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Performance Analysis of an ATM-LAN IWU with a Dynamic Bandwidth Allocation Scheme

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ABSTRACT

In this paper, we propose an ATM-LAN IWU(interworking unit) with threshold based dynamic bandwidth allocation scheme. We analyze a discrete-time based finite queueing model with deterministic service times in order to investigate the performance of the proposed scheme. It is known that the arrival process of IP packets is bursty. So we use an MMPP(Markov Modulated Poisson Process) to model the bursty input traffic. As performance measures, we obtain the packet loss probability and the mean packet delay. We present some numerical results to show the effects of the thresholds on the performance of the DBAS(dynamic bandwidth allocation scheme).

I. Introduction

An ATM(Asynchronous Transfer Mode) has been developed and standardized for B-ISDN and is now being applied to LAN (Local Area Networks) for supporting multimedia traffic including high speed data and motion video. In the evolution of B-ISDN, the main issue is to interconnect existing LANs and MANs to B-ISDN based on ATM. However, LANs supporting IP(Internet Protocol) provide connectionless services, whereas the ATM network provides connection oriented services.

The conversion between the IP protocol and ATM is performed in some ATM-LAN IWU (Interworking Unit) which may be a router or a sever. Some mechanisms are needed in the IWU to establish and release an ATM connection. In addition, the traffic characteristic of IP packets is bursty and unpredictable, which makes virtual channel bandwidth assignment a difficult task.

In this paper, we propose a DBAS (dynamic bandwidth allocation scheme) of the IWU, which offers QoS(Quality of service) support to IP based service and optimizes the network resources regardless of the ability of feedback services by ABR(Available Bit Rate) notifications. Many studies[1-3] have already been done on the DBAS. F. Robles-Roji et al.[1] have analyzed the periodical modification algorithms(PMA), that control the instant of bandwidth modification procedure at fixed predetermined time periods.

S. Halberstadt et al.[3] have analyzed a DBAS with the threshold based algorithm (TBA), where a bandwidth modification request is issued whenever the predetermined threshold values are crossed.

In IP layer, all messages are segmented into almost fixed size transmission units, called IP packets. In ATM layer, these IP packets are again segmented into small fixed-size units, called cells. Thus the service time of an IP packet can be naturally taken as a packet transmission time including its segmentation time[4]. So we can denote a unit service time as one cell transmission time and we can denote S_0 as a default deterministic service time of a packet. In this paper, we analyze the proposed DBAS with

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two thresholds in the packet buffer by using a discrete-time based finite queueing model with deterministic service times.

Resent studies[5,6] on Internet traffic characteristics have revealed that the arrival process of IP packets is bursty in nature. We use an MMPP process to model the bursty characteristic of IP packet arrivals in the IWU[7]. Consequently, we can build an MMPP/D/1/K queueing model to study the performance of our proposed DBAS with two thresholds TBA algorithm.

The overall organization of this paper is as follows. In the section II, we describe the system model of the IWU with a TBA based DBAS. In the section III, we present the performance measures of our proposed scheme by using queuing analysis. In the section IV, we give some numerical examples for the performance measures. Finally we make a conclusion in the section V.

II. System Model

In this section, we present the proposed DBAS for carrying IP traffic on ATM networks. The queueing model of the ATM-LAN IWU with two thresholds TBA under consideration is depicted in figure 1. A packet buffer with finite capacity K including a single server is fed by an *m*-state MMPP process, which is characterized by the infinitesimal generator Q of the underlying Markov chain(MC) and by an arrival rate matrix $\Lambda = \text{diag}(\lambda_1, \cdots, \lambda_m)$. The buffer has two thresholds T_1 and T_2, $(0 \le T_1 \le T_2 < K)$. Service times are deterministic with rates varying according to the threshold values of the buffer content in packet.

Thus we can derive an MMPP/D/1/K queueing system. The queue is analyzed under the following assumptions. (1) The system is a discrete time system with a slot size(unit time) equal to the transmission time of one cell. (2) IP packet arrival takes place just prior to slot boundaries, while IP packet departure are completed at slot boundaries. (3) There is the changing instant of the service rates at slot boundaries after arrival epoch and the service completion.

