RATE-BASED FLOW FUZZY CONTROLLER
FOR
COMMUNICATION SYSTEMS*

J. Zrida‡, A. Benzaouia⊥, F. Mesquine⊥, and S. El Faiz⊥

‡*Unité Signaux et Systèmes (U2S)*
Ecole Nationale d'Ingénieurs de Tunis
B.P. 37, 1002, Le Belvédère, Tunis, Tunisie
e-mail : jalel.zrida@esstt.rnu.tn

⊥*Unité Régulation Robuste et Contrainte*
Faculté des Sciences Semlalia
B.P.2390, Marrakech, Maroc

Abstract: This paper addresses the rate-feedback data flow control problem in one-source single bottleneck communication systems and proposes a fuzzy logic based controller that guarantees stability and performance. The controller is also robust with respect to the uncertainty caused by the channel time-delay known to be significantly characterizing communication systems. The advantage of this solution is its simplicity when compared to other propositions and its independence on the adopted model.

Keywords: Communications systems, data flow control, fuzzy control, uncertain dynamic systems, time delay.

1. INTRODUCTION

One of the crucial problem in data communication systems is data flow congestion control. Congestion control is a process by which networks adjust the influx of data flowing into it, such that the customer's quality of service is never compromised, while, simultaneously attempting to optimize the utilization of all the network resources. Aimed at avoiding traffic congestion by controlling the rate at which data is sent from the source into the network, the flow control is a way by which good quality and satisfactory service is provided to the network users. Networks that attempt to deliver more data than their capacity will experience congestion which leads to data loss and excessive service delays. There exist two main strategies for feedback flow control: the rate-base and window-base. The window-base flow control is bit-based and is generally used in the internet TCP/IP network. The rate-based flow control is the standard flow control scheme in asynchronous transfer mode (ATM) switching networks adopted by (ATM forum, 1996). This paper is concerned with the explicit rate-feedback flow control problem in data communication systems. Such systems are known to include important time delays which are generally uncertain and time-varying. This constitutes a challenging obstacle to the problem of searching a controller which not only stabilizes the system but also achieves some desired and necessary performance. Many authors devoted a lot of attention to this particular problem. A good historical overview of rate-based congestion control algorithms is given by (Ohsaki et al., 1995) and shows how these algorithms fit into the ATM forum standard regarding data flow traffic management. In (Altman *et al.*, 1998; Ataslar, 2000; Quet *et al.*, 2002), the authors proposed a H^{∞} robust controller which guarantees stability robustness with respect to uncertain time-varying time-delays in the channels and also insures some weighted fairness condition for better services to the users. The fairness condition is required to avoid the situation in which the network might maximize its throughput while denying access to some users. A proportional or weighted fairness condition gives proportionate priorities to users that are willing to pay for better services. In (Quet *et al.*, 2001), the authors further assumed that, besides the queue information, the controller has access to the network data flow capacity. In (Laberteaux et al., 2002), the authors developed a model of the plant and proposed an adaptive controller for the congestion control problem that improves the performance of the system. In (Altman *et al.*, 1997), the authors presented a different approach to the problem of congestion control in both of the ATM network and in the internet TCP/IP network using optimal control and dynamic game theory. In (Kelly *et al.*, 1998), the authors analyzed stability and fairness of two classes of rate control algorithms, namely, congestion indication-based and explicit rate-based types of algorithms.

This paper proposes a fuzzy logic based controller which has a number of interesting advantages when compared with other type of controllers. Besides being very simple to implement, the proposed controller is system model independent as no analytic system model is needed and only the measure of the queue length is required for its realization. As to the stability and/or performance requirements, tuning of the fuzzy logic controller parameters to the sufficient resolution is generally possible until the desired objectives are reached. The main objective of this controller is to asymptotically regulate the queue length to a desired final value.

