous AQM algorithm, has obtained great success in network congestion control, but it is difficult to tune RED parameters under different network environments and the RED parameters are sensitive to the network load. In (Hollt *et al.*, 2001), a linear system analysis method was developed as a new AQM scheme. They do not seem to perform well under highly dynamic environments with uncertainties and time delay.

Robust control is a approach for dealing with the varying network conditions but without the requirement of an exact model. Sliding Mode Control (SMC) is a well known technique for robust control. The principal advantage of sliding mode control is using the robustness of the controller to compensate for network parameter variations and the unmodeled traffic. Some robust variable structure based schemes (Ren *et al.*, 2003; Li *et al.*, 2004; Mahdi, 2004) for DiffServ network perform well with respect to the uncertainties of the internet parameters. But in these papers they only using a simplified model without considering the time delay of the control signal, and the impact of uncertain time-delay was only discussed through simulation.

In this paper, we need to investigate how to compensate for time-delay in a nonlinear model. Based on the nonlinear fluid flow model and the integrated dynamic congestion control structure (IDCC), a robust control law based sliding mode control is designed. The robust control law is derived to ensure the existence of a sliding mode and to overcome the effects of the delay and uncertainties in the sliding mode dynamics. By using Lyapunov function, the necessary and sufficient condition is presented, under which the sliding mode control system for both premium and ordinary services are arrival.

The paper is organized as follows: Section II gives the DiffServ network model based on fluid flow theory, then illustrate the premium traffic model and the ordinary traffic model respectively. Section III presents the design of the sliding mode controller for the two services differently. Simulation results and analysis of the proposed scheme for various scenarios are presented in section IV.

2. THE DIFFSERV NETWORK MODEL

2.1 Integrated Dynamic Congestion Control (IDCC) scheme

Adopting the spirit of IETF DiffServ working group, we divide traffic into three basic types of service: Premium Traffic Service, Ordinary Traffic Service, and Best Effort Traffic Service (Blake *et al.*, 1998).

Use the IDCC scheme in Fig.1 to implement our control strategy (Pitsillides *et al.*, 2005), note that the link capacity for ordinary traffic is any left over capacity from premium traffic, that is $C_r(t) = C_{server} - C_p(t)$.

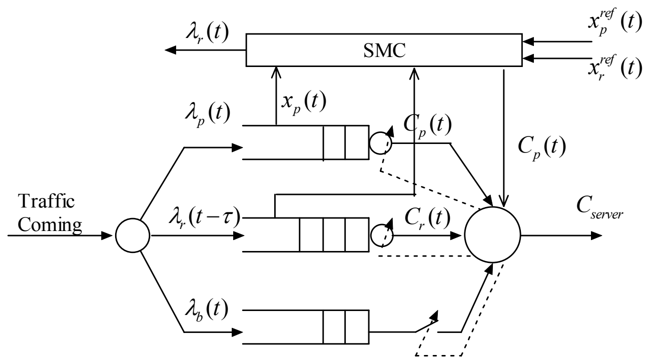

Fig.1. Control strategy implemented at switch output port

2.2 Fluid Flow Active DiffServ Network Model

Based on fluid flow theory, a nonlinear DiffServ Network buffer model is given as follows (Pitsillides *et al.*, 2005).

$$\dot{x}(t) = -C(t)(\frac{x(t)}{1+x(t)}) + \lambda(t) \quad (1)$$

For different traffic, rewrite the model differently:

$$\dot{x}_p(t) = -C_p(t)(\frac{x_p(t)}{1+x_p(t)}) + \lambda_p(t) \quad (2)$$

$$\dot{x}_r(t) = -C_r(t)(\frac{x_r(t)}{1+x_r(t)}) + \lambda_r(t-\tau) \quad (3)$$

where $x_p(t)$ is the queue length of premium traffic buffer, $C_p(t)$ is the link capacity of premium traffic, and $\lambda_p(t)$ is the arrival rate of premium traffic; $x_r(t)$ is the queue length of ordinary traffic buffer, $C_r(t)$ is the capacity of ordinary traffic, which satisfies $C_r(t) = C_{server} - C_p(t)$ and $\lambda_r(t-\tau)$ is the arrival rate of ordinary traffic, τ is the round-trip delay from bottleneck router to ordinary sources and back to the router.

The plant (3) can be described as:

$$\dot{x}(t) = f(x(t),t) + bu(t-\tau) \quad (4)$$

where $x(t) = x_r(t)$, $f(x(t)) = -C_r(t)\frac{x_r(t)}{1+x_r(t)}$, $b = 1$.