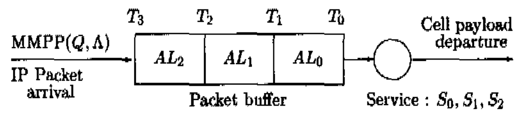

Fig. 1 Queueing model of an ATM/IWU

The transmission time devoted to packets of almost same size requires several cell slot times, which is represented by the default service time S_0 in the ATM-LAN IWU. The service time varies according to the following mechanisms. The default value for service time is S_0, which corresponds to allocation level 0. We denote $AL_0 = \{T_0, T_0+1, \cdots, T_1\}$ as the state space of the allocation level 0, where $T_0 = 0$. When the buffer content exceeds a threshold value T_1, the service time changes to $S_1 (S_0 > S_1)$, which corresponds to allocation level 1. We denote $AL_1 = \{T_1+1, \cdots, T_2\}$ as the state space of the allocation level 1.

But for simplicity, we assume that though the level of packet buffer exceeds T_1 during AL_0, the predetermined service interval S_0 is still enforced. When this service time interval is expired and the content of packet buffer is greater than or equal to T_1, the new service time interval with S_1 starts at this time point. Once the buffer content drops under a threshold value T_1, the service time resumes the value S_0.

When the buffer content exceeds a threshold value T_2, service time changes to $S_2 (S_1 > S_2)$, which corresponds to allocation level 2. We denote $AL_2 = \{T_2+1, \cdots, T_3\}$ as the state space of the allocation level 2, where $T_3 = K-1$. Though the buffer level exceeds T_2 during AL_2, the predetermined service interval S_1 is still enforced for simplicity. When this service interval is expired and the contents of packet buffer is greater than of equal to T_2, the new service time interval with S_2 starts at this time point. Once

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the buffer content drops under a threshold level T_2, the service time resume the value S_1.

Ⅲ. Analysis

In this section, we use an m-state MMPP to model the bursty input traffic to the proposed DBAS with two thresholds in the packet buffer. The m-state MMPP is characterized by the infinitesimal generator Q of the underlying MC and by an arrival rate matrix $\Lambda = \mathrm{diag}(\lambda_1, \lambda_2, \cdots, \lambda_m)$.

Let $A(t)$ be the number of arrival packets during the time interval $[0, t)$ and let $J(t)$ be the state of the underlying MC at time t. We denote the transition probabilities of $\{(A(t), J(t)), t \geq 0\}$ by

$$P_{ij}(n, t) = P\{A(t) = n, J(t) = j \mid A(0) = 0, J(0) = i\} \tag{1}$$

The $m \times m$-matrix $P(n, t)$ of the transition probabilities has the probability generating function as follows[8]

$$P^*(z, t) \equiv \sum_{n=0}^{\infty} P(n, t) z^n = e^{R(z)t}, \quad |z| \leq 1, \tag{2}$$

where $R(z) = Q + (z-1)\Lambda$.

Let $X(t)$ be the number of IP packets in the packet buffer at time t. Let t_n be the n-th IP packet departure instant and let $X_n = X(t_n+)$ and $J_n = J(t_n+)$ be the state of the system and the state of the underlying MC just after t_n respectively. Then $\{(X_n, J_n), \ n \geq 0\}$ forms a MC with its state space $\{0, 1, \cdots, K-1\} \times \{1, 2, \cdots, m\}$. The one-step transition probability matrix $\tilde{P}$ is given by

