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ATM 근거리 망에서의 REQ/ACK와 ON-THE-FLY 방식의 고속 예약 프로토콜에 대한 성능해석

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PERFORMANCE ANALYSIS OF REQ/ACK and ON-THE-FLY FAST RESERVATION PROTOCOLS IN ATM LANS

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要 約

본 논문에서는 ATM 근거리 망에서의 버스트 단위의 대역폭 예약방법들에 대한 고찰과 단일 ATM 스위치로 연결된 클라이언트-서버 모델에 대하여 REQ/ACK와 on-the-fly 예약방식에 대한 성능을 비교 분석하였다. 성능 비교를 위하여 버스트의 평균 전달지연 시간, 블럭킹 확률과 수율에 대한 수학적 해석 모델을 유도하였다. 그리고, 이러한 성능 파라미터들의 전파지연 대 버스트 기간의 비, 최대 전송률 대 링크 속도의 비 등에 대한 의존도를 분석하였다. REQ/ACK 예약 방식은 고속 예약 트래픽에 대하여 버스트 전송을 위한 대역폭을 요청하고 응답 받을 때까지의 대역폭 낭비로 인하여 제한된 수율을 가지기 때문에, 전파지연 대 버스트 기간의 비가 클수록 on-the-fly 예약 방식이 REQ/ACK 방식에 비해 훨씬 바람직한 것으로 나타났다. 또한, 버스트의 길이가 일정할 경우 REQ/ACK 방식의 지연 성능은 on-the-fly에 비해 최대 전송률의 변화에 매우 민감한 것으로 나타났다.

ABSTRACT

In this paper, we investigate burst-level bandwidth reservation schemes in ATM LANs and compare the performance of REQ/ACK and on-the-fly fast reservation schemes for a client-server model with a single ATM switch. To compare performance, we derive an analytical model for the mean burst transfer delay, blocking probability and throughput. We discuss the dependence of these performance parameters on the propagation delay-to-burst duration ratio and peak rate-to-link speed ratio. We show that, for moderate propagation delay-to-burst duration ratio, the on-the-fly scheme is more desirable since the REQ/ACK scheme has limited achievable throughput for fast reservation traffic due to unused bandwidth during the REQ-ACK cycle. Also, for a given burst length (in bits), the delay performance of REQ/ACK scheme is more sensitive to increase in the peak rate than the on-the-fly scheme.

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I. Introduction

ATM-based Local Area Networks (ATM LAN) are currently being developed for high-speed LANs, for high-speed LAN backbones and for Customer Premises Networks in B-ISDN [1, 2]. ATM LANs have the advantages of high-speed networking/multimedia service capabilities, seamless interworking with B-ISDN, virtually unlimited scalability and cost effectiveness in comparison to Gb/s shared medium designs [2].

In many applications of ATM LANs such as distributed computing, multimedia, high-speed file transfer and image retrieval, traffic exhibits high peak rates and long burst lengths (in bits). Also, the burst lengths are variable and unpredictable. Due to a relatively high peak rate-to-link speed ratio in ATM LANs, statistical multiplexing at the call level with moderate buffer size fails. To obtain a substantial network efficiency, a dynamic bandwidth management at the burst level is more desirable.

The Fast Reservation Protocol (FRP) was originally proposed for efficient resource management for bursty traffic in B-ISDN, but the FRP is expected to be more suitable for ATM LANs due to small propagation delay. In traditional FRP schemes, the network allocates a bandwidth equivalent to the peak rate for each burst [3]-[6]. But, in many applications of ATM LANs, the throughput for each burst could be negotiated between source and network as long as the burst transmission delay is kept within an acceptable range. By dynamically adjusting the bandwidth allocation to the transfer rate, it is possible to achieve guaranteed zero cell loss [7]. Recently, some analytical models for the FRP schemes are available in some literatures [4]-[8], but the most of papers assume an infinite population and Poisson arrivals [4]-[6]. However, our analysis considers finite and ON/OFF sources.

