http://dx.doi.org/10.5755/j01.eee.19.1.3264

Congestion Control of Differentiated Services Networks by Sliding Mode Control

R. Barzamini[1], M. Shafiee[1]
[1]Amirkabir University of Technology,
424 Hafez Ave, Tehran, Iran, phone: +98- 2164543387
barzamini@aut.ac.ir

***Abstract*—In this paper sliding mode controllers (SMCs)' techniques used and investigated for congestion control problem of differentiated Services (Diff-Serv) networks. Robustness against modelling uncertainties and disturbances are major feature of sliding mode controller. Chattering phenomenon affects sliding mode congestion control; to overcome this problem second order sliding mode control (SOSMC) is proposed as a congestion controller. There are three type of traffic in Diff-Serv networks; i.e. there are three types of queues and based in that, the quality of their services are categorized. Each of these types of traffic has its own congestion control mechanisms. Stability of each controller is proved by Lyapunov stability law. To evaluate the capabilities of our proposed robust control strategy, simulation results are provided for both sliding mode controllers and second order slide mode controllers and their corresponding efficiencies are compared.**

***Index Terms*—Second order sliding mode control, congestion, differentiated services networks**

I. INTRODUCTION

Traffic control is the process of managing networks traffic. Particularly bandwidth has been used to reduce congestion, latency and packet loss. In order to increase quality of service (QoS) and appropriate using of network resources such as buffer capacity, bandwidth and processor capacity congestion control mechanism seems to be necessary. Due to limited buffer capacity and bandwidth, network resources may not be able to respond when requests increase. In order to solve this problem Differentiated Service (Diff-Serv) networks are introduced[1].The most important types of service in Diff-Serv networks are ordinary and premium services. Premium service is used for providing bandwidth for delay- and loss-sensitive users while ordinary Service is for regular users for which delay is not critical. In addition, sometimes the best effort traffic is considered as the lowest priority service that assigns the band width remained. Queue in Diff-Serv networks for each class is created and managed separately; hence, different congestion control strategies should be applied for each class. Sliding Mode Control (SMC) is famous for its robust behavior in presence of uncertainties and disturbances. In sliding mode control, states should be reached a predefined surface (sliding surface) in a limited time and remain at the same surface over time. Controlling of the system state as it slides along these boundaries is called a sliding mode control [2] and the geometrical locus consisting of the boundaries is called the sliding surface. Also, several new congestion control schemes for Diff-Serv networks whose performance can be analytically established have been presented in the literature by using sliding mode control [3]. Due to crossing states of surface, the controller may move toward a state on the surface and cross the state on the surface which forces the controller to move back toward the state on the surface successive crossings with fast repetition of this process may lead to chattering phenomenon to appear in sliding mode control. In this paper, a new second order sliding mode controller (SOSMC) for Diff-Serv networks is proposed that eliminates the chattering issue. Authors of this have experience in other networks [4], [5].

In Section II, congestion control strategy for each class of Diff-Serv networks is described briefly. Sliding mode controllers are introduced in section III. In section IV, sliding mode control is applied for Diff-Serv networks congestion control. The results of comprehensive simulations using MATLAB are provided in Section V. Finally, conclusions are stated in Section VI.

II. CONGESTION CONTROL STRATEGY

The model used in this paper is the Fluid Flow Model (FFM) that is [6]. In order to reach the desired queue length, transmission rate should be calculated by congestion control algorithms. In general, FFM for bottleneck node can be described by the following first-order state-space presentation

$$\dot{x}(t)=\left(-x(t)/\left(1+x(t)\right)\right)C(t)+\lambda(t), \tag{1}$$

where $x(t)$ is the queue length, $C(t)$ is the link capacity and $\lambda(t)$ is the input traffic rate. There are three types of traffic in Diff-Serv networks based on which the quality of their services are categorized. Each types of these traffics has its own congestion control mechanisms.

A. *Congestion control strategy for premium traffic*

The goal of congestion control is reaching the desired queue length in each node. Congestion control for premium

Manuscript received November 27, 2012; accepted April 30, 2012.

