Optimal Feedback Control of Available Bit Rate Traffic in ATM using Receding Horizon Control

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ABSTRACT

In this work, the problem of regulating and tracking available bit rate (ABR) traffic in ATM network. The issue of providing control signals to throttled sources at distant location from bottlenecked node is of particular interest. Network modeling and design of controller is outlined. To obtain optimal control, receding horizon control (RHC) theory is applied. Simulation results are presented in views of regulation and tracking problems with or without constraints.

Keywords: ABR, ATM, Feedback Congestion Control, Optimal Control, Receding Horizon Control, Regulation, Tracking

1. INTRODUCTION

Available Bit Rate (ABR) service defined in ATM standards[1] is to be used to support applications that can be accommodated using excess network capacity. This is done by dynamically adjusting the source data transmission rate based on the available resources in the network. To do so, information of the current network status is returned to the source. For feedback control schemes, time delays incurred in the feedback path the temporal variation in the link capacity are considered to be challenging problems. Therefore, successful ABR source rate control will depend on the effectiveness of the controller to overcome these delays and to adapt to the temporal variation in the excess bandwidth.

Developing a good rate control mechanism for ABR service has been the focus of many recent papers, especially in the ATM forum [2,4,5,6]. These proposed schemes use explicit rate indication mechanism. They differ primarily in the way in one monitors the congestion and in how one computers an explicit rate which is called fair-share. Most of these algorithms use heuristic solutions to the problem. So results of these methods don't allow one to easily relate the resulting traffic features with the control action. So many papers have been appeared to obtain analytic relations using control theory[10]. Analytical study has been done in [3] where the design of a proportional-derivative (PD) feedback controller was examined the regulation of traffic at a congested node. The parameters of the controller were determined using pole placement method. In [8] utility of this controller handling ABR traffic congestion was examined. In [9] the problem of regulating ABR traffic was examined using modern control theory, but it just handled the parameter decision without constraints.

In this work, the problem of regulation and tracking ABR traffic using receding horizon control theory. And not just optimal parameter decision, optimal control input and optimal state are examined both unconstrained and constrained cases. The objective of this work is to examine the ability of RHC and to improve network utilization of closed feedback loop system using RHC.

The remaining paper is structured as follows. In Section 2, problem is described and the ATM network system is modeled. And buffer and controller are also modeled. A brief introduction about RHC using semi-definite programming is given in section 3. Section 4 presents the numerical and simulation results. In section 5, this work is concluded with some remark about future works.

2. MODEL DESCRIPTION

In this work, the control of ABR traffic over ATM networks is examined. The management of ABR traffic at a bottleneck node is of particular interest. Congestion arises when the sum of the source traffic rates at an intermediate node along the transmission path exceed ether the prescribed cell delay or buffer capacity. In such a case, the congested node is required to communicate its status to up-stream sources using resource management(RM) cell. The status update is used to determine the appropriate source transmission rate for subsequent incoming cells. This status information is used to evaluate the degree of congestion and is comprise of the service rate, buffer occupancy and incoming traffic rate at the bottleneck node.

For simple system analysis, the dynamics of the system are considered at discrete interval, *n*. The source traffic reaching the bottleneck node are delayed by *d* time units where d ranges from 0 to *D*. At the delay index *d*, l_d sources are taken to have transmitted cells at a rate q_d cells per unit time, where q_d is taken to be the average rate, the sum of the rates all sources at delay *d* divided by l_d.

Therefore the traffic entering the node the node at time index is

$$q_{total}(n+1)=\sum_{d=0}^{D} l_d q_d(n+1-d) \qquad (1)$$

The problem at hand is to determine how one can best adjust the transmission rate of the source at delay *d*, q_d given the buffer occupancy and available rate at the bottleneck node will serve as control inputs to system. This is illustrated in Figure 1. By doing so, the source transmission to follow temporal variations in allocated network resources is adjusted.