In this paper, we investigate the FRP schemes in ATM LANs and compare the performance of REQ/ACK and on-the-fly reservation methods for a client-server model using a single ATM LAN switch. To compare performance, we use as performance criteria the mean burst transfer delay, the burst blocking probability and the burst throughput. Using the analytical results, we discuss the dependence of these performance parameters on the propagation delay-to-burst duration ratio and peak rate-to-link speed ratio. We also investigate the impact of peak rate increase on the performance as network and workstation speeds increase.

II. Network Model and Analysis

1. FRP Schemes Considered

In this section, we describe two FRP schemes considered, REQ/ACK and ON-THE-FLY, both of which are assumed to use the random backoff and the peak bandwidth methods. If the peak bandwidth is not available upon request, the source tries again after an exponential backoff time. For simplicity of analysis, we consider a client-server model connected through a single ATM LAN switch, in which distributed client computers share a single server. As shown in Fig. 1, N identical clients are connected to the ATM switch by each line and the peak bandwidth requests are assumed to be 1/M of the total output link capacity.

Fig. 2 shows procedural sequences in each FRP scheme. Before transmitting a burst, the client first sends a reservation_request

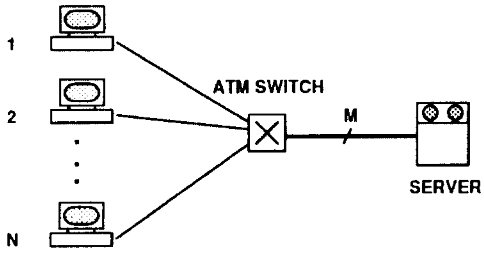
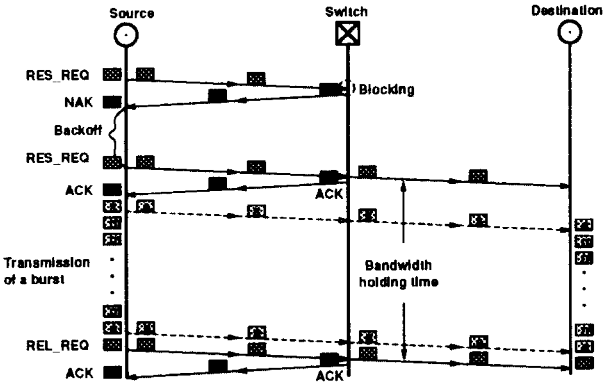
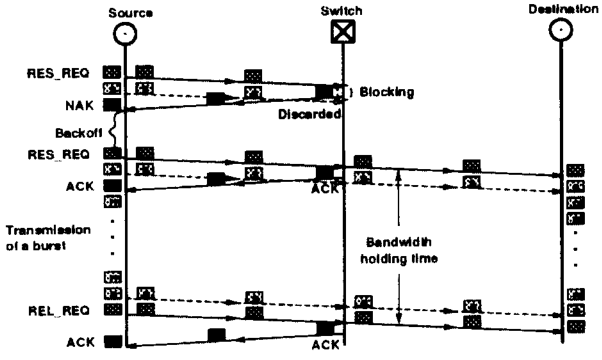


Figure 1. A client-server model.



(a) The REK/ACK



(b) The ON-THE-FLY

Figure 2. The FRP schemes considered.

(RES_REQ) cell, and after transmitting the last cell of the burst it sends a release_request (REL_REQ) cell. In the REQ/ACK scheme, bandwidth is reserved for each burst during a round-trip delay between client and switch plus a burst transmission time, while in the ON-THE-FLY scheme, bandwidth is reserved just during the burst transmission time.

2. Assumption and Notation

We consider an interactive data communication between N statistically identical clients and a single server as shown in Fig. 1, in which only idle clients can generate a burst. The idle duration of each ON/OFF source can be considered as the time period for waiting response from the server and thinking time in the client. We focus on the bandwidth sharing of the output link to the server by clients. In effect, this system is self-regulating, since the arrival rate of bursts becomes smaller as the system gets busier.