$$\tilde{P} = \begin{pmatrix} A_0^* & A_1^* & \cdots & A^*_{T_1} & \cdots & A^*_{T_2} & \cdots & \overline{A^*}_{K-1} \\ A_0 & A_1 & \cdots & A_{T_1} & \cdots & A_{T_2} & \cdots & \overline{A}_{K-1} \\ 0 & A_0 & \cdots & A_{T_{1-1}} & \cdots & A_{T_{2-1}} & \cdots & \overline{A}_{K-2} \\ \vdots & \vdots & \vdots & \vdots & \ddots & \vdots & \ddots & \vdots \\ 0 & 0 & \cdots & A_1 & \cdots & A_{T_2 - T_{1+1}} & \cdots & \overline{A}_{K-T_1} \\ 0 & 0 & \cdots & B_0 & \cdots & B_{T_2 - T_1} & \cdots & \overline{B}_{K-T_{1-1}} \\ \vdots & \vdots & \ddots & \vdots & \ddots & \vdots & \ddots & \vdots \\ 0 & 0 & \cdots & 0 & \cdots & B_1 & \cdots & \overline{B}_{K-T_2} \\ \vdots & \vdots & \ddots & \vdots & \ddots & \vdots & \ddots & \vdots \\ 0 & 0 & \cdots & 0 & \cdots & 0 & \cdots & \overline{C}_1 \end{pmatrix},$$

where $A_k = P(k, S_0)$, $B_k = P(k, S_1)$, $C_k = P(k, S_2)$, $k = 0, 1, \cdots$, $\overline{A}_k = \sum_{i=k}^{\infty} A_i$, $\overline{B}_k = \sum_{i=k}^{\infty} B_i$, and $\overline{C}_k = \sum_{i=k}^{\infty} C_i$, $1 \leq k \leq K-1$. To find A_k^*, let U be the matrix which accounts for the evolution of $J(t)$ during server's idle periods and whose (i,j)-entry denotes the conditional probability of reaching phase j at the end of an idle period, starting from phase i, then we have

$$U = \int_0^{\infty} e^{(Q-\Lambda)t} \Lambda dt = (\Lambda - Q)^{-1} \Lambda.$$

By using the matrices U and A_k, we can obtain A_k^* as follows

$$A_k^* = U A_k = (\Lambda - Q)^{-1} \Lambda A_k.$$

Let $\pi_{k,j}$ be the limiting probability such that

$$\pi_{k,j} = \lim_{n \to \infty} P\{X_n = k, J_n = j\},$$

and let $\pi = (\pi_0, \cdots, \pi_{K-1})$ with $\pi_k = (\pi_{k,1}, \cdots, \pi_{k,m})$, $0 \leq k \leq K-1$. Then the steady-state probability vector π is obtained by

$$\pi \tilde{P} = \pi, \quad \pi e = 1,$$

where e is a column vector with all ones.

Next we will find the limiting distribution of $(X(t), J(t))$ at an arbitrary time. Let $x_{n,j}$ be the limiting probability as

$$x_{n,j} = \lim_{\tau \to \infty} P\{X(\tau) = n, J(\tau) = j \mid X(0) = 0, J(0) = i\},$$

and $x = (x_0, \cdots, x_K)$, with $x_n = (x_{n,1}, \cdots, x_{n,m})$.

To find the steady-state probability vector x, let S_- be the elapsed time of a tagged packet from the last packet departure instant t_l, i.e., $S_- = \tau - t_l$ and let S_+ be the remaining time until the next packet departure instant t_{l+1}, i.e., $S_+ = t_{l+1} - \tau$. Let the random variable η denote the steady state of server, namely $\eta = 1$ if the server is busy and $\eta = 0$ if the server is idle. Then the probability of the system being busy is

$$\eta_1 \equiv P\{\eta = 1\} = \frac{S}{S + \pi_0 (\Lambda - Q)^{-1} e}, \tag{3}$$

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where S is the mean service time given by

$$S=\sum_{k=0}^{T_1} S_0\pi_k e+\sum_{k=T_1+1}^{T_2} S_1\pi_k e+\sum_{k=T_2+1}^{K-1} S_2\pi_k e.$$

