PROCEEDINGS OF SPIE

SPIE—The International Society for Optical Engineering

Performance and Control of Network Systems

Wai Sum Lai
Hisashi Kobayashi
Chairs/Editors

3–5 November 1997
Dallas, Texas

Volume 3231

A traffic management mechanism for intranets with available bit rate access to the Internet

Mahbub Hassan[a], Harsha Sirisena[b], and Mohammed Atiquzzaman[c]

[a]School of Computing & Information Technology
Monash University, Churchill, Victoria 3842, Australia

[b]Department of Electrical and Electronic Engineering
University of Canterbury, Christchurch 8020, New Zealand

[c]Department of Electrical & Computer Engineering
University of Dayton, Dayton, Ohio 45469-0226, USA

ABSTRACT

The design of a traffic management mechanism for intranets connected to the Internet via an *available bit rate* access-link is presented. Selection of control parameters for this mechanism for optimum performance is shown through analysis. An estimate for packet loss probability at the access-gateway is derived for random fluctuation of available bit rate of the access-link. Some implementation strategies of this mechanism in the standard intranet protocol stack are also suggested.

Keywords: intranet, Internet, traffic management, ATM, available bit rate service

1. INTRODUCTION

Intranet is a rapidly growing internetworking technology for connecting local computers and resources within an organisation using the *standard* Internet protocols such as Transmission Control Protocol/Internet Protocol (TCP/IP). Such intranets have enormous benefits over proprietary networking as it provides ready access to the global Internet which connects millions of computers all over the world. Corporations world-wide are rapidly deploying intranets for their organisations.

The intranet of an organisation is connected to the global Internet via an access-gateway and access-link. Traffic that flows between the intranet and the rest of the Internet travels through this gateway and access-link. At the access-gateway, traffic from many sources within the organisation is statistically multiplexed onto the access-link. If the traffic rate momentarily exceeds the link bandwidth, some data will be lost. In order to prevent or reduce such loss of data, the gateway has some buffer to accommodate the excess traffic temporarily. These data are transmitted later once the traffic burst is over.

The access-link is usually established over a leased line from a telecommunication service provider. The bitrate or the transmission speed of the leased line is fixed and guaranteed throughout the lease period. The capacity of the leased line is provisioned according to the traffic profile of the organisation to ensure minimum congestion in the gateway.

For bursty data traffic, the bandwidth of the leased line is not utilised efficiently. The organisation has to pay for the bandwidth for the entire duration whether there is traffic or not. The cost of maintaining leased lines is, therefore, very high.

With Asynchronous Transfer Mode (ATM),[1] a cell-switching network, set to become the world-wide standard[2] for the next generation of telecommunication networks, it is expected that such leased lines will be replaced by ATM virtual circuits (VCs). Interconnection of an intranet to the Internet via such an ATM VC is shown in Figure 1.

Other author information: (Send correspondence to Mahbub Hassan)
Mahbub Hassan: Email: mahbub.hassan@fcit.monash.edu.au; Telephone: +61-3-9902 6568; Fax: +61-3-9902 6842 ;
Harsha Sirisena: Email: sirisehr@elec.canterbury.ac.nz; Telephone: +64-3-366 7001 ; Fax: +64-3-364 2761 ;
Mohammed Atiquzzaman: Email: atiq@eng.monash.edu.au; Fax: +1-513-229 2471

