Fast Flow Control in High-Speed Communication Networks

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Abstract

A new approach to flow control in high speed communication networks is proposed where the flow control problem is modeled as a dynamic system with time delay. The main advantage is that it can assure stability of system as well as maintaining certain throughput of the communication channel. Inside the controller, there is a term which predicts the future backlogs in the system. The controller is easy to implement. Simulation results show that the method offers significant less delay than existing methods.

1. Introduction

Tremendous amount of research has been done recently on the distribution of video, including how to accommodate both broadcast and interactive services (video conferencing and video on demand) onto a single system. It is expected that a significant portion of the communication capacity of future networks will be consumed by these signals. The transmission of these signals requires high speed networks such as broadband XSDN through the use optical fibers. To maintain certain maximum delay and minimum transmission rate is crucial in these applications related to voice and video signals: if the delay is beyond certain levels, the received signals will not be tolerable.

In many networks, even the traffic is routed optimally, there are situations where the total traffic into the network is much larger than the network can handle. If no strategies are present to limit the traffic into the network, queue sizes at bottleneck links will grow and packet delays will increase which may violate some maximum delay specifications. Moreover, the buffer space at some nodes may be exhausted. Some of the packets arriving at these nodes will have to be discarded and later retransmitted, thereby wasting communication resources.

There are several ways to flow control such as call blocking (circuit switched networks in telephony systems), packet discarding and packet blocking (packet switched networks). etc. One popular technique for implementing flow control is the window flow method. A virtual circuit between a transmitter A and a receiver B is under window flow control if there is an upper bound on the number of data units that have been transmitted by A and are not yet known by A to have been received by B. The upper bound is called the window size.

The window flow control is not suitable for hi&-speed wide area networks because the propagation delays are relatively large. An even more important reason is that windows do not regulate end-to-end packet delays well and do not guarantee a minimum data rate. Voice, video services depend on upper bounds on delay and lower bounds on rate. High-speed wide area networks increasingly carry such traffic, and many lower-speed networks also carry such traffic, making windows inappropriate.

In [5], the flow control within a virtual circuit on a high speed network is modeled as a fluid-flow queue with a fixed propagation delay. Data from other virtual circuits are modeled as disturbances of the available service capacities. The model has the following features:

- The rate of data entering the network is controlled.
- The available service capacity is reduced by an unspecified but observable piecewise constant disturbances which correspond to capacity assigned to traffic from other virtual circuits.
- The information of backlog and disturbance are continuously fed back to the source through a reverse channel.
- There is a fixed delay on the forward and reverse channels.

In Section 2, we will consider the flow control model of a single channel. Section 3 introduces the control strategy. Extensive simulation results will be presented in Section 4. Finally, some comments will be included in Section 5.

2. Flow Control Model

Consider a fluid-flow channel with flow control shown in Fig. 1.

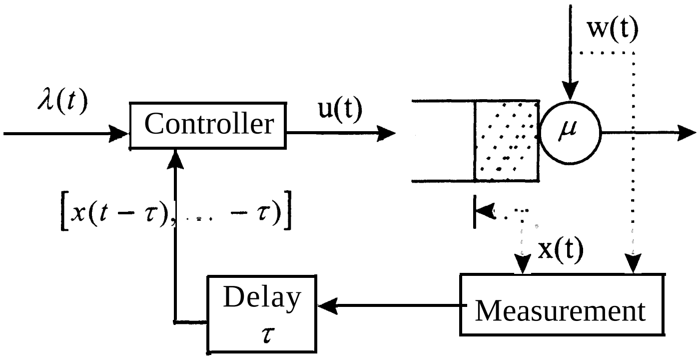

Fig. 1 A fluid flow channel model.

The dynamics of the backlog can be written as

$$\dot{x} = bu - b\mu(1-w) \tag{2.1}$$

with x the backlog of data in the channel from the virtual circuit, μ the transmission rate of the channel, λ the traffic load on the virtual circuit, u the rate of traffic allowed into the network by the controller ($0 \le u \le \lambda$), w the portion of service capacity used by other virtual circuits, τ the lumped propagation delay from the source to the channel transmitter and back, including any additional fixed processing times, b a logical variable indicating whether data arriving at the channel transmitter can be served immediately, i.e.

$$b = \begin{cases} 1, & x > 0 \text{ or } u > \mu(1-w) \\ 0, & x = 0 \text{ and } u \le \mu(1-w) \end{cases} \tag{2.2}$$

The disturbance $w(t)$ is assumed to be piecewise constant and driven by an unspecified train of weighted impulses $\sigma_w(t)$ as

$$\dot{w} = \sigma_w . \tag{2.3}$$

The arrival times and weights of the impulses are constrained only in that w is bounded by 0 and 1, and in that only a finite number of arrivals are permitted in a finite interval.

The control objectives are: (1) to drive the backlog x to zero; (2) to maintain the rate of traffic departing the channel at a rate $\mu\psi$ where ψ is a specifiedportion of channel capacity. The value of ψ may be chosen by the network designer for the best tradeoff of throughput and delay. Driving x to zero is equivalent to reducing the amount of queuing delay and maintaining certain rate of traffic is necessary in certain applications such as voice and video messages.