Therefore, the vector x_0 satisfies

$$x_0=\frac{\pi_0(\Lambda-Q)^{-1}}{S+\pi_0(\Lambda-Q)^{-1}e}.$$

Let consider a cell arriving at time instant τ and take the service interval $[t_l, t_{l+1})$ containing τ. Then $x_{n,j}$ can be written in the following form, for $1\le n\le K-1$,

$$x_{n,j}=\lim_{\tau\to\infty}\int_0^{\infty} P\{X(\tau)=n, J(\tau)=j, t<S_+\le t+dt\}.$$

To find the joint probability $x_{n,j}$, we define conditional probabilities $\Gamma^d_{ij}(n,k;t)\,dt$ for $k\in AL_d, d=0,1,2,$ as follows

$$\Gamma^d_{ij}(n,k;t)dt=\lim_{l\to\infty}P\{A(S_-)=n, J=j, t<S_+\le t+dt|X_l=k\in AL_d, J_l=i\}.$$

Then in the matrix notation, we have

$$x_n=\eta_1\Big\{\pi_0 U\int_0^{S_0}\Gamma^0(n-1,1;t)\,dt+\sum_{d=0}^{2}\sum_{k=T_d+1}^{n\wedge T_{d+1}}\pi_k\int_0^{S_d}\Gamma^d(n-k,k,t)dt\Big\}, \quad (4)$$

where $\Gamma^d(n,k,t)=(\Gamma^d_{ij}(n,k,t)), d=0,1,2,$ and $n\wedge T_i=\min(n,T_i)$. Now we assert that

$$\int_0^{S_d}\Gamma^d(n,k,t)dt=\frac{1}{S_d}\Big(U^n-\sum_{l=0}^{n}D_l^{(d)}U^{n-l}\Big)(\Lambda-Q)^{-1}, \quad (5)$$

where $D_l^{(d)}=A_l, B_l, C_l, d=0,1,2,$ respectively.

We have to show that the equation (5) holds. To do this ,we have

$$\begin{aligned}&\Gamma^d_{ij}(n,k,t)\,dt\\&=\lim_{l\to\infty}\int_0^{S_d}P\{N(S_-)=n, J=j|S_+=t, S_-=u, X_l=k,\ J_l=i\}\times P\{t<S_+<t+dt, u<S_-<u+du|X_l=k, J_l=j\}\\&=\int_0^{S_d}P_{ij}(n,u)P\{t<S_+<t+dt, u<S_-<u+du\}\\&=\frac{1}{S_d}P_{ij}(n,S_d-t)dt,\end{aligned}$$

where the last equality comes from the fact that the distribution of an interval between two adjacent packet departure epochs has a point mass at S_d, $d=0,1,2$. Hence in the matrix notation, we have

$$\begin{aligned}\sum_{n=0}^{\infty}z^n\int_0^{S_d}\Gamma^d(n,k,t)dt&=\frac{1}{S_d}\int_0^{S_d}\sum_{n=0}^{\infty}z^nP(n,t)dt\\&=\frac{1}{S_d}(e^{R(z)S_d}-I)R(z)^{-1}.\end{aligned}$$

Since $\sum_{n=0}^{\infty}D_n^{(d)}z^n=e^{R(z)S_d}$, and $\sum_{n=0}^{\infty}U^nz^n(\Lambda-Q)^{-1}=-R(z)^{-1}$, we have

$$\begin{aligned}&\sum_{n=0}^{\infty}z^n\int_0^{S_d}\Gamma^d(n,k,t)dt\\&=\frac{1}{S_d}\sum_{n=0}^{\infty}z^n\Big(U^n-\sum_{l=0}^{n}D_l^{(d)}U^{n-l}\Big)(\Lambda-Q)^{-1}.\end{aligned}$$

By comparing the coefficients of z^n on both sides, we have (5). Substituting (5) into (4), we have the steady-state probabilities at an arbitrary time

$$x_n=\eta_1\Big\{\frac{\pi_0 U}{S_0}\Big(U^{n-1}-\sum_{l=0}^{n-1}A_lU^{n-1-l}\Big)+\sum_{d=0}^{2}\sum_{k=T_d+1}^{n\wedge T_{d+1}}\frac{\pi_k}{S_d}\Big(U^{n-k}-\sum_{l=0}^{n-k}D_l^{(d)}U^{n-k-l}\Big)\Big\}\times(\Lambda-Q)^{-1}, \quad (6)$$

where $n=1,2,\cdots,K-1$ and η_1 is given in (3).