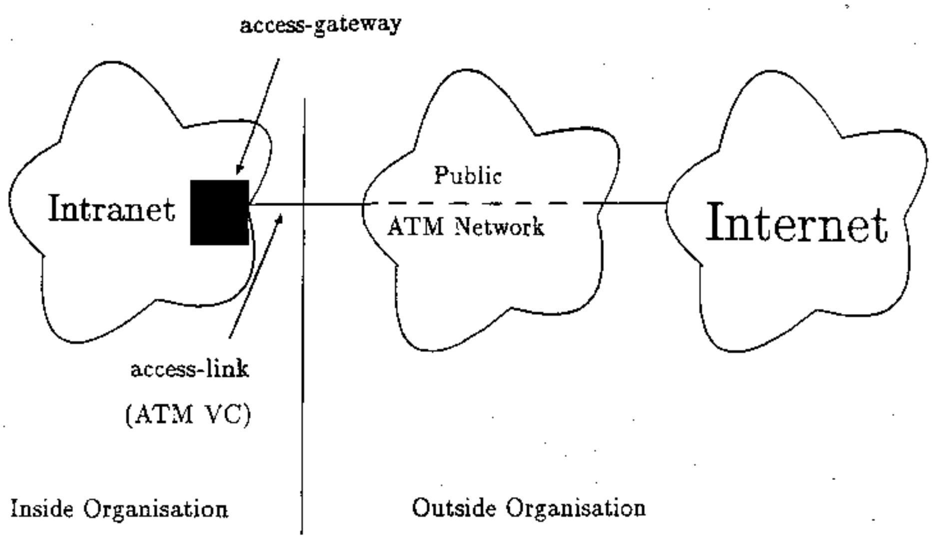

Figure 1. The interconnection of an intranet to the Internet via public ATM network.

Unlike the constant bitrate leased lines, ATM networks provide an Available Bit Rate (ABR) service for data communications, where the bandwidth of the VC is controlled by the ATM network and varies between a specified minimum and maximum negotiated during the VC set-up process. If there is enough resources available in the ATM network, the gateway may be allowed to transmit at the maximum rate. However, if congestion occurs within the ATM network, the gateway may be asked to reduce the transmission rate.

Since ATM networks allow the gateways to utilise only the available bandwidth within the network, it is expected that the cost of data communications will be significantly reduced with ABR service. Such cost reduction may become a major driving force in replacing the existing leased lines with ATM ABR connections in the near future for connecting the intranets to the global Internet.

A major problem with the ABR service is the increased buffering requirement in the access-gateway.[3-7] With ABR connections, the transmission rate of an access-link is directly controlled by the ATM network without any regard to the current traffic rate from the local intranet. If the transmission rate of the access-link is suddenly throttled to a minimum, a large amount of data, that may be arriving from the local intranet at a high rate, have to be buffered in the gateway. If there is not enough buffer, some data will be lost.

While implementing large buffers in the gateway may prevent data loss, it will increase the delay in the gateway significantly. Such unexpected delay may cause retransmissions from the hosts which exacerbates the congestion. It is, therefore, absolutely necessary to implement a traffic management mechanism between the access-gateway and the hosts in the intranet. The goal of such traffic management is to control the transmission rate of the processes in the local hosts which are sending traffic to the gateway according to the available bit rate of the access-link.

There is no suitable traffic management mechanism available in the standard Internet protocol suite which can effectively control the transmission rate of the hosts for available bit rate access-links. It was shown[3] that the implicit flow-control mechanism embedded in the Internet protocol suite is not capable of controlling the traffic rate satisfactorily which eventually requires large buffers in the gateway for effective operation.

In this paper, the design of a traffic management mechanism for intranets is presented which takes the available bitrate of the access-link into consideration. The problem of traffic management is formulated as a classical feedback control system with a goal to maintain the buffer population in the gateway at a desired level by providing rate feedback to the hosts. The optimisation of the control parameters for minimum variance of the buffer level due to fluctuation in the available bit rate in the access-link is obtained through analysis. An estimate for packet loss probability for finite buffers in the gateway is also presented.