2. THE MODEL

The adopted model for the one-source single bottleneck communication system is, in this paper, the one given by (Quet *et al.*, 2001,2002) and has the following block diagram representation in which the fuzzy logic controller proposed in this paper is inserted in the feedback loop:

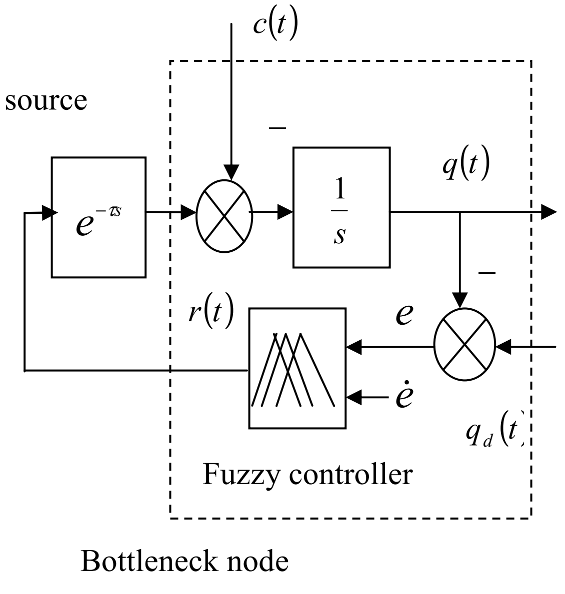

Fig. 1. The rate-feedback flow control system.

This represents a single data source feeding a single bottleneck node and a fuzzy logic controller at the feedback loop. At the bottleneck node, a queue forms a waiting buffer whose dynamics are described by

$$\dot{q}(t) = r(t-\tau) - c(t) \qquad (1)$$

with $q(t)$ represents the queue length in packets of data, $r(t)$ is the source data flow rate in packets per second, and $c(t)$ represents the outgoing node data flow rate in packets per second. The channel of the source is assumed to introduce an unknown and possibly time-varying total round trip delay τ in both the feedback and the forward path of the network. If the desired queue length is $q_d(t)$, we define the error $e(t)$ as being the difference between the actual queue length and the desired queue length, namely,

$$e(t) = q_d(t) - q(t) \qquad (2)$$

3. THE FUZZY LOGIC CONTROLLER

The used fuzzy logic controller receives the queue length error $e(t)$ as well as the derivative of this error $\dot{e}(t)$. These variables are first normalized between -1 and +1 according to their minimum and maximum values. The same membership function is then adopted which consists of three fuzzy sets named ''N'', ''AZ'', and ''P'' for negative, almost zero, and positive values, respectively. Fig 2 shows the proposed membership function.

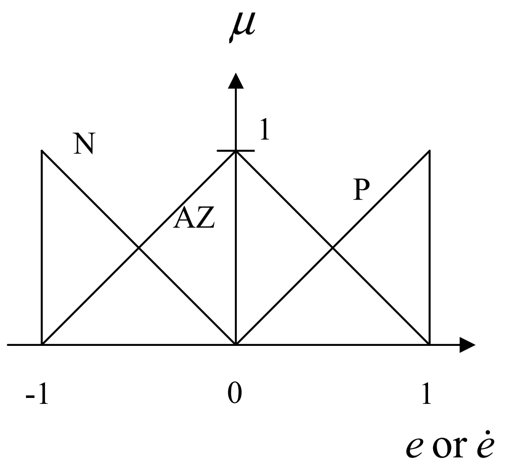

Fig. 2. The membership function for e or $\dot{e}$.

As to the control law $r(t)$, the output of the fuzzy logic controller is defined as to provide an increment $\Delta r(t)$ to it. For this control law increment $\Delta r(t)$, a membership function with five fuzzy subsets is used to yield the desired resolution. These fuzzy sets are named ''LN'', ''N'', ''AZ'', ''P'', and ''LP'' for large negative, negative, almost zero, positive and large positive values, respectively. This membership function is represented in Fig.3.

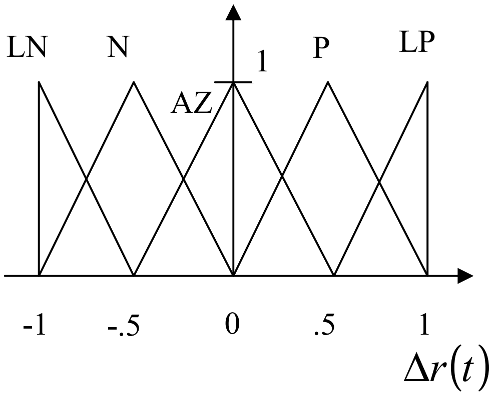

Fig. 3. The membership function for $\Delta r(t)$.