By the definition, we have the equation

$$x_K=x-\sum_{n=0}^{K-1}x_n,$$

where x is the steady-state probability such that $xQ=0$. The above result (6) can be generalized to the case where the number of thresholds is an arbitrary M

$$x_n=\eta_1\Big\{\frac{\pi_0 U}{S_0}\Big(U^{n-1}-\sum_{l=0}^{n-1}A_lU^{n-1-l}\Big)+\sum_{d=0}^{M}\sum_{k=T_d+1}^{n\wedge T_{d+1}}\frac{\pi_k}{S_d}\Big(U^{n-k}-\sum_{l=0}^{n-k}D_l^{(d)}U^{n-k-l}\Big)\Big\}\times(\Lambda-Q)^{-1}.$$

The packet loss probability P_B for an arbitrary packet is given by

$$P_B=x_K\Lambda e/\Big(\sum_{k=0}^{K}x_k\Lambda e\Big).$$

We can easily find the mean packet delay W by Little's law as follows

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$$x\Lambda e(1-P_B)W=\sum_{k=1}^{K}kx_k e.$$

Ⅳ. Numerical Result

In this section we present some numerical results to show the performance of the proposed DBAS with two thresholds. There are several factors that can affect the performance of the scheme, such as the burstiness of input traffic, effective arrival rate, buffer size, threshold values and service times. We use a simple two-state MMPP (Q, Λ) as an input source, which has the following representation with the effective arrival rate $\lambda^*=(q_2\lambda_1+q_1\lambda_2)/(q_1+q_2)$,

$$Q=\begin{pmatrix}-q_1 & q_1\\ q_2 & -q_2\end{pmatrix},\qquad \Lambda=\begin{pmatrix}\lambda_1 & 0\\ 0 & \lambda_2\end{pmatrix}.$$

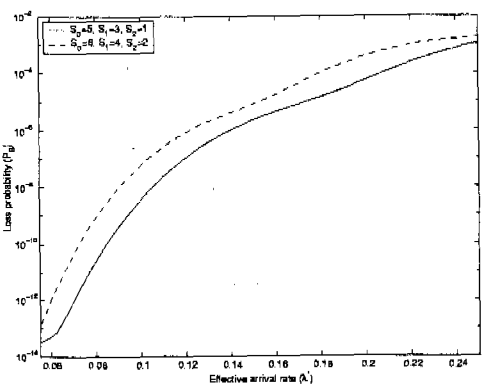

Fig. 2 Effective arrival rate vs. loss probability ($K=100$, $T_1=20$, $T_2=50$, $q_1=0.2$, $q_2=0.1$)

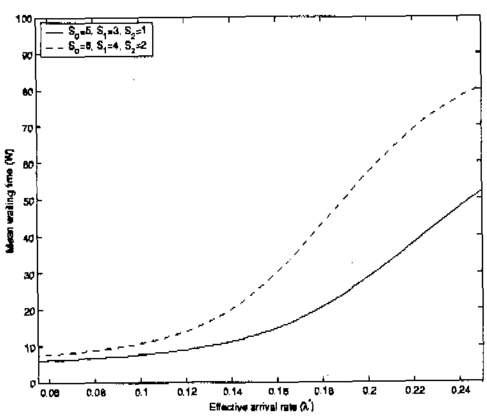

Fig. 3 Effective arrival rate vs. mean waiting time ($K=100$, $T_1=20$, $T_2=50$, $q_1=0.2$, $q_2=0.1$)

Figures 2 and 3 illustrate how the effective arrival rate(λ^*) has influence on the performance of the system for two cases of service time combinations. The parameters λ_1 and λ_2, are adjusted to get the desired λ^*. The loss probability and the mean waiting time become larger as the effective arrival rate becomes larger. It can also be observed from these figures that the performance values are substantially improved for smaller values of the service times than for larger values of them. A better performance can always be achieved by the DBAS, especially if S_1 and S_2 are small, which means to server cells faster during the control period