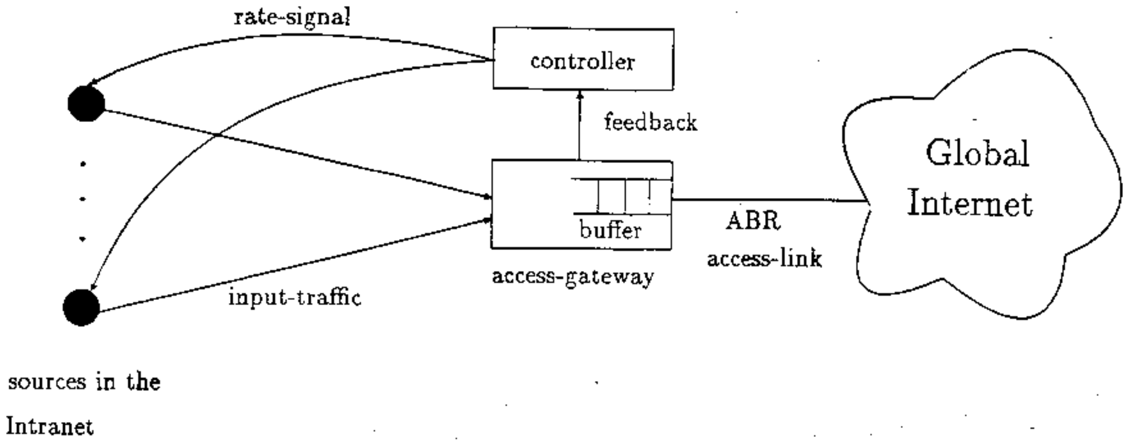

Figure 2. The layout of the traffic management mechanism for an intranet.

The remainder of the paper is organised as follows. The layout of the feedback control system is illustrated in Section 2. The design of the control system and the analysis for optimisation of the control parameters are presented in Section 3. An estimate for the packet loss probability for finite buffers in the gateway is derived in Section 4. Section 5 looks at some possible techniques for implementing the proposed traffic management mechanism in the standard intranet protocol stack. Finally, a conclusion is provided in Section 6.

2. LAYOUT OF TRAFFIC MANAGEMENT MECHANISM

Figure 2 illustrates the layout of the proposed traffic management mechanism for an intranet connected to the Internet via an access-gateway and an ABR ATM link. There are many sources in different hosts in the intranet sending traffic to the Internet through the gateway. The gateway has a buffer to hold the arriving traffic when the bitrate of the access-link is suddenly reduced by the ATM network.

The current status of the buffer level and the bitrate of the access-link is periodically fed back to a controller in the gateway. The controller calculates an appropriate transmission rate for the sources according to these feedback and sends a rate control signal to the sources informing the allowed transmission rate. The transmission rate of the sources are controlled according to the allowed rate received in the rate signal from the gateway.

The aim of the controller is to keep the buffer at a desired level set by the network operator. Fluctuations in the traffic flow and the available bit rate of the access-link may cause the buffer level to deviate from the desired level. The job of the feedback controller is to adjust the input traffic rate to bring the buffer level back to the desired level. The design and analysis of the controller is presented in the following section.

3. DESIGN AND ANALYSIS OF FEEDBACK CONTROLLER

3.1. Controller Design

The controller and the buffer form a feedback control system where the current buffer status is fed back to the controller for effective calculation of the required input traffic rate. The behaviour of the buffer and the design of the controller are given below.

Buffer

This is the main component of the control system. The goal of the control system is to maintain the output of the buffer, the queue length q, at a desired set point q_r. The input to the buffer is the aggregate traffic rate R from all the hosts in the local intranet sending traffic to the Internet through the access-gateway. An appropriate R is calculated by the controller.

In addition to the controlled input R, there is another input to the Buffer — the transmission rate B of the access-link. This is considered noise to the system and is beyond the control of the Controller. Any fluctuation in B will cause the q to deviate from q_r. This effect of noise on the output variable q is fed back to the controller which adjusts R to bring q back to q_r.

The queue length dynamics can be expressed as an approximation of the following *fluid flow* model[8]:

$$m' = w_{in} - w_{out}$$

where m' is the rate of change of mass, w_{in} is the rate of flow in, and w_{out} is the rate of flow out. Therefore, the aggregate rate R will affect the queue length according to the following equation:

$$\begin{aligned} \frac{q(n+1) - q(n)}{\mathrm{T}} &= \mathrm{R}(n) - \mathrm{B}(n) \\ q(n+1) &= q(n) + \mathrm{TR}(n) - \mathrm{TB}(n) \end{aligned} \tag{1}$$

where $q(n+1)$ and $q(n)$ are the buffer levels measured at the $(n+1)th$ and nth samples respectively and T is the sampling period.