We assume that the idle and burst durations of each ON/OFF source are exponentially distributed. However, in the analysis we approximate the bandwidth holding time and the additional burst delay for each blocking as being exponentially distributed with means $1/\mu$ and $1/\delta$, respectively. If the round-trip delay is small enough in comparison to the mean burst duration and the mean backoff time, these approximations would be accurate for a constant round-trip delay. The bandwidth usage by reservation-related cells and cell queueing delay at the switch will be neglected, and the round-trip delay is assumed to be the same as the round-trip propagation delay. Since the output channel for each burst plays the role of a server in a queueing model, the system can be considered as a multi-server queueing model.

We define following notation which will be used in the analysis:

- B_m: the mean burst length (in bits).
- R_p: the peak rate for each ON/OFF source (in b/s).
- C: the output link rate to server (in b/s).
- T_{OFF}: the mean idle duration of each source $1/\gamma$
- T_{ON}: the mean burst duration of each source = B_m/R_p.
- τ_b: the mean backoff time for each burst blocking instance.
- τ_p: the one-way propagation delay between client and switch.
- $1/\delta$: the mean burst delay for each burst blocking.
- M: the maximum number of channels which can be supported at the peak rate = $\lfloor C/R_p \rfloor$
- N: the total number of sources.
- W: the mean reservation delay from the instant a burst is generated until the bandwidth reservation is successful.
- H: the mean bandwidth holding time $1/\mu$
- D: the mean burst transfer delay from the first attempt until the last bit is successfully transmitted = W + H.

We can consider the output link to the server as consisting of M channels, each of which has the capacity of the burst peak bandwidth. In Fig. 3, we describe the relationship between the various time parameters.

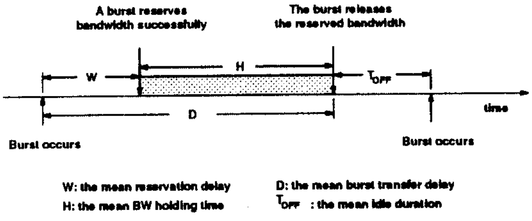


Figure 3. The relationship between some notations.

In the REQ/ACK scheme, bandwidth is reserved for each burst during the round-trip propagation delay plus the burst duration, while in the ON-THE-FLY scheme, bandwidth is reserved just during the burst duration. We can then represent the mean bandwidth holding time, $1/\mu$, for each reservation schemes as

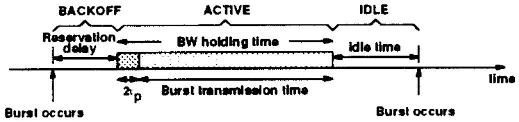
$$\frac{1}{\mu} = \begin{cases} 2\tau_p + T_{ON} & \text{for the REQ/ACK} \\ T_{ON} & \text{for the ON-THE-FLY.} \end{cases} \tag{1}$$

For every burst blocking instance, burst transmission is delayed by a round-trip delay plus a backoff time. Hence, the mean burst delay for each blocking, $1/\delta$, is given by

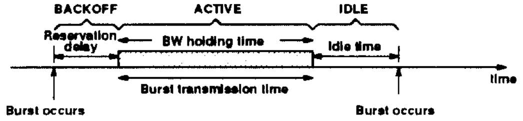
$$\frac{1}{\delta} = \tau_b + 2\tau_p. \tag{2}$$

3. Closed Queueing Network Model

Each source alternates between three states: idle, backoff and active as shown in Fig. 4. A source must wait for service in the backoff state if all M channels are busy when placing a reservation request, and then retries after an exponential backoff time. We say that a source is in the active state if it is in the period which begins with sending a RES_REQ cell which is accepted successfully until completing the transmission of the REL_REQ cell. We can then represent the REQ/ACK and ON-THE-FLY schemes as a closed queueing model as shown in Fig. 5. In this queueing model, the residence time for each source in the idle state can be considered as its idle duration, while the residence time in the active state is equivalent to the bandwidth holding time. In the backoff state, the residence time is identical to the sum of a



(a) The REQ/ACK



(b) The ON-THE-FLY

Figure 4. The system states of the REQ/ACK and ON-THE-FLY schemes.