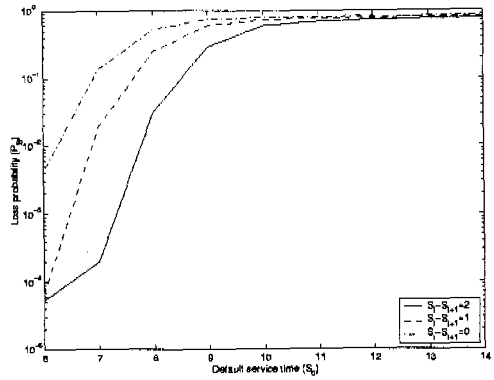

Fig. 4 Default service time vs. loss probability ($K=100$, $T_1=50$, $T_2=80$, $\lambda_1=0.6$, $\lambda_2=0.3$)

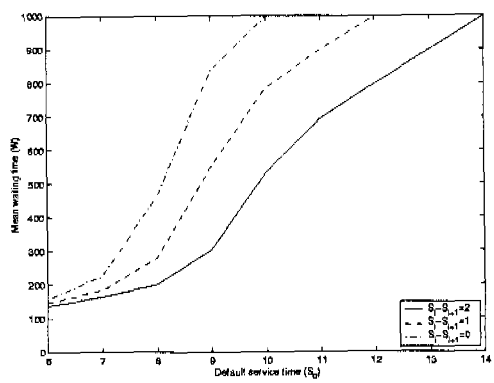

Fig. 5 Service time(S0) vs. mean waiting time ($K=100$, $T_1=50$, $T_2=80$, $\lambda_1=0.6$, $\lambda_2=0.3$)

To see the effect of service time on the proposed DBAS scheme, figures 4 and 5 compare the performance of static case $(S_i-S_{i+1}=0,$

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i=0,1) to that of dynamic case ($S_i - S_{i+1} = 1, 2$) for $\lambda_1 = 0.6$ and $\lambda_2 = 0.3$. The gain obtained by the proposed scheme is noticeable. In these figures, when the service time is small ($S_0 = 6$) at allocation level 0, the packet loss performances get improved, but the mean delay performances are slightly different. On the other hand, when the service time is large ($S_0 = 11$), the mean delay performances get improved, but the packet loss performances are similar.

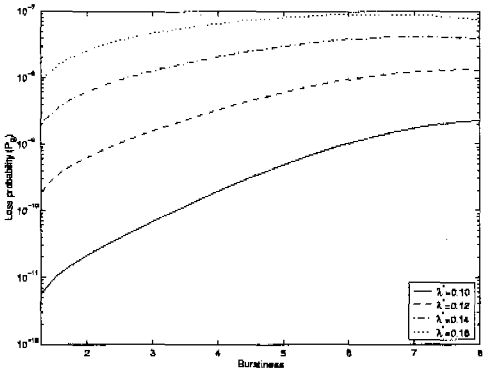

Fig. 6 Burstiness vs. loss probability ($K=100$, $T_1=50$, $T_2=80$, $q_1=0.9$, $q_2=0.1$)

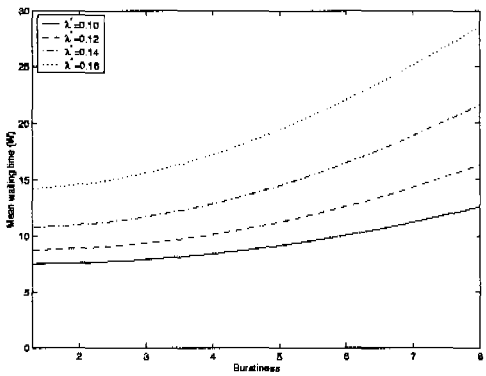

Fig. 7 Burstiness vs. mean waiting time ($K=100$, $T_1=50$, $T_2=80$, $q_1=0.9$, $q_2=0.1$)

Figures 6 and 7 show the effect of the burstiness on the performance in some cases of various effective arrival rates, when the parameters $q_1 = 0.9$, $q_2 = 0.1$, $S_0 = 5$, $S_1 = 3$ and $S_2 = 1$ are fixed. The burstiness of source traffic is defined as the ratio of the peak cell rate to the mean cell arrival rate.