Taking the *z-transform* of Eq. (1), the following transfer function between Buffer output q and Buffer input R is obtained:

$$q(z) = \frac{T}{z-1}(R(z) - B(z)) \tag{2}$$

Controller

The main function of this component is to calculate the required input rate R to the access-link as a function of the current queue length. R is the output of the Controller and at the same time the input to the Buffer. The input to the Controller is the *error*, the difference between the desired queue length q_r and the current observed queue length q.

The transfer function of the Controller depends on the choice of controller. The simplest controller is a *proportional* controller[8] whose output is directly proportional to the input. The adjustment of R according to a proportional controller is simply given by:

$$\begin{aligned} \mathrm{R}(n) &= \mathrm{K}(q_r - q(n)) \\ &= \mathrm{K}e(n) \end{aligned} \tag{3}$$

where K is the *gain* of the controller and e is the observed error in the output.

The advantage of using a proportional controller is its simplicity; there is only one parameter (gain K) to adjust and the stability analysis of the control system is quite simple. However, a major drawback of a proportional controller is the non-zero steady-state error in the output as explained below.

In the steady state, the input rate R is equal to the output rate (transmission rate of the access-link) B. This results in (from Eq. (3)) the finite error $\frac{\mathrm{B}}{\mathrm{K}}$ for the proportional feedback controller. In other words, if a simple proportional controller is used, the buffer level will stabilise at $q_r - \frac{\mathrm{B}}{\mathrm{K}}$ instead of at q_r.

The performance of a proportional feedback controller can be significantly improved (by reducing or eliminating the steady state error) by adding an *integral** controller, which forms a PI (proportional plus integral) controller. However, an integral controller typically reduces the stability of the system. In order to increase the stability, a *derivative*† controller is usually used in conjunction with a PI controller to form a PID controller.[8]

A PID controller provides an acceptable degree of error reduction simultaneously with acceptable degree of stability. However, a PID controller has three parameters to adjust (K,K_1 and K_2), one for each type of controller (proportional, integral and derivative). This increases the complexity of the control system.

*An integral controller uses the equation[8]: $R(n) = R(n-1) + K_1 e(n)$, where R is the input and e is the error in the output.

†A derivative controller uses the equation[8]: $R(n) = K_2[e(n) - e(n-1)]$, where R is the input and e is the error in the output.

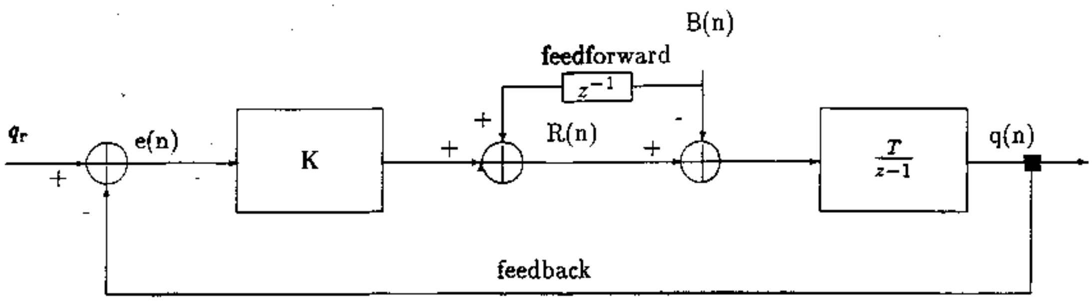

Figure 3. Block diagram of a proportional controller with noise feed forward

If a PID controller were used for the control system, the network administrator would have to adjust three control parameters to achieve the optimum performance. Adjusting such parameters can be quite costly; a wrong setting could result in large error, which in turn could degrade the performance of the control mechanism significantly.

Our objective is to design a control system, which provides an acceptable level of error reduction simultaneously with an acceptable level of stability with a *minimum* number of control parameters. One way to reduce the steady state error is to measure the noise and take appropriate actions before the noise has any effect (error) on the output. This type of control is called feed forward control.[9]

Disturbance feed forward can be a very effective strategy for reducing error if (i) the effect of the noise on the output is known and (ii) the noise can be measured easily and accurately. In addition to reducing the error, noise feed forward has the benefit of not affecting the feedback loop (and hence the stability properties of the controller) present in a feedback control system.