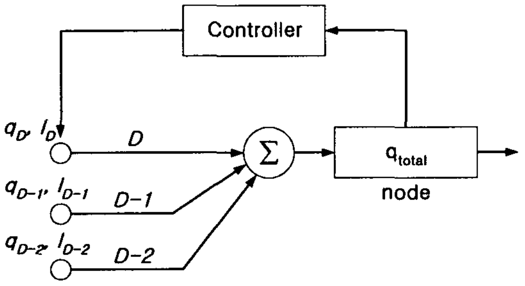


Figure 2. Rate control of multiple sources using feedback

This simplification will allow the queue to be considered as an auto-regressive moving-average (ARMA) system[3,9].

In [9], the buffer and controller equations are drived using pole placement method. The derived equations are shown in equation (2).

$$\begin{cases} x(n+1)=x(n)+\sum_{d=0}^{D} l_d(n)q(n+1-d)+r^0(n)-c \\ q(n+1)=q(n)-\sum_{j=0}^{J}\alpha_j\left(x(n-j)-x^0\right)+ \\ \qquad -\sum_{k=0}^{K}\beta_k q(n-k) \end{cases} \qquad (2)$$

In this system, for compensator delay, larger than or equal value to real delay must be chosen to maintain system stability[3]. That is *K D-1*, so *K* is set equal to *D*.

The system equations can be reformulated in terms of state variables. The closed loop control system described in equation (2) has two type of variables *x* which dependent on *J*+1 time lags and *q* on *D*+1 time lags. Define a vector $\underline{y}$

$$\underline{y}(n)=\left(y_1,y_2,\ldots,y_{D+J+1},y_{J+D+2}\right)^T \qquad (3)$$

consisting of *J*+*D*+2 elements as follows;

$$y_i(n)\equiv x(n-J+i-1)\ \ for\ \ i=1,\ldots,J+1$$
$$y_{J+i+1}(n)\equiv q(n-D+i-1)\ \ for\ \ i=1,\ldots,D+1$$

where

Substituting the values of yi's(I=1,.....,J+D+2) for x and q in equation (3), the system can be described in matrix notation

$$\underline{y}(n+1)=A\underline{y}(n)+B\underline{u}(n) \qquad (4)$$

$$\underline{z}(n)=C\underline{y}(n) \qquad (5)$$

as the system and output equations respectively;
where $\underline{z}(n)=(x(n),q(n))^T$.

3. SIMULATION RESULTS

In this section, numerical example and simulation results are presented. Let J=1 to consider information of buffer occupancy just two time unit ago, i.e., at time n+1, only *x(n)* and *x(n-1)* affect current admission rate, *q(n)*. The most distant source experiences delay D=2 time units. For this case the queuing model and rate controller equations can be written as Equation

$$\begin{cases} x(n+1)=Sat_\infty\left[x(n)+l_0q(n+1)+l_1q(n)\right. \\ \qquad \left.+l_2q(n-1)-Q_0(n)\right] \\ q(n+1)=Sat_\infty\left[q(n)-\alpha_0\left(x(n)-x_0\right)-\right. \\ \qquad +\alpha_1\left(x(n-1)-x_0\right)-\beta_0q(n) \\ \qquad \left.-\beta_1q(n-1)-\beta_2(n-2)\right] \end{cases} \qquad (6)$$

(6).

where $Q_0(n)=c-q_u(n)$.

The parameter $x_0(n)$ is the set-point for the buffer at the bottleneck node and $Q_0(n)$ is the excess capacity. The number of sources at each delay index is l_0, l_1 and l_2. Each l_d is set to 1.

The values of α and β are determined by pole placement method. For the characteristic polynomial with degree 4, desired poles are set to be $\lambda_1=\lambda_2=0$, and $\lambda_{3,4}=0.4\pm j0.3$ where $l_1=l_2=l_3=1$ and the r_i's are determined. Then, the parameters α_0, α_1, β_0, β_1, and β_2 are obtained. And then the system in the state space form by defining state variable y_i's (i=1,...,5) as in Equation (3) so that the system can be described in matrix notation as described in Equation (4) and (5) These results are as follows:

$$\left(\alpha_0,\alpha_1,\beta_0,\beta_1,\beta_2\right)=\left(0.55,\text{-}0.4,0.65,\text{-}0.25,\text{-}0.4\right)$$