From basic svstem control theory, the presence of time delay in information feedback may cause the system to go unstable. In other words, the backlog x may go to very large values which also means the packet delay may go beyond certain maximum delay tolerance. The key to guarantee the stability of the system is to find some ways to compensate the propagation delay.

In the next section, we will propose a new method to flow control that can guarantee the maximum packet delay and, at the same time, can maintain a desired throughput rate. The controller also uses the fluid-flow mode1 as described in [6]. Inside the controller, a term is present which can generate some predictive information about the future backlogs x in the system. This predictive information is crucial to the success of the control scheme since it guarantees that the time delay of packets will not go unstable. Thus the maximum time delay performance criterion can be assured. In addition the new flow control method can also maintain certain throughput of the system which is very important in applications such as video distribution. Another advantage is that the controller is easy to implement.

3. Fast Flow Control Strategy

Throughout this paper, we will assume $b = 1$ since this is the case that needs the controller to be activated. We will divide the study into two cases. The first case deals with the ideal situation where the information in backlog $x(t)$ and disturbance $w(t)$ are fed back to the controller with no delay. The purpose of this is to set a benchmark to evaluate the performance of control strategies when delav is present. The second case deals with the more realistic situation where delay in information feedback is present.

3.1 No delav in information feedback

To maintain the system throughput at, for example, $\mu\psi$ with $0 < \psi < 1$. We propose the following controller

$$u = \mu\psi - kx - \mu w(t) . \tag{3.1}$$

Substituting (3.1) into the system equation (2.1) yields

$$\dot{x} = -kx + \mu(\psi - 1) \tag{3.2}$$

which implies the queuing backlog will decay since $\psi < 1$. The rate of convergence is controlled by k. A control block diagram is shown in Fig. 2.

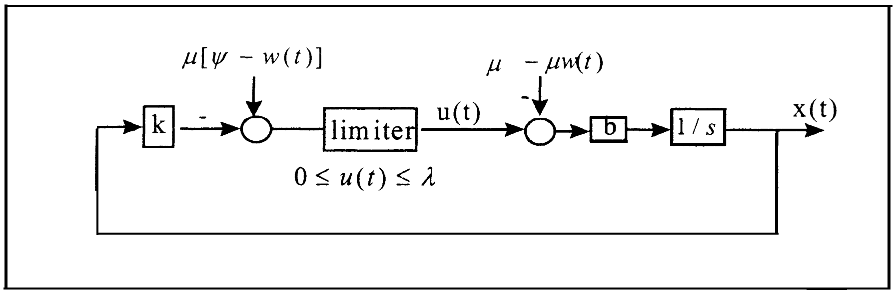

Fig. 2 Linear controller with no information delay.

Note that the steady state value of backlog is nonzero. It can be verified that, the steady state value of backlog equals to

$$x(\infty) = \frac{\mu(\psi - 1)}{k}. \tag{3.3}$$

Hence the value of backlog can be reduced to arbitrarily small values by choosing large enough *k.*

3.2 Time delay in information feedback

In systems with time delay, it is very hard to control them since all the available information happened τ seconds ago. Without predictive information about the system behavior, it would be very difficult to control the system. We propose the following control structure to deal with the time delay effect. The idea is to make use of the known dynamics of the system to compensate for the time delay effects. This technique is well known in control system community and is known as the Smith predictor. Fig. *3* shows a block diagram of the linear controller with compensation of time delay.

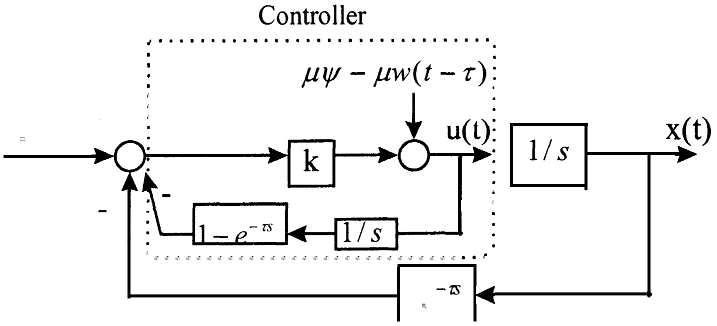

Fig. 3 Linear controller with information feedback delay.

From Fig. 3, it can be seen that the controller is of the form

$$u = \mu\psi - kx(t - \tau) - \mu w(t - \tau) - [x(t) - x(t - \tau)].$$

The term inside the square bracket provides predictive information about the system. The implementation of the above system is not difficult since the time delay is known in communication networks.

4. Simulation Studies

To facilitate our verification of the proposed method, we developed a simulation tool based on the SIMULINK environment. A diagram of the tool is shown in Fig. 4. The dynamics of the system were simulated with a propagation delay of 5 ms. The service capacity of the channel is 100 Mbps and the offered traffic was also set at 100 Mbps. The disturbance was driven by a Poisson jump process. The amplitude of the piecewise constant disturbance is random numbers between 0 and 1.