With the proportional rate control system described above, both the effect of noise on the queue length and the measurement[‡] of noise can be easily obtained. From Eq. (3) it can be seen that for a given K, the higher the B, the greater the magnitude of the error in the steady state (R=B). The steady state error can be eliminated if the noise B is fed forwarded to the controller in a manner so that the controller output is augmented with the feed forward value as shown in Figure 3.

The input rate R of the feed forward system is now obtained as:

$$\begin{aligned} \mathrm{R}(n) &= \mathrm{B}(\mathrm{n}-1) + \mathrm{K}(\mathrm{q_r} - q(n)) \\ &= \mathrm{B}(\mathrm{n}-1) + \mathrm{K}e(n) \end{aligned} \tag{4}$$

The reason that $B(n-1)$ is fed forwarded instead of $B(n)$ is because the controller can only act on the information gathered in the last sampling. It can be seen from Eq. (4) that there is no error (e=0) in the steady state (when R=B). By taking the z-transform of Eq. (4), the transfer function for the Controller for the feed forward is obtained as:

$$\mathrm{R}(z) = z^{-1}\mathrm{B} + \mathrm{K}e(z) \tag{5}$$

The noise feed forward eliminates the steady state error experienced under the proportional feedback controller. However, unlike the integral controller, the feed forward does not reduce the stability of the system; the stability properties remain the same because the feedback loop is unchanged. In addition to this, the number of control parameters (gain parameters) remains one (only K), which significantly simplifies the operation of the control system.

Adjustments for Rate Calculation

Some adjustments are necessary to implement the linear controller of Eq. (4) for a practical control scheme in an intranet. For a given B, Eq. (4) yields a negative rate R for $q > \frac{\mathrm{B}+\mathrm{K}\times\mathrm{q_r}}{\mathrm{K}}$, which is not acceptable. The input traffic rate has to be greater than or equal to zero and hence the R in the gateway is calculated as:

$$\mathrm{R}(n) = max(0, \mathrm{B}(\mathrm{n}-1) + \mathrm{K}e(n)) \tag{6}$$

[‡]The noise in this case is simply the transmission rate of the access-link. In case of ATM-ABR connections, the instantaneous rate of the link is simply obtained as the ACR (Available Cell Rate) of the interface.

3.2. Performance analysis

3.2.1. Stability analysis

Stability is a very important factor in evaluating the performance of any traffic rate control system. If the system is not stable, changes in intranet traffic pattern or the available bandwidth of the access-link may cause buffer overflow and (data loss) or underflow (bandwidth underutilisation).

A variety of methods exist to analyse the stability of a linear control system. In this section, the stability analysis of the control system is performed using the *frequency-response* method.[10] The phase margin (PM) is the frequency-response specification which determines the relative stability of the system. A control system is marginally stable if the phase margin is zero. The system is unstable for negative phase margin and stable for positive phase margin. Therefore, the gain K has to be selected to achieve a positive phase margin, the larger the phase margin the greater the stability.

The phase margin of a control system can be determined by looking at the open-loop transfer function of the system which is obtained by multiplying all the block transfer functions in the loop. Thus the open-loop transfer function of Figure 3 is obtained as $\frac{\mathrm{KT}}{z-1}$.

From the definition of PM,[10]

$$\mathrm{PM} = 180^\circ + \angle \frac{\mathrm{KT}}{z-1} \tag{7}$$

where $\angle\frac{\mathrm{KT}}{z-1}$ is the phase of $\frac{\mathrm{KT}}{z-1}$ at the *gain crossover frequency*, which is defined as the frequency at which the magnitude of $\frac{K_pT}{z-1}$ is one (0 dB). Thus

$$\left|\frac{\mathrm{KT}}{z-1}\right| = 1 \tag{8}$$

From Eqs. (7) and (8), the phase margin can be calculated as:

$$\mathrm{PM} = tan^{-1}\frac{\sqrt{4-(\mathrm{KT})^2}}{\mathrm{KT}} \tag{9}$$

Therefore, for a stable system ($\mathrm{PM} \geq 0$), K should be selected smaller than or equal to $\frac{2}{\mathrm{T}}$, where T is expressed in seconds.