class is done by allocating bandwidth. This means that in order to keep queue length at the desired value, maximum bandwidth ($C_{\max}$) is assigned to Premium traffic dynamically. The $C_{\max}$ should assign appropriately for premium traffic when input rate increased or decreased

$$0 \le C_p(t) \le C_{\max}. \tag{2}$$

The premium traffic dynamic is described in what follows

$$\dot{x}_p(t) = (-x_p(t)/(1 + x_p(t)))C_p(t) + \lambda_p(t). \tag{3}$$

B. Congestion control strategy for ordinary traffic

The ordinary traffic service controller regulates the flow of ordinary traffic into the network, by monitoring the length of its queues and the available capacity. In order to maintain the desired queue length, congestion controller in this class measures the queue length and informs the sender about the input rate of next time step. The bandwidth for ordinary traffic is as follows

$$C_r(t) = C_{\max} - C_p(t) \tag{4}$$

There is just a physical constraint on $C_r(t)$ that must always be greater than zero. The ordinary traffic dynamic is described as follows

$$\begin{aligned}\dot{x}_r(t) &= (-x_r(t)/(1 + x_r(t)))C_r(t) + \lambda_r(t) = \\ &= (-x_r(t)/1 + x_r(t))\left(C_{\max} - C_p(t)\right) + \lambda_r(t),\end{aligned} \tag{5}$$

where $x_r(t)$ is the queue length, $C_r(t)$ is the link capacity and $\lambda_r(t)$ is the input traffic rate.

C. Congestion control strategy for best effort traffic

The Best Effort traffic controller operates on an instantaneous (packet or cell) time scale. It utilizes any instantaneous left over capacity to transmit a packet from the best effort buffer. Fig. 1, shows the congestion control strategy for Diff-Serv networks. It is clear that each traffic has its own controller.

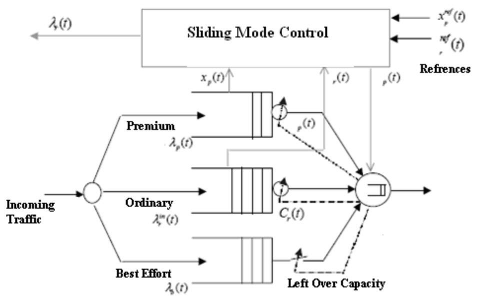

Fig. 1. Control strategy at each switch output port.

III. SLIDING MODE CONTROL

At the first sliding mode controllers should be introduced briefly.

A. First order sliding mode control

In order to introduce sliding mode control consider the following system:

$$\begin{aligned}\dot{x}_1 &= x_2 \\ \dot{x}_2 &= h(x) + g(x)u\end{aligned} \tag{6}$$

Where g and h are unknown nonlinear functions.

$$g(x) \ge g_0 > 0 \qquad \forall x \tag{7}$$

Consider $S=wx_1+x_2$ as sliding surface, then states move on $\dot{x}_1 = -wx_1$ and by selecting $w > 0$ moving states toward zero is guaranteed. Note that w is the convergence rate. The basic issue is how the states can reach the sliding surface (S = 0) and already been validated and utilized in a number of previous work maintain. Lyapunov stability law can be applied to tackle this problem. According to Lyapunov, a positive definite function candidate should be defined whose derivative is negative. By means of this law, reaching to and staying at the sliding surface is guaranteed. For example, consider the following positive definite function as a Lyapunov function

$$V = 1/2\,\rho s^2 + \varepsilon\,|s|, \tag{8}$$

where ρ and ε are constants, Then

$$\dot{V} = \rho \dot{s} s + \varepsilon \dot{s}\,\mathrm{sgn}(s) = \dot{s}[\rho s + \varepsilon\,\mathrm{sgn}(s)]. \tag{9}$$

By considering the following assumption, $\dot{V}$ will be negative

$$s = -1/\rho[\dot{s} + \varepsilon\,\mathrm{sgn}(s)] \quad \to \dot{V} = -\dot{s}^2. \tag{10}$$

By selecting $\dot{s} = w\dot{x}_1 + \dot{x}_2 = wx_2 + h(x) + g(x)u$, control law will be as follows

$$\begin{aligned}&s = -1/\rho[wx_2 + h(x) + g(x)u + \varepsilon\,\mathrm{sgn}(s)] \to \\ &\to u = 1/g(x)[-\rho s - wx_2 - h(x) - \varepsilon\,\mathrm{sgn}(s)].\end{aligned} \tag{11}$$

By applying the above control law, it is expected that the system reaches equilibrium and is stable on moving on the predefined sliding surface. Sine the controller may cross the states on the surface, it should switch and then state back on surface and crossing again. With fast repetition of this process, chattering phenomenon appears in sliding mode control. In practice and in mechanical cases, it may sound like buzz.

B. Second order sliding mode control

The main idea in the second order sliding mode control (SOSMC) is using the second order derivative of sliding surface S, instead of first order derivative. A main advantage of SOSMC is elimination of chattering. In SOSMC, the derivative of control signal $\dot{u}(t)$ instead of $u(t)$ is calculated and therefore the integral of the control signal can be easily calculated. This leads to a smooth movement and elimination of chattering. Note that the design process is the same as standard sliding mode control but, in this method second derivative of the sliding surface appears.