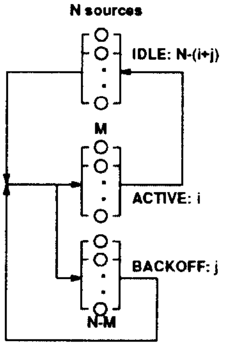


Figure 5. Closed queueing model of the REQ/ACK and ON-THE-FLY schemes.

round-trip propagation delay and a backoff time.

In the queueing model of Fig. 5, if all M channels are busy, a source from a backoff state reenters the same state after its residence time in the backoff state. But, in a continuous-time Markov chain, since the system state cannot go into the same state, we consider each backoff state with all servers busy as consisting of a pair of odd/even states internally and the system as alternating between odd/even states whenever a backed-off source requests bandwidth. However, since we are concerned only with the number of backed-off sources, it doesn't matter whether the system resides in the odd or even backoff states. Therefore, we don't have to identify even and odd states and can consider them as if they were the same state. Letting the number of sources which are in the active and backoff states as i and j respectively, a pair (i, j) forms a two-dimensional Markov chain, and the total number of system states is (N-M+1)(M+1) as in Fig. 6.

Denoting $\pi_{ij}^{[N]}$ as the steady-state probability of the N-source system being in a state (i, j), we can represent the global balance equations for each state (i, j), $0 \le i \le M$, $0 \le j \le N-M$, as follows:

1) $1 \le i \le M-1$, $0 \le j \le N-M-1$:

$$[\,i\mu+(N-i-j)\gamma+j\delta\,]\,\pi_{ij}^{[N]} = (N-i-j+1)\gamma\pi_{i-1j}^{[N]} + (i+1)\mu\pi_{i+1j}^{[N]} + (j+1)\delta\pi_{i-1j+1}^{[N]},$$

2) $1 \le i \le M-1$, $j=N-M$:

$$[\,i\mu+(M-i)\gamma+(N-M)\delta\,]\,\pi_{iN-M}^{[N]} = (M-i+1)\gamma\pi_{i-1N-M}^{[N]} + (i+1)\mu\pi_{i+1N-M}^{[N]},$$

3) $i=0$, $1 \le j \le N-M$:

$$[\,(N-j)\gamma+j\delta\,]\,\pi_{0j}^{[N]} = \mu\pi_{1j}^{[N]},$$

4) $i=M$, $0 < j \le N-M-1$:

$$[\,M\mu+(N-M-j)\gamma\,]\,\pi_{Mj}^{[N]} = (N-M-j+1)\gamma\pi_{M-1j}^{[N]} + (N-M-j+1)\gamma\pi_{Mj-1}^{[N]} + (j+1)\delta\pi_{M-1j+1}^{[N]},$$

5) $i=0$, $j=0$:

$$N\gamma\pi_{00}^{[N]} = \mu\pi_{10}^{[N]},$$

6) $i=M$, $j=N-M$:

$$M\mu\pi_{MN-M}^{[N]} = \gamma\pi_{M-1N-M}^{[N]} + \gamma\pi_{MN-M-1}^{[N]},$$

7) $i=M$, $j=0$:

$$[\,M\mu+(N-M)\gamma\,]\,\pi_{M0}^{[N]} = (N-M+1)\gamma\pi_{M-10}^{[N]} + \delta\pi_{M-11}^{[N]}. \tag{3}$$

We note that μ has a different value for the REQ/ACK and ON-THE-FLY schemes as shown in the equation (1).