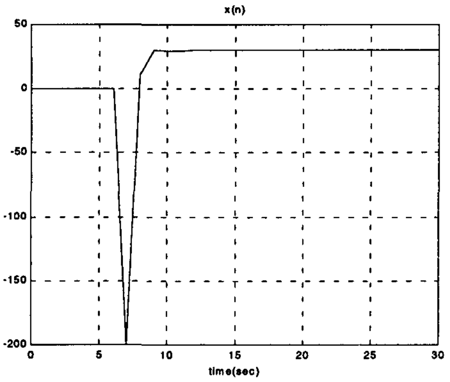
$$A=\begin{bmatrix} 0 & 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 1 & 1 \\ 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 1 \\ 0.40 & -0.55 & 0.40 & 0.25 & 0.65 \end{bmatrix} \quad (7)$$

$$B=\begin{bmatrix} 0 & 0 \\ -1 & 0 \\ 0 & 0 \\ 0 & 0 \\ 0 & 0.15 \end{bmatrix}, \quad C=\begin{bmatrix} 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 \end{bmatrix}$$

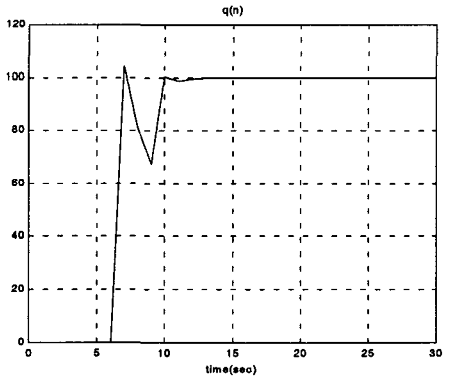
where $y(n)=\left(x(n-1), x(n), q(n-2), q(n-1), q(n)\right)^T$ and $\underline{u}(n)=\left(Q_0(n), x_0(n)\right)^T$

To obtain optimal feedback control input for this system, following matrices are for the performance index given as $Q=\mu C^T C$ and $P=I_2$, where P is a 2×2 identity matrix.

Simulation results for constrained tracking problem are shown in Fig 1. The references for this simulation are x(n)=30, and q(n)=100. Here, input constraints are $|x_0(n)| \le 1200$ and $|Q_0(n)| \le 250$, and state constraints are $|x(n)| \le 100$ and $|q(n)| \le 90$

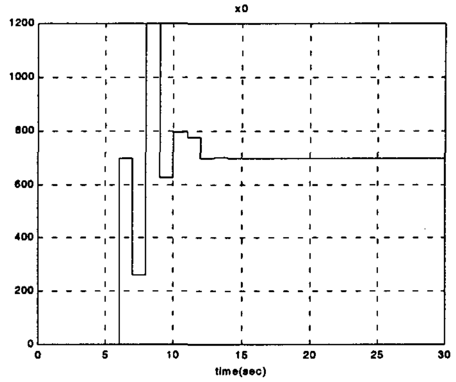


(a) Buffer Occupancy

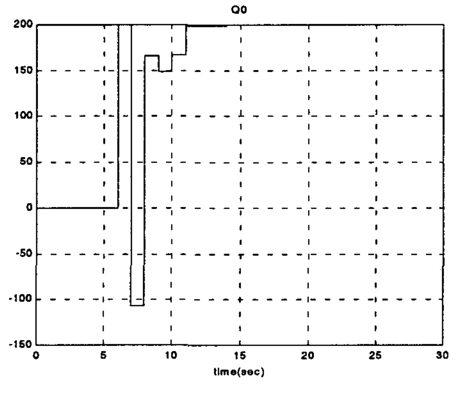


(b) Input Rate

Figure 1. Constrained Tracking problem



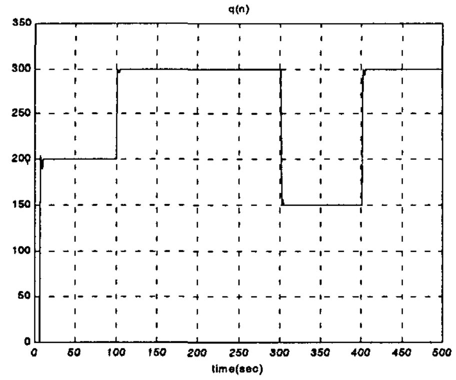
(a) Optimal Input ($x_0(n)$)