3.2.2. Minimum buffer variance

Although the control system of Figure 3 will keep the buffer level at the desired setting of q_r in the steady state, sudden fluctuation in the available bandwidth of the access-link will cause momentary shifts of the buffer level from q_r. Therefore, the variance σ_q^2 of the buffer level around the desired setting q_r is an important performance factor for the intranet traffic management system. If the variance is large, there may be buffer overflow and data loss in the access gateway. In this section, we analyse the buffer level variance σ_q^2 as a function of K. This analysis will allow us to select a K which provides a low buffer level variance.

We need to obtain the transfer function between the noise source and the buffer level in order to calculate the variance in the buffer level. The available bitrate B can be modeled by the following difference equation

$$B(n+1) = \alpha B(n) + (1-\alpha)\beta W(n) \tag{10}$$

where $W(n)$ is a random noise source[§], β is a constant to indicate the magnitude of the noise and α is the probability of change of available bandwidth from one sample to the next. For $\alpha = 1$, there is no noise and the available bandwidth remains constant (this models a leased line); for $\alpha = 0$, B is a pure random number. For realistic networks, α will be a fraction between 0 and 1.

Taking *z-transform* of Eq. (10) we get,

$$\frac{B(z)}{W(z)} = \frac{(1-\alpha)\beta}{z-\alpha} \tag{11}$$

[§]For an ATM-ABR access-link, the noise source can a VBR (Variable Bit Rate) connection multiplexed with the ABR connection within the ATM network. The ABR rate is affected whenever the VBR rate is changed.

From the block diagram in Figure 3 we get the transfer function between Q and B as:

$$\frac{Q(z)}{B(z)} = \frac{\frac{(z^{-1}-1)T}{z-1}}{1+\frac{K_pT}{z-1}} = \frac{T(1-z)}{z(z-(1-KT))} \tag{12}$$

Multiplying (11) and (12) we obtain the transfer function between noise source W and buffer level Q as:

$$\frac{Q(z)}{W(z)} = \frac{(1-\alpha)\beta T(1-z)}{z(z-\alpha)(z-(1-KT))} = \frac{b(z)}{a(z)} \tag{13}$$

Applying variance calculation theorem[11] and *Cauchy's residue theorem*,[12]

$$\begin{aligned} E[q^2] &= \sigma_q^2 = \frac{1}{2\pi j}\oint \frac{b(z)b(z^{-1})dz}{a(z)a(z^{-1})z} \\ &= \sum[\text{residues of } \frac{b(z)b(z^{-1})}{a(z)a(z^{-1})z} \text{ at poles inside unit disc}] \\ &= \frac{(1-\alpha)\beta^2T^2[(\alpha^2-\alpha+2)KT-2(\alpha-1)^2]}{(1+\alpha)(1-\alpha+\alpha KT)(\alpha-1+KT)(2-KT)} \end{aligned} \tag{14}$$

3.3. Results

Eq. (14) provides the buffer level variance as a function of the controller gain K. The optimum value for K is the one for which the expression at the right hand side of Eq. (14) is minimised. In deriving the optimum K, we obtain the following results:

- *Optimum K does not depend on the noise parameter β.* This result is obtained as follows. For a given value of α and T, we equate the first derivative of the right hand side of Eq. (14) to zero and solve for K. We find that The solution for K for does not contain the parameter β.
- *Optimum K does not significantly depend on the noise parameter α.* For a range of practical values of T, the optimum K as a function of α is shown in Figure 4. It can be seen, the optimum K decreases only *slightly* for increasing α. The amount of decrease for optimum K is negligible.
- *Optimum K is inversely proportional to T and is roughly equal to $\frac{1}{T}$.* This result can be obtained from Figure 4. For K = $\frac{1}{T}$, the control system has a phase margin of 60 degrees (from Eq. (9)), which guarantees a good stability for the control system.