Representing the steady-state probabilities $\{\pi_{ij}^{[N]}\}$ as a row vector Π, the global balance

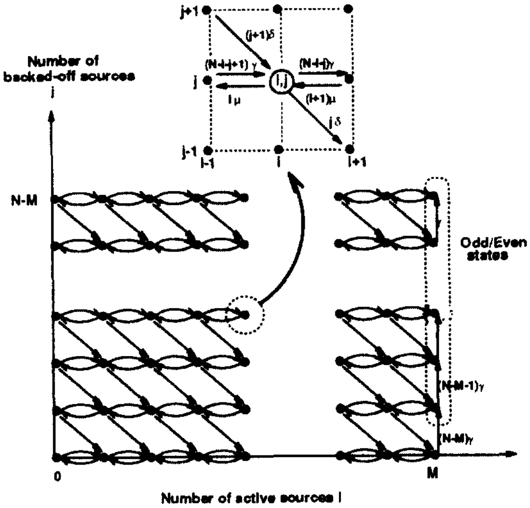


Figure 6. The state transition diagram of the REQ/ACK and ON-THE-FLY schemes.

equations can be expressed in matrix form as

$$\Pi Q = 0 \tag{4}$$

where Q is a transition rate matrix of (N-M+1)(M+1)x(N-M+1)(M+1). Also, the total sum of $\pi_{ij}^{[N]}$ must be equal to 1, hence it is given by

$$\sum_{j=0}^{N-M}\sum_{i=0}^{M}\pi_{ij}^{[N]} = 1. \tag{5}$$

Since the rate matrix Q is very sparse (the maximum number of nonzero elements of each column is 4), if we use a sparse matrix technique, we can obtain numerically the steady-state probabilities $\pi_{ij}^{[N]}$ for large values of N and M from (4) and (5). Actually, we are interested in highly bursty and high peak-rate traffic, so M may be at most a few tens and N would be an order of magnitude more than M.

4. Performance Measures

The burst blocking probability P_{block} at the first attempt for an N-source system is the same as the probability that all M channels are busy for (N-1)-source system at a random instant. For simplicity of notation, we let

$$\phi_i^{[N]} = \sum_{j=0}^{N-M}\pi_{ij}^{[N]}, \tag{6}$$

where $\phi_i^{[N]}$ denotes the probability that the number of sources in the active state is equal to i for the N-source system. Hence, Pblock can be obtained as

$$P_{block} = \phi_M^{[N-1]}. \tag{7}$$

If we define total burst throughput Λ as the total rate at which bursts are successfully transferred through the output link to the server, Λ (in bursts/sec) is given by

$$\Lambda = \sum_{i=1}^{M} i\mu\phi_i^{[N]}. \tag{8}$$

For a stability condition, the total burst arrival rate from sources should be equal to Λ. Hence, for an N-source system, the mean cycle time for a source is obtained from Little's formula as

$$\textit{the mean cycle time} = W + H + T_{OFF} = \frac{N}{\Lambda}. \tag{9}$$

Therefore, from (9) the mean burst transfer delay D can be represented as

$$D = W + H = \frac{N}{\Lambda} - T_{OFF}. \tag{10}$$

If we normalize the total burst throughput by link capacity, the normalized burst throughput ρ represents the effective link utilization, and ρ is obtained as

$$\rho = \frac{\Lambda T_{ON}}{M}. \tag{11}$$

Ⅲ. Numerical Results and Discussion

When burst blocking occurs, the ON-THE-FLY scheme wastes bandwidth which otherwise could be exploited by best-effort service. However, from the viewpoint of fast reservation traffic, both the REQ/ACK and the ON-THE-FLY schemes waste bandwidth since the bandwidth reserved until receiving the NAK cell cannot be used for other traffic. For a single switch ATM LAN, the bandwidth is wasted only on input links to the switch, it therefore does not affect the bandwidth efficiency of the output link to the server. In order to compare the performance of REQ/ACK and ON-THE-FLY schemes, we use as performance criteria the mean burst transfer delay, the burst blocking probability and the total throughput. In all numerical examples, the output link capacity C is assumed to be 100 Mb/s for simplicity.