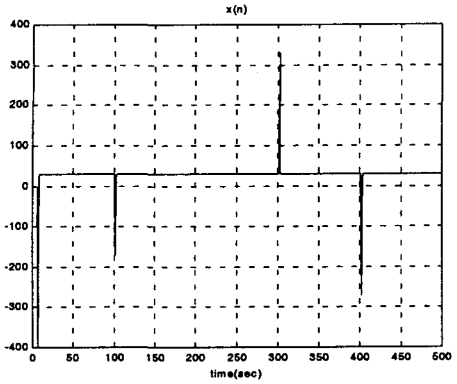
(b) Optimal Input ($Q_0(n)$)

Figure 2. Optimal Input for Constrained Tracking

Now, Simulation Results in using RHC when ABR bandwidth are time variying are shown in Figure 3



(a) Input Rate



(b) Buffer Occupancy

Figure 5. Simulation Results in this work

From the simulation results, the utilization of network resource is more effective in this work than prior results(nearly 100% utilization). But buffer undershoot and overshoot are much larger than that of prior results. It may be caused by the effect of computation time with receding horizon control.

4. CONCLUSION

In this work, the first attempt is done for feedback control of ABR service in ATM network using receding horizon control. And optimization problem with input and state constraints are handled using modern control theory for the first time. Also by contrary to prior results concerning with optimal parameter determination, optimal input for optimization are considered.

Due to great feature of RHC, that the tracking performance is good, the utilization of network resource is nearly 100%. But because computation of RHC is so complex, the transient behavior of buffer occupancy is badly performed.

For future works, undershoot and overshoot should be decreased. And nonlinear model caused by saturation of input rate and buffer size is challenging task. And modeling and analysis about network with feedback control, such as TCP, will become another challenging task.

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5. REFERENCES

[1] ATM Forum, "The ATM Forum Traffic management Specification", February 1995.

[2] A.W. Barnhart, "Baseline Performance using PRCA Rate-control", *ATM Forum/94-0597*, July 1994.

[3] L. Benmohamed and S. M. Meerkov, "Feedback Control of Congestion in Packet Switching Networks: The Case of a Single Congested Node", *IEEE/ACM Transaction on Networking*, vol. 1, no. 6, pp.693-708, December 1993.

[4] A. Charny, D. Clark, and R. Jain, "Congestion Control with Explicit Rate Indication", *Proceedings of IEEE ICC'95*, pp. 883-891, June 1995.

[5] R. Jain, S. Kalyanaraman, and R. Viswanathan, "The OSU scheme for Congestion Avoidance using Explicit Rate Indication", *ATM Forum/94-883*, September 1994.

[6] L. Roberts, "Enhanced PRCA (Proportional Rate Control Algorithm)", *ATM Forum/94-0735R1*, August 1994.

[7] D. Cavendish, S. Mascolo, and M. Gerla, "ATM Rate Based Congestion Control Using a Smith Predictor: an EPRCA Implementation", *Proceedings of IEEE INFOCOM'96*, pp. 569-576, March 1996

[8] G. Ramamurth and A. Kolarov, "Application of control theory for the design of closed loop rate control for ABR service", *Proceeding of the 15th International Teletraffic Congress*, 1997.

[9] B.K Kim and C. Thompson, "Optimal Feedback Control in ATM Networks using Optimal Control Theory", *st International Conference on ATM*, pp327-336, 1998

[10] H. S. Kim and W. H. Kwon, "A Survey on applications of control theories to wire and wireless communication", *will appear in Journal of Control, Automation and Systems Engineering, June, 2000*

[11] H. J. Lim, "A Study on Receding Horizon Control for Constrained Systems using Semi-Definite Programming", *MSC thesis. Seoul National University.*

[12] K.B. Kim and W. H. Kwon, "Receding Horizon Predictive Control", *will be published.*