IV. APPLYING SMCS ON DIFF-SERV NETWORKS

In this section proposed SMC and SOSMC congestion control are presented.

A. SMC

Firstly, sliding surfaces are defined as follows:

$$\begin{cases} S_p(t) = x_p(t) - x_{pref}(t) = e_p(t), \\ S_r(t) = x_r(t) - x_{r,ref}(t) = e_r(t). \end{cases} \quad (12)$$

Then

$$\dot{S}_p(t) = \dot{e}_p(t) = (-x_p(t)/1 + x_p(t))C_p(t) + \lambda_p(t) - \dot{x}_{p,ref}(t). \quad (13)$$

In the second step, by choosing the following Lyapunov function, stability of system is guaranteed

$$V = 1/2\, S_p^T(t) S_p(t) \Rightarrow \dot{V} = S_p(t)\dot{S}_p(t) < 0. \quad (14)$$

Third step is finding control signal; by assuming

$$\dot{S}_p(t) = -\eta_{1p} S_p(t) - \eta_{2p} Sign(S_p(t)). \quad (15)$$

The stability of the system is guaranteed. From equations (13) and (15), we have:

$$\begin{aligned} &(-x_p(t)/1 + x_p(t))C_p(t) + \lambda_p(t) - \dot{x}_{p,ref}(t) = \\ &= -\eta_{1p} S_p(t) - \eta_{2p} Sign(S_p(t)) \Rightarrow \\ &\Rightarrow C_p(t) = (1 + x_p(t)/x_p(t)) \begin{pmatrix} \lambda_p(t) - \dot{x}_{p,ref}(t) + \\ +\eta_{1p} e_p(t) + \eta_{2p} Sign(e_p(t)) \end{pmatrix}. \end{aligned} \quad (16)$$

Thus, the control law for the premium service is obtained. Similarly, a control law can be obtained for ordinary service

$$\begin{aligned} &\dot{S}_r(t) = \dot{e}_r(t) = (-x_r(t)/1 + x_r(t))C_r(t) + \lambda_r(t) - \dot{x}_{r,ref}(t) = \\ &= (-x_r(t)/1 + x_r(t))(C_{\max} - C_p(t)) + \lambda_r(t) - \dot{x}_{r,ref}(t). \end{aligned} \quad (17)$$

By choosing the following Lyapunov function:

$$V = 1/2\, S_r^T(t) S_r(t), \quad (18)$$

$$\dot{V} = S_{or}(t)\dot{S}_{or}(t) < 0 \quad (19)$$

and by considering the following surface

$$\dot{S}_r(t) = -\eta_{1r} S_r(t) - \eta_{2r} Sign(S_r(t)). \quad (20)$$

The stability of the system is guaranteed. From equations (17) and (20), we have

$$\begin{aligned} &-x_{or}(t)/1 + x_{or}(t)(C_{\max} - C_p(t)) + \lambda_{or}(t) - \dot{x}_{or,ref}(t) = \\ &= -\eta_{1or} S_{or}(t) - \eta_{2or} Sign(S_{or}(t)) \Rightarrow \\ &\Rightarrow \lambda_{or}(t) = x_{or}(t)/1 + x_{or}(t)(C_{\max} - C_p(t)) + \\ &+\dot{x}_{or,ref}(t) - \eta_{1or} e_{or}(t) - \eta_{2or} Sign(e_{or}(t)). \end{aligned} \quad (21)$$

Thus the control law for the ordinary service is obtained.

B. SOSMC

As mentioned, the main advantage of SOSMC to the SMC is reduction of chattering. In this method derivative of the control signal has been calculated. Practically, some kind of implicit integrator for applying this controller is required and this is the main feature of SOSMC. In order to apply this controller for Diff-Serv networks such SMC there are three steps. Firstly, a first order sliding surface should be defined. Sliding surface is defined as follows:

$$\begin{cases} S_p(t) = \dot{e}_p(t) + h_p e_p(t) = 0, \\ S_r(t) = \dot{e}_r(t) + h_r e_r(t) = 0. \end{cases} \quad (22)$$