The controller design should take into account the time delay and uncertain nature of the fluid model, so we consider a fluid model with uncertainties and delay of the form:

$$\dot{x}(t) = f(x(t),t) + bu(t-\tau) + g_1(x(t),t) + g_2(x(t-\tau),t) \quad (5)$$

where g1, g2 are smooth uncertainties depending on network parameters uncertainties and transmition delay. Further, we assume that the following matching condition exists

$$\begin{aligned} g_1(x(t),t) &= b\gamma_1(x(t),t) \\ g_2(x(t-\tau),t) &= b\gamma_2(x(t-\tau),t) \end{aligned} \quad (6)$$

where $|\gamma_1(x(t),t)| \le q_1|x(t)| + p_1$, $q_1, p_1 > 0$, $|\gamma_2(x(t-\tau),t)| \le q_2|x(t-\tau)|$, $q_2 > 0$, and q_1, q_2, p_1 are known constants.

The following initial conditions are assumed for system (4),

$$x(\theta) = \varphi(\theta) , \ -\tau \le \theta \le 0 \quad (7)$$

Note that the plant model (1) is only an approximate model and it ignores many uncertainties. So the system model is strongly uncertain, nonlinear and subject to additive noise. Taking the nonlinearity and the unmodeled uncertainties into consideration, the sliding mode controller of AQM with uncertainty restrain and delay compensation would be an ideal methodology for robust AQM.

3. DESIGN OF SLIDING MODE CONTROLLER

3.1 Premium Traffic Control Strategy

We adopt a fuzzy sliding mode control scheme for premium traffic plant (2) as follows.

Design the sliding surface as:

$$S_p(t) = x_p(t) - x_p^{ref}(t) \quad (8)$$

and the controller

$$C_p(t) = u_{p0} + u_{p1} \quad (9)$$

where

$$u_{p0} = \frac{-kS_p(t) - \xi\,\text{sgn}(S_p(t)) - \lambda_p(t) + \dot{x}_p^{ref}(t)}{-\frac{x_p(t)}{1+x_p(t)}} \quad (10)$$

$$u_{p1} = -\eta S_p(t) \quad (11)$$

u_{p0} uses a exponential reaching law, u_{p1} uses a fuzzy logic to accelerate the arriving time and eliminate shiver, k 、 ξ and η are all positive constants.

The input variables for fuzzy logic are $S_p(t)$ and $\dot{S}_p(t)$, the output variable is η . The fuzzy language for input is {NB, NS, ZO, PS, PB} and for output is {S, Z, B}.

When state track is far from sliding surface, we should make the switch gain larger, vice versa. When state track departures from sliding surface, if $|S_p(t)|$ is big we should increase the switch gain to make the state track back to the sliding surface; And when state track arrives at the sliding surface, if $|S_p(t)|$ is big we should reduce the switch gain to eliminate shiver. Based on the principle above (Ha *et al.*, 2001), make the fuzzy rule as following:

Table 1. Fuzzy rule

$S_p(t)$	$\dot{S}_p(t)$				
	NB	NS	ZO	PS	PB
NB	B	B	B	B	S
NS	B	S	S	S	Z
ZO	S	Z	Z	Z	B
PS	S	Z	S	S	B
PB	S	B	B	B	B

Choose the Lyapunov function $V(t)=\frac{1}{2}S_p^{\,2}(t)$. The time derivation of *V(t)* along the trajectories of the system (2) is

$$\dot V(t)=S_p(t)\dot S_p(t)$$
$$=S_p(t)\left[-\left(\frac{-kS_p(t)-\xi sgn(S_p(t))-\lambda_p(t)}{-\frac{x_p(t)}{1+x_p(t)}}-\eta S_p(t)\right)\times\left(\frac{x_p(t)}{1+x_p(t)}\right)+\lambda_p(t)\right]$$
$$=S_p(t)\left(-kS_p(t)-\xi sgn(S_p(t))+\eta S_p(t)\frac{x_p(t)}{1+x_p(t)}\right) \tag{12}$$
$$<S_p(t)\left(-kS_p(t)+\eta S_p(t)-\xi\,\mathrm{sgn}(S_p(t))\right)$$
$$<-\xi\left|S_p(t)\right|+(\eta-k)S_p(t)^2$$

In order to guarantee the sliding surface $S_p(t)$=0 always exists in a finite time, we should choose $\eta\le k$.

3.2 Ordinary Control Strategy

Let us design the control law for system (4) in the form

$$u_r(t-\tau)=u_{r0}(x(t-\tau))+u_{r1}(t) \tag{13}$$

where $u_{r0}(x(t-\tau))$ is the ideal memoryless feedback designed, and $u_{r1}(t)$ is the relay control generating the integral sliding mode in some auxiliary space to reject uncertainties g_1, g_2.