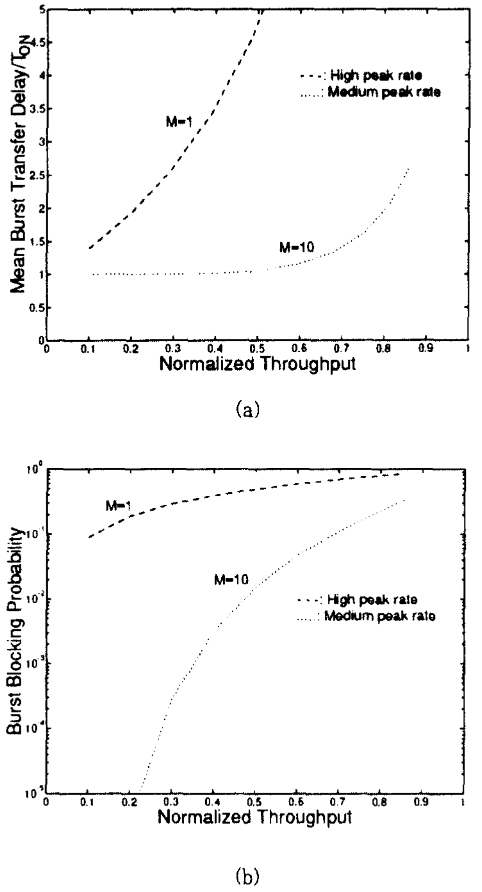
Table 1. Parameters considered in Figs. 7 - 10 (T_{ON} and T_{OFF} are normalized to the mean burst duration).

Source Type	Rp	M	(T_{ON}, T_{OFF})	α
Medium peak rate	10 Mb/s	10	(1,9)	0 0.01 0.1 1
High peak rate	100 Mb/s	1	(1,99)	

We first investigate the dependence of these performance parameters on the peak rate and propagation delay. We consider two different peak-rate sources with the same activity: medium peak-rate traffic Rp = 10 Mb/s and high peak-rate traffic Rp = 100 Mb/s. The mean backoff value τ_b is assumed to be three times of the mean burst duration T_{ON} if not specified otherwise [9]. The mean burst transfer delay is normalized to the mean burst duration, and for simplicity of notation we let $\alpha \equiv 2\tau_p/T_{ON}$ and $\beta \equiv \tau_b/T_{ON}$. In Table 1, we summarize the parameter values considered.

Fig. 7: shows burst delay and blocking probability characteristics for different peak rates for zero propagation delay. When the propagation delay is zero, there is no fundamental difference between the REQ/ACK and ON-THE-FLY reservation schemes. This figure shows that the medium peak-rate traffic can be multiplexed with high utilization while ensuring short burst transfer delay and low burst blocking probability. However, the high peak-rate traffic experiences larger burst delay and high burst blocking probability unless the network utilization is very low. From this result, we conclude that the performance of FRP schemes is highly dependent on the peak rate-to-link speed ratio. Therefore, to get high utilization for high peak-rate traffic in ATM LANs, channel or trunk grouping to provide higher output link capacity may be desirable.

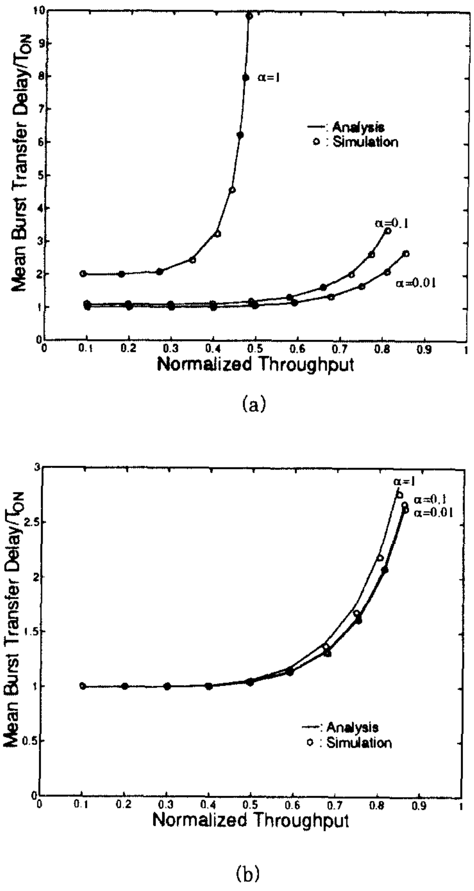
Figs. 8 - 9 show burst delay and blocking probability characteristics with different propagation delay for the medium peak-rate traffic, respectively. The circle mark indicates the simulation results for constant round-trip propagation delay. These figures show that there is no significant difference between the REQ/ACK and ON-THE-FLY schemes for relatively low propagation delay-to-burst duration ratio. But, for higher propagation delay-to-burst duration ratio, the REQ/ACK scheme exhibits limited achievable throughput since bandwidth goes unused for fast reservation traffic during the REQ-ACK cycle. For example, in the case of $\alpha = 1$, the maximum achievable throughput cannot