As Mented for SMC after applying SOMC method the control law for the premium service is obtained as follow:

$$\begin{aligned} \dot{C}_p(t) = &\frac{1 + x_p(t)}{x_p(t)} \left(-C_p(t) \left(\frac{\dot{x}_p(t)}{(1 + x_p(t))^2} + h_p \frac{x_p(t)}{1 + x_p(t)} \right) + \dot{\lambda}_p(t) - \right. \\ &\left. -\ddot{x}_{p,ref}(t) + h_p(\lambda_p(t) - \dot{x}_{p,ref}(t)) + \eta_{1p} S_p(t) + \eta_{2p} Sign(S_p(t)) \right). \end{aligned} \quad (23)$$

Next, is finding the control law for ordinary service. The queue length regulation of ordinary classes is done by determining the transmit rate. Therefore, the control signal for this class is optimal transmit rate. According to the rest of bandwidth and optimal transmit rate, queue length is kept at the reference point. First order for ordinary service is as follow

$$\dot{S}_r(t) = \ddot{x}_r(t) - \ddot{x}_{r,ref}(t) + h_r(\dot{x}_r(t) - \dot{x}_{r,ref}(t)). \quad (24)$$

Then we have

$$\begin{aligned} &\dot{\lambda}_r(t) = \dot{C}_r(t)(x_r(t)/1 + x_r(t)) + C_r(t)(\dot{x}_r(t)/(1 + x_r(t))^2) + \\ &+\ddot{x}_{r,ref}(t) + C_r(t)h_r(x_r(t)/1 + x_r(t)) - h_r(\lambda_p(t) - \dot{x}_{r,ref}(t)) - \\ &-\eta_{1r} S_r(t) - \eta_{2r} Sign(S_r(t)). \end{aligned} \quad (25)$$

Thus the control law for the premium and ordinary services are obtained. As mentioned, In order to control the queue in premium class, C_p and ordinary class, λ_r should be used. Allocated $C_p(t)$ for the premium queue affects determining $\lambda_r(t)$ for ordinary class. For example, if $C_p(t)$ has some fluctuations, these fluctuations are transmitted to $\lambda_r(t)$. This problem imposes restrictions on determining $C_p(t)$. So, the way to overcome this problem is reducing the possible fluctuations of the control signal $C_p(t)$ to minimum. One way to reduce fluctuations in queue for both classes is using second order sliding mode control. By use of this type of control, $\lambda_r(t)$ will be smooth. If there are more fluctuations, there is one more integrator for ordinary class and it would be helpful. As expected, the first order sliding mode control has limited performance for Diff-Serv networks.

V. SIMULATION RESULTS

The proposed congestion control mechanism for premium and ordinary classes of a Diff-Serv network are simulated with MATLAB and the results are discussed. The models for the Diff-Serv network described in section II are considered in the simulation. Main network parameters of the network are overall server capacity that is set to 1000 pkt/s, disturbance input rate that is 80pkt/s and desired queue length that is 50 packets.

A. *First order sliding mode Control*

Fig. 2 shows the queue length for premium and ordinary classes. Control signal (band width for premium Class and transmission rate for ordinary class) is shown in Fig. 3. As can be seen in the figures and as expected first order sliding mode controller has fast response and control signal has chattering.

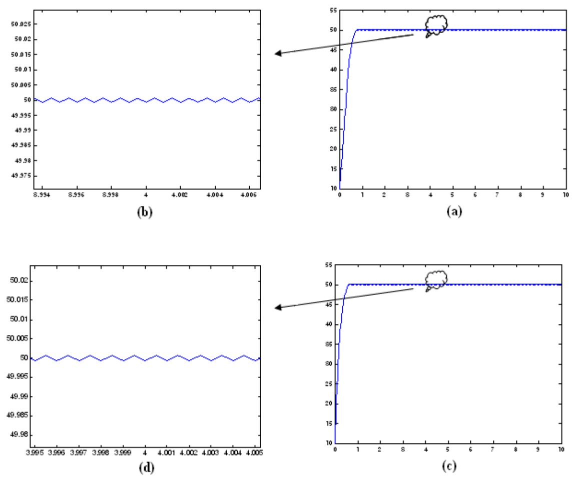

Fig. 2. (a) and (c) show premium and ordinary services queue with first order sliding mode controller; (b) and (d) show zoomed part of (a) and (d) respectively.