In these figures we also adjusted λ_1 and λ_2 to achieve the desired effective arrival rate and burstiness. The loss probability and the mean waiting time increase as the burstiness increases.

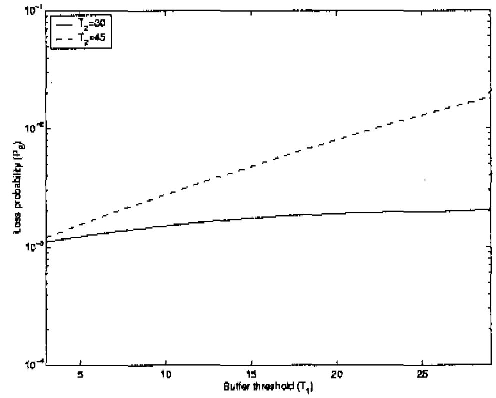

Fig. 8 Buffer threshold vs. loss probability ($K=50$, $S_0=6$, $S_1=4$, $S_2=2$, $\lambda_1=0.4$, $\lambda_2=0.2$)

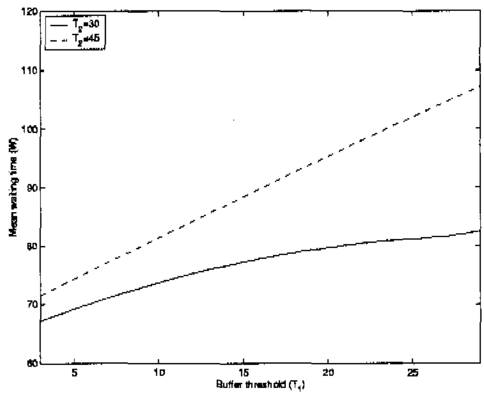

Fig. 9 Buffer threshold vs. mean waiting time ($K=50$, $S_0=6$, $S_1=4$, $S_2=2$, $\lambda_1=0.4$, $\lambda_2=0.2$)

Figures 8 and 9 show the loss probability and the mean waiting time for the two cases $T_2 = 30$ and $T_2 = 45$, when the threshold (T_1) varies, and the parameters $K = 50$, $\lambda_1 = 0.4$, $\lambda_2 = 0.2$, $S_0 = 6$, $S_1 = 4$ and $S_2 = 2$ are fixed. In these figures, we can see that both the loss and delay performances get deteriorated, when the buffer threshold T_1 becomes bigger(in precise, the service time becomes larger).

V. Conclusion

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In this paper, we study the performance of a TBA based DBAS with two thresholds in the ATM-LAN IWU such as a router or a server. To do this, we analyze a discrete time based finite queueing model with deterministic service time and an MMPP process as a bursty input traffic model of IP packets. We assume that the segmentation processing time of a packet to cell payloads requires several slot times in cell. Thus we derive an MMPP/D/1/K queueing model. Service rate changes dynamically as a function of the buffer content, following threshold values of packet buffer content.

As performance measures, we obtain the packet loss probability and the mean packet delay. We show the effect of two thresholds on the performance of the proposed DBAS. We also show the effects of the burstiness of traffic, effective arrival rate, buffer size and service time on the performance of the scheme. The proposed TBA based DBAS model with two thresholds can be extended to the case where the number of thresholds is arbitrary.

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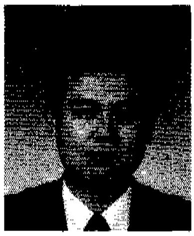

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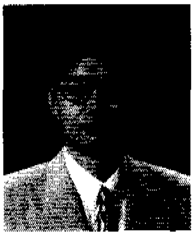

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