(a)

(b)

Figure 7. Burst delay and blocking characteristics for different peak rates for zero propagation delay (α =0,β=3). (a) Mean burst transfer delay (b) Burst blocking probability



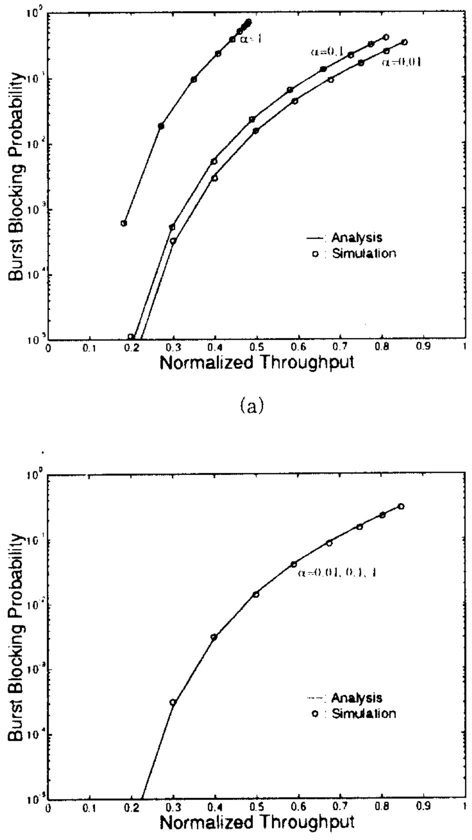
(a)

(b)

Figure 8. Mean burst transfer delay versus normalized throughput for different propagation delays (M=10, β=3). (a) The REQ/ACK (b) The ON-THE-FLY

exceed over 0.5. We know that the efficiency of REQ/ACK scheme is highly sensitive to the propagation delay-to-burst duration ratio while the ON-THE-FLY scheme is insensitive. Therefore, we conclude that for higher propagation delay-to-burst duration ratio, the ON-THE-FLY scheme is more desirable than the REQ/ACK scheme in terms of fast reservation traffic performance.

Fig. 10 shows the sensitivity of delay performance of FRP schemes to backoff values for the medium peak-rate traffic with α = 1. In this figure, the dotted, dashed and solid lines indicate for β = 0, 0.5 and 3, respectively. Other parameter values are the same as in Table 1. This figure shows that, for low utilization, the burst delay performance is insensitive to backoff values, and that the REQ/ACK and ON-THE-FLY schemes exhibit almost the same degree of sensitivities to backoff values. In the single switch ATM LAN considered, since bandwidth waste



(a)

(b)

Figure 9. Burst blocking probability versus normalized throughput for different propagation delays (M=10, β=3). (a) The REQ/ACK (b) The ON-THE-FLY