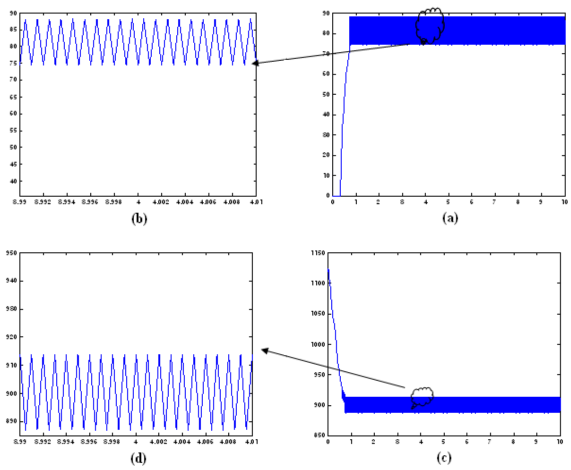

Fig. 3. (a) and (c) show control signals for premium and ordinary classes with first order sliding mode controller; (b) and (d) show zoomed part of (a) and (d) respectively.

B. *Second order sliding mode control*

Fig. 4 shows second order sliding mode controller performance and rise time are more than of first order sliding mode control in both classes. Control signal of both classes are presented in Fig. 5 (Band width for premium class and transmission rate for ordinary class). As expected, fluctuations and chattering problem is solved. This is due to the existence of the integrator in second order sliding mode controller design.

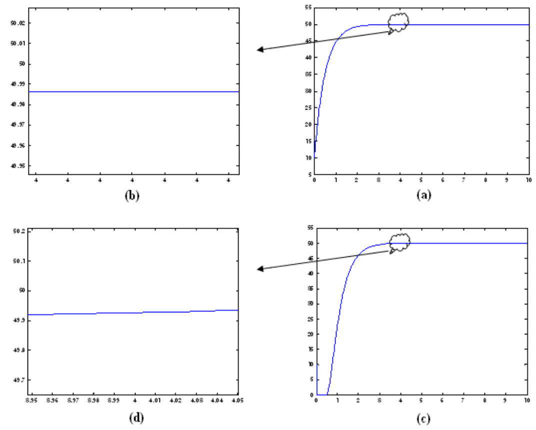

Fig. 4. (a) and (c) show premium and ordinary services queue with second order sliding mode controller; (b) and (d) show zoomed part of (a) and (d) respectively.

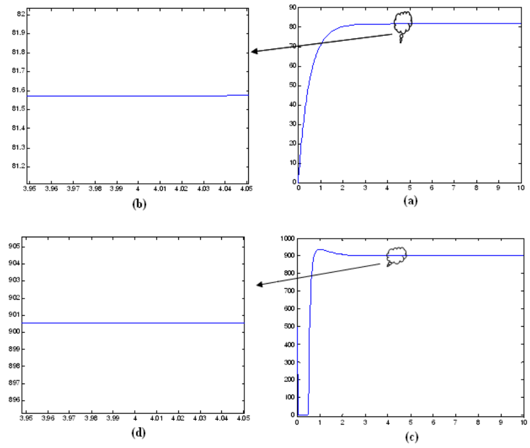

Fig. 5. (a) and (c) show control signals for premium and ordinary classes with second order sliding mode controller. (b) and (d) show zoomed part of (a) and (d) respectively.

VI. CONCLUSIONS

In this paper, first order and second order sliding mode controllers are designed and applied to control the queue length of the Diff-Serv networks. Stability of the system for both controllers is guaranteed via Lyapunov function. Advantages and disadvantages of each controller described in simulation results. SMC has fast response with chattering and SOSMC has slow response without chattering. To use advantages of both controllers combination of the two methods is one of future works.

REFERENCES

[1] S. Blake, F. Baker, *Definition of the Differentiated Services Field (DS Field)*, Cisco Systems, 1998.

[2] N. Zhang, G. Wang, L. Zhao, Y. Jing, X. Li, "Sliding mode congestion control algorithm for a class of large-scale networks based on T–S model", in *Proc. of the Chinese control and decision conference (CCDC 2008),* 2008, pp. 3504–3508.

[3] K. Khalil, *Nonlinear Systems, 3rd ed.* New Jersey, Upper Saddle River: Prentice Hall, 2002.

[4] R. Barzamini, M. Shafiee, "LMI Based Switching Congestion Controller for Multiple Bottleneck Packet Switching Networks", *Journal of American Science,* vol. 7, no. 6, pp. 254–261, 2011.

[5] R. Barzamini, M. Shafiee, "Adaptive Generalized Minimum Variance Congestion Controller for Dynamic TCP/AQM Networks", *Computer Communications*, no. 35, pp. 170–178, 2012. [Online]. Available: http://dx.doi.org/10.1016/j.comcom.2011.08.010

[6] V. Guffens, G. Bastin, H. Mounier, "Fluid flow network modeling for hop by hop feedback control design and analysis", in *Proc. of the Internetworking,* San Jose, 2003.