A classical nine rule strategy is used for the fuzzy inference engine. Table 1 gives these rules which are expressed in terms of the error e , its derivative $\dot{e}$, and the control law increment $\Delta r(t)$.

Table 1: The fuzzy inference rules

$\Delta r(t)$		e		
		N	AZ	P
	N	N	P	P
$\dot{e}$	AZ	N	AZ	P
	P	LN	N	LP

This table tells that if, for instance, e is negative meaning that the queue length is more than desired, and $\dot{e}$ is negative meaning that e tends to decrease, an appropriate action is to lower slightly the source sending rate. Other less aggressive strategies are possible. If, however, $\dot{e}$ is positive meaning that e is on the rise, a drastic decrease in the source sending rate must be immediately demanded before things get out of hands. Similar explanation of the adopted strategy is visible in Table 1. The different possibilities actually help in achieving a given performance or in avoiding stability problems.

To illustrate the efficiency of the proposed fuzzy logic controller, a simulation example is treated for which the source can send data at a rate not exceeding 130 packets per second, while the outgoing data flow rate is prescribed to a constant rate of 60 packets per second. The desired queue length is taken to be 30 packets. The sampling period is taken to be 0.1 sec and the channel total delay is assumed, for simplicity, to be constant at 0.2 sec, although an unknown time-varying time-delay is similarly handled. The simulation results are depicted in Fig.4 and Fig.5 showing very satisfactory behaviour of the queue length and the rate at which the source data is sent.

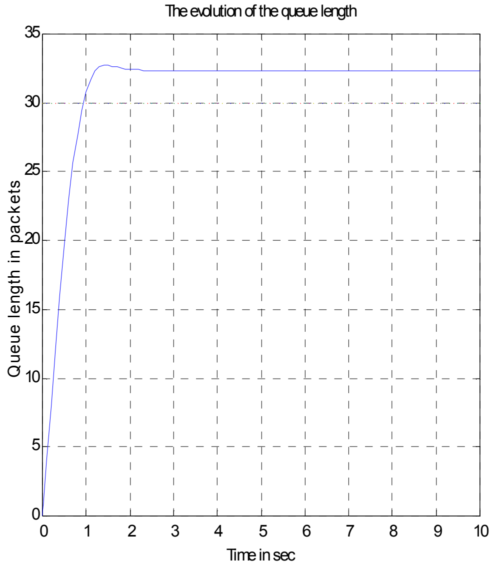

Fig. 4. The queue length profile.

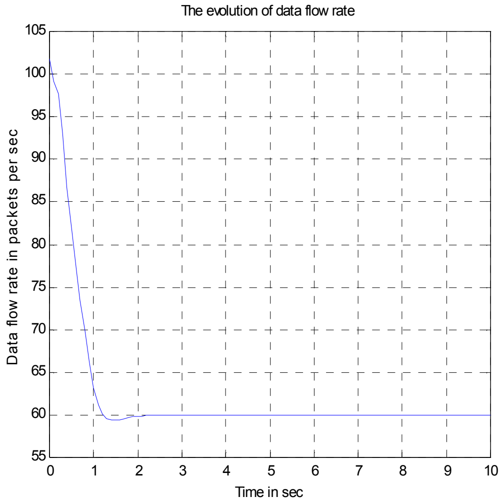

Fig. 5. The data flow rate profile.

A comparison with the more classical PID strategy has shown that the performance of the fuzzy-based controller is by far superior.

4. CONCLUSION

This paper has proposed a fuzzy logic controller that regulates data flow in one-source single bottleneck communication systems which are characterized by important channel time-delays that are uncertain and possibly time-varying. The proposed controller not only stabilizes the system, but also insures some desired performances, one of which is to asymptotically regulate the queue length to a desired steady state value. Further work is needed in order to incorporate the stability and performance requirements into the fuzzy inference rules and qualitatively assess the fuzzy controller parameter settings on the overall performance of the system.

ACKNOWLEDGEMENTS

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