The first two of the above results suggest that the proposed feedback control mechanism is robust to system variations and can guarantee a low buffer level variance for a wide range of bandwidth fluctuations for the access-link. This will minimise the buffer requirement at the access gateway. The third result confirms that the proposed control mechanism is stable for the choice of gain K for which the buffer variance is minimised.

4. ESTIMATE OF PACKET LOSS PROBABILITY

If the noise due to fluctuation in the available bit rate in the access-link is approximated as a random white noise, the effect is such that the buffer level will fluctuate around the steady state value (desired level) q_r with a normal distribution. For such fluctuations, one can readily calculate the buffer overflow probability for a given buffer size L and standard deviation σ_q around a mean q_r. The probability of buffer overflow p is calculated as $\Pr\{q \geq L+1\}$ where q is the instantaneous buffer level. Converting the normal distribution with parameters q_r and σ_q^2 into a *standard* or *unit* normal distribution,[13] this probability becomes equivalent to

$$p = 1 - \Pr\left\{X < \frac{L+1-q_r}{\sigma_q}\right\} \tag{15}$$

where X is a normal variable with mean 0 and variance 1, and can be looked up in the normal distribution table.

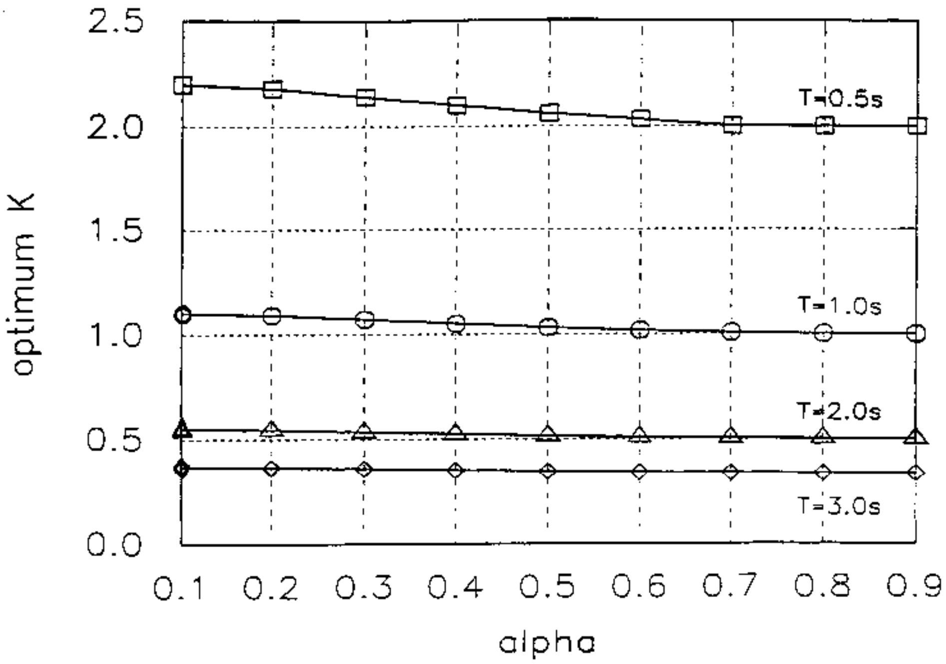

Figure 4. Optimum K as a function of noise parameter α.

The buffer overflow calculation shown above gives only an approximate result for the packet loss probability due to buffer overflow. This is because the above probability actually defines the probability of the buffer level exceeding beyond L assuming *infinite* buffer size. For finite buffer size of L, the packets arriving when the buffer is full will be lost and will not be waiting in any buffer to be processed by the access-link. This will reduce the probability of buffer overflow and therefore, our estimate of packet loss probability is a conservative one.

5. IMPLEMENTATION

In order to implement the proposed rate control mechanism in an intranet, the following mechanisms have to be developed:

- **Rate management at the individual hosts.** When a traffic source (an application process) sends traffic to a destination outside the organisation, it will receive rate control signals from the access-gateway. Upon receiving such rate signals, the rate of the source has to be managed to make sure that it does not exceed the rate as indicated by the gateway.