Define the sliding surface

$$S_r(t)=z(t)+s_{r0}(x(t)) \tag{14}$$

where $s_{r0}(x(t))=u_{r0}(x(t))$, and *z(t)* is an auxiliary variable defined below.

$$\dot z(t)=-\frac{ds_{ro}(x(t))}{dx(t)}[f(x(t),t)+u_{r0}(x(t-\tau))] \tag{15}$$

The sliding surface $S_r(t)$ corresponds to a combination of the queue length error between incoming traffic rate and link capacity.

Theorem 1: If the control law is chosen as follows:

$$u_{r0}(x(t-\tau))=ke_r(t-\tau) \tag{16}$$

$$u_{r1}(t)=-M(x(t),x(t-\tau),t)\,\mathrm{sgn}(s(t))$$
$$M=q(\left|x(t)\right|+\left|x(t-\tau)\right|)+p \tag{17}$$

where $e_r(t)=x_r(t)-x_r^{ref}(t)$, $q>q_1,q_2$, $p>p_1$ and $k\ge 0$. Then, the sliding mode, $S_r(t)$=0, is reachable in a finite time.

Proof: Choose the Lyapunov function as

$$V(t)=\frac{1}{2}S_r^{\,2}(t) \tag{18}$$

The time derivation of *V(t)* along the trajectories of the system is

$$\dot V(t)=S_r(t)\dot S_r(t)$$
$$=S_r(t)[\dot z(t)+\frac{ds_{r0}(x(t))}{dx(t)}\dot x(t)]$$
$$=S_r(t)\Big\{-\frac{ds_{r0}(x(t))}{dx(t)}[f(x(t),t)+u_{r0}(x(t-\tau))]+\frac{\mathrm{d}s_{r0}(x(t))}{dx(t)}[f(x(t),t)+u_{r0}(x(t-\tau))+u_{r1}(t)+g_1(x(t),t)+g_2(x(t-\tau),t)]\Big\} \tag{19}$$
$$=S_r(t)\frac{ds_{r0}(x(t))}{dx(t)}[u_{r1}(t)+g_1(x(t),t)+g_2(x(t-\tau),t)]$$

Substitute (6), (17) into the above equation we can get

$$\dot V(t)=S_r(t)k[-M(x(t),x(t-\tau),t)\,\mathrm{sgn}(S_r(t))+\gamma_1(x(t),t)+\gamma_2(x(t-\tau),t)]$$
$$\le S_r(t)k[(-q\left|x(t)\right|-q\left|x(t-\tau)\right|-p)\,\mathrm{sgn}(S_r(t))+q_1\left|x(t)\right|+p_1+q_2\left|x(t-\tau)\right|] \tag{20}$$
$$\le k[(-q\left|x(t)\right|-q\left|x(t-\tau)\right|-p)\left|S_r(t)\right|+q_1\left|x(t)\right|+p_1+q_2\left|x(t-\tau)\right|S_r(t)]$$

Because $k\ge 0$, if $S_r(t)\ge 0$, we can get $\dot V(t)\le 0$ from (20); and if $S_r(t)<0$, we can also get $\dot V(t)\le 0$. So from theorem 1 the sliding mode of the system along the sliding surface $S_r(t)$=0 always exists in a finite time.

4. SIMULATION ANALYSIS

In this section we validate the effectiveness and performance of the scheme for DiffServ network by simulation. During the designing of the controller, the two conflicting requirements must be taken into consideration at the same time. The first requires the controller to have good transient response, such as, the regulating time is rather short and the overshot is very small. The second emphasizes the steady performance, such as small steady error and accurately tracking capability.

During the simulation, the parameters are chosen as follows: the max available capacity C_{server} is 10^5 packets/s, the max buffer length of router is 1000 packets.

For premium traffic, the coming traffic is showed in Fig. 2. The desired reference queue length is a sine wave showed in Fig. 3 in solid and the actual trajectory is in dashed. It shows that $x_p(t)$ converges to $x_p^{ref}(t)$ very quickly. The locus of the sliding surface that converge to zero and the control signal are showed in Fig. 4 and Fig. 5.

For ordinary buffer the desired reference queue length is a constant 150, the desired and actual trajectories are showed in Fig. 6. It is showed that $x_r(t)$ converges to $x_r^{ref}=500$ very quickly. The sliding surface and the control signal $\lambda(t)$ are presented in Fig. 7 and Fig. 8, respectively.