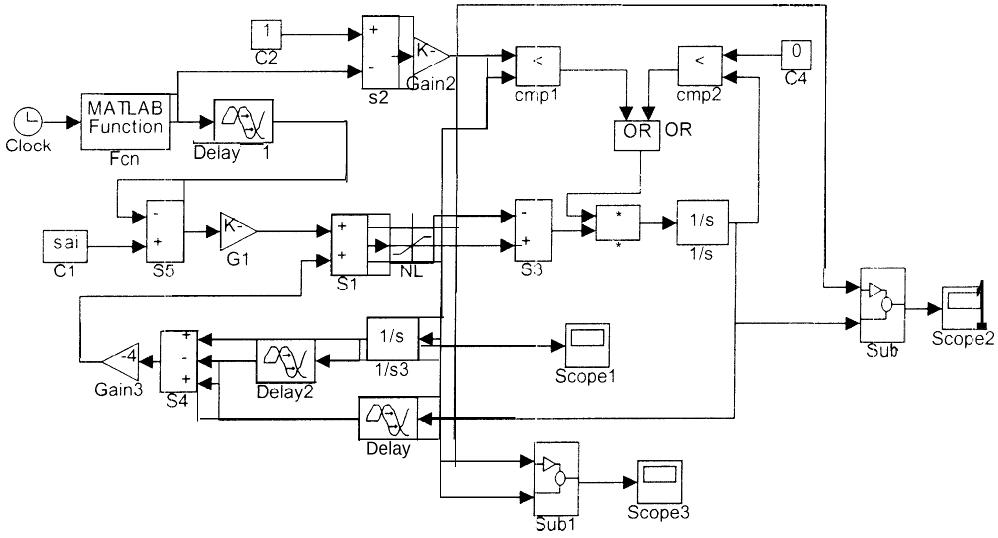

Fig. 4 Simulation of a new flow control scheme using SIMULINK.

Although the control method is simple to implement, it is proven to be very effective in dealing with propagation delay. We have performed extensive simulations to check the performance of the system. The delay throughput curve is shown in Fig. 5. It can be seen that, for the single channel case, the proposed method improved the delay quite significantly.

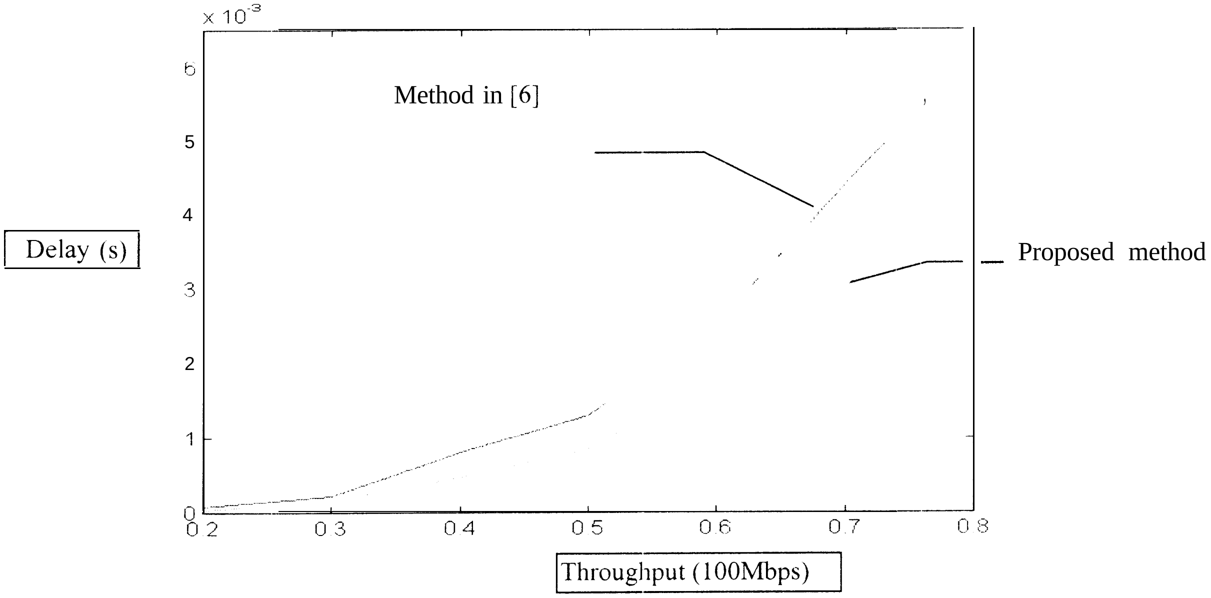

Fig. 5 Delay-throughput curve of flow control methods.

It should be noted that Smith predictor is not the only approach to deal with the propagation delay. Other approaches such as Model Predictive Control may also be useful in this case.

5. Conclusion

A new framework for flow control in high speed communication networks is proposed, which makes use of the known dynamics between backlog and disturbance. Within the framework, a new controller has been proposed which can guarantee the system stability and certain throughput rate. Extensive simulations have been done to verify the performance of the controller.

Future work includes extending the current method to tandem communication links.

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