  This may be implemented at the IP layer in each individual hosts. The IP layer will have to separate the traffic with destinations outside the organisation from the local traffic and enforce the rate control on this traffic only. Such separation of traffic will not affect the rate of traffic with local destinations.

  Since IP modules in the local hosts will not know in advance whether an IP packet is going to travel through the gateway, a mechanism has to be established for the gateway to inform each host about the destination upon transmitting an IP packet to the outside of the organisation. The hosts can then separate traffic for that destination.

- **Transportation of rate signal from the gateway to the hosts.** A mechanism has to be implemented for the gateway to provide rate signal to the individual hosts. The standard Internet Control Message Protocol (ICMP),[14] which is an integral part of the Internet Protocol for handling various error and control messages, may be used to generate such rate signals.

6. CONCLUSION

The need for traffic rate control at the access-gateway of an intranet connected to the Internet via an ATM ABR link is introduced in this paper. A traffic management mechanism is designed for intranets using a proportional feedback controller which is augmented with a noise feedforward to minimise the effect of bandwidth fluctuation in the ABR access-link on the performance of the control system. The controller is expected to reduce the buffer requirement at the access gateway of the intranet. For a given amount of buffer, the proposed control mechanism will minimise or eliminate buffer overflow and packet loss at the access gateway by keeping the buffer level at a desired set point.

The variance of the buffer level at the access gateway around the desired set point has been obtained through analysis. The proportional gain of the controller has been optimised to achieve the minimum possible variance for the buffer level. It has been demonstrated that the dependence of the optimum gain on the noise parameters is minimal, which makes the controller robust to system variations. It has been further established that the optimum gain guarantees stability of the control system.

For a given amount of buffer at the access gateway, the probability of packet loss at the gateway due to buffer overflow has been estimated as a function of the buffer level variance. Finally, some techniques have been suggested for implementing the proposed control mechanism within the standard intranet protocol stack.

REFERENCES

1. M.D. Prycker. *Asynchronous Transfer Mode*. Prentice Hall, third edition, 1995.
2. ITU-TS. *Recommendation I.121: Broadband Aspects of ISDN*. ITU, Geneva, 1991.
3. M. Hassan. Impact of Variable Bandwidth on the Performance of Data Communications over ATM-ABR Based LAN Interconnection. In *20th Australasian Computer Science Conference, Sydney, Australia*, pages 422–429, February 1997.
4. S. Kalyanaraman, R. Jain, S. Fahmy, R. Goyal, and S. Kim. Performance of TCP over ABR on ATM Backbone and with Various VBR Traffic Patterns. ATM Forum Contribution: 96-1294, October 1996.
5. N. Yin and S. Jagannath. End-to-End Traffic Management in IP/ATM Internetworks. ATM Forum Contribution: 96-1406, October 1996.
6. S. Jagannath and N. Yin. End-to-End TCP Performance in IP/ATM Internetworks. ATM Forum Contribution: 96-1711, December 1996.
7. W. Ren, K. Siu, H. Suzuki, and G. Ramamurthy. Performance of TCP over ATM with Legacy LAN. ATM Forum Contribution: 96-1716, December 1996.
8. G.F. Franklin, J.D. Powell, and A. Emami-Naeini. *Feedback Control of Dynamic Systems*. Addison Wesley, 1986.
9. C.C. Bissell. *Control Engineering*. Chapman & Hall, second edition, 1994.
10. Stefani, Savant, Shahian, and Hostetter. *Design of Feedback Control Systems*. Saunders College Publishing, 1994.
11. K.J. Astrom and B. Wittenmark. *Computer Controlled Systems*. Prentice Hall, second edition, 1990.
12. E. Kreyszig. *Advanced Engineering Mathematics*. Wiley, fourth edition, 1979.
13. S.M. Ross. *Introduction to Probability and Statistics for Engineers and Scientists*. John Wiley & Sons, 1987.
14. J. Postel. *RFC 792: Internet Control Message Protocol*, September 1981.