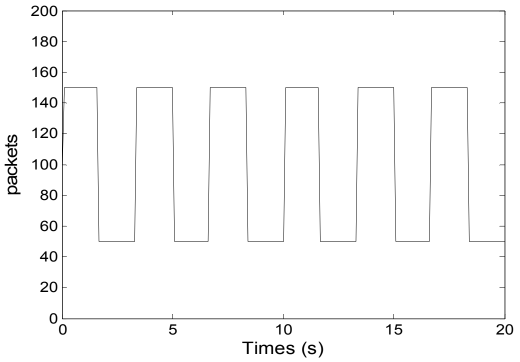

Fig. 2 The coming traffic of premium buffer

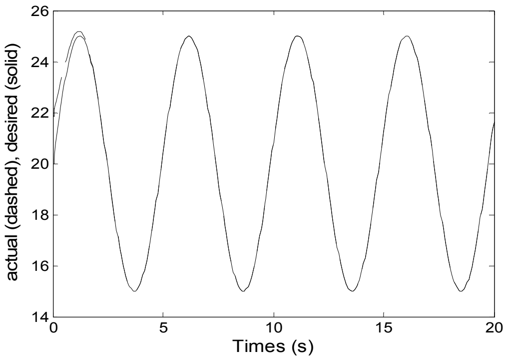

Fig. 3 The queue length of premium buffer

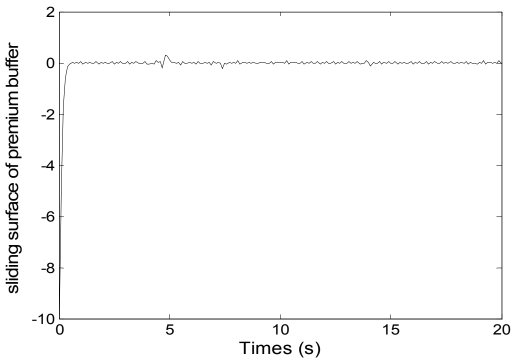

Fig. 4 The sliding surface of premium buffer

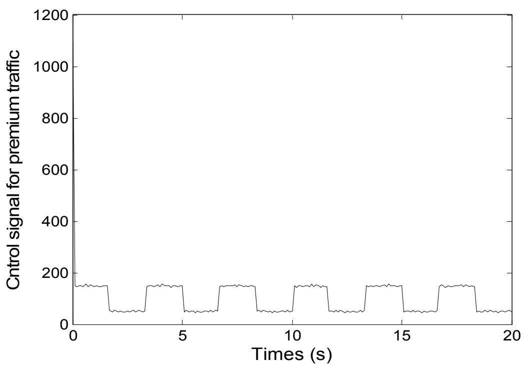

Fig. 5 The link capacity of ordinary traffic

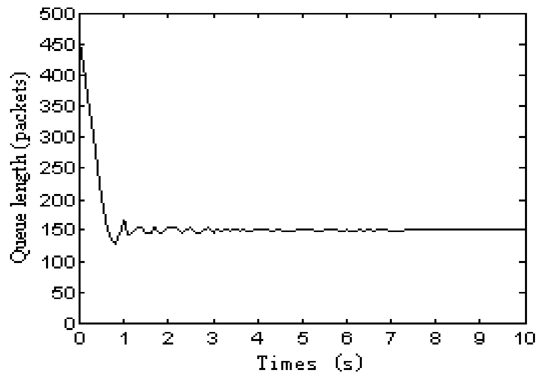

Fig. 6 The queue length of ordinary buffer

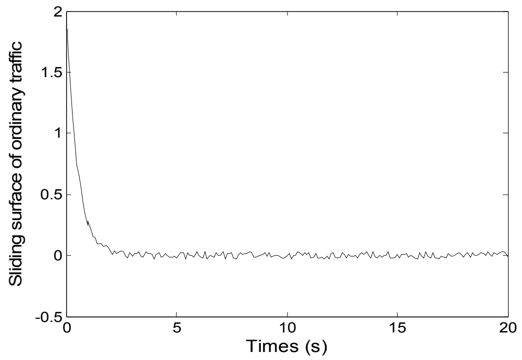

Fig. 7 The sliding surface of ordinary buffer

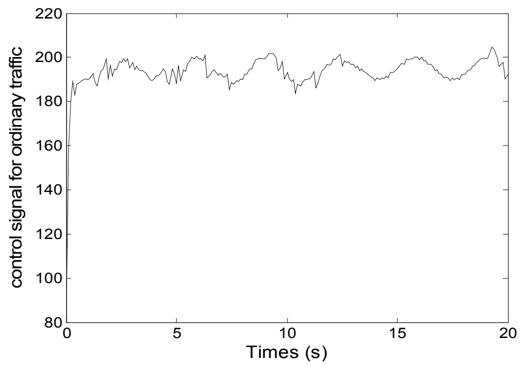

Fig. 8 The control signal for ordinary traffic

5. CONCLUSIONS

In this paper, we propose a robust AQM control scheme for DiffServ network. The two typical services of DiffServ network are premium traffic service and ordinary traffic service. For different characteristics of the two services, we adopt a fuzzy sliding mode control algorithm and a integral sliding mode control method respectively. The simulation results demonstrate the validity of the proposed scheme.

6. ACKNOWLEDGEMENT

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