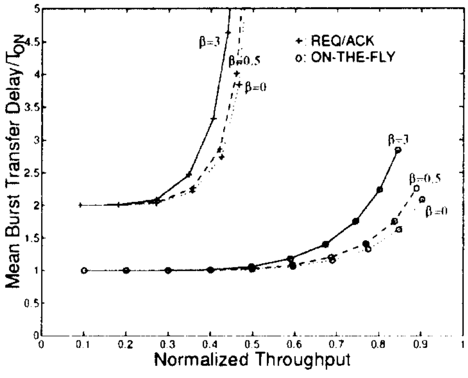


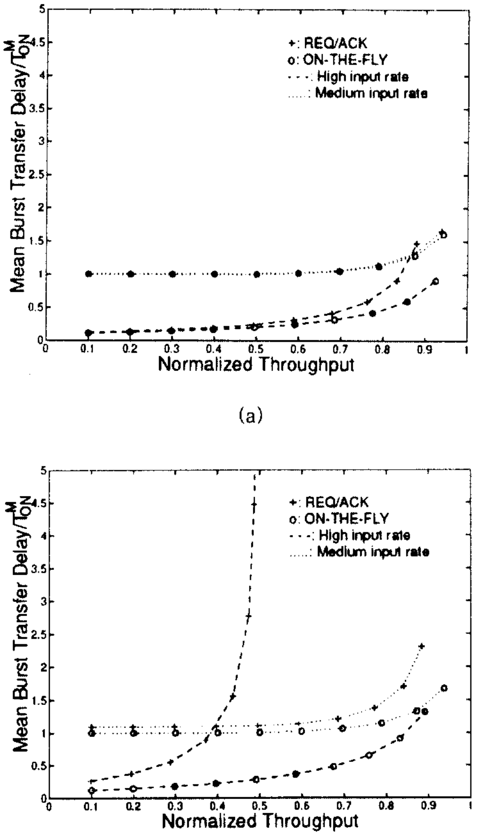
Figure 10. The sensitivity of mean burst transfer delay to backoff values (M=10, α=1).

occurs only on the input line to the switch, zero backoff gives lowest burst transfer delay for single source per input line applications. However, in multiple switches, there would be a nonzero backoff value optimizing the burst delay-throughput curve.

We next investigate the effect of peak rate increase on performance in order to assess the impact of network and workstation speed increases. We can classify bursty traffic into two types. For the first traffic type, the peak rate is determined by intrinsic source characteristics such as coding scheme. A typical example is variable bit-rate video. For the second traffic type, the peak rate is dependent on external characteristics such as network and workstation speeds. In the latter case, the peak rate increases as network and workstation speed increases, thus making the traffic more bursty. Most data traffic such as may arise in distributed computing, file transfer and image retrieval belong to this case. We investigate the performance dependence for the second type traffic on the input rate increase.

We consider two different input link speeds: 10 Mb/s medium input rate and 100 Mb/s high input rate. We assume that the peak rate of each source is the same as the input link speed. We also assume that the mean burst length (in bits) and burst arrival rates are the same for these two cases. For a given burst length (in bits), the burst duration (in sec) decreases as the peak rate increases. In other words, the propagation delay-to-burst duration ratio increases as network and workstation speed increases. If we denote each mean burst duration for the medium and high input speeds as T^{M}_{ON} and T^{H}_{ON}, then T^{H}_{ON} is one tenth of T^{M}_{ON} . Other traffic parameters for the medium and high input rates are the same as those for the medium and high peak rate traffics in Table 1, respectively. We here denote $2\tau_p/T^M_{ON}$ as α'.

Fig. 11 compares the impact of peak rate increase on delay-throughput performance for the REQ/ACK and ON-THE-FLY schemes with $\alpha' = 0.01, 0.1$. In this figure, zero back-off value is assumed, and the solid and dotted lines indicate the high input speed and medium input speed, respectively. To compare the absolute delay, the burst delays for different input rates are normalized by T^M_{ON}. This figure shows that the ON-THE-FLY scheme always gives lower burst delay for higher input speed with the same output link capacity. The REQ/ACK scheme however does not guarantee lower delays for higher input rates beyond some traffic load because the maximum achievable throughput decreases as the input speed increases for a given burst length. Therefore, the delay performance of REQ/ACK scheme is more sensitive to increase in the peak rate than ON-THE-FLY scheme as network and workstation speed increases.



(a)

(b)

Figure 11. The impact of peak-rate increases on delay performance for a given burst length (in bits) ($\beta = 0$). (a) $\alpha' = 0.01$ (b) $\alpha' = 0.1$

Ⅳ. Conclusions

In this paper, we investigated burst-level bandwidth reservation schemes in ATM LANs and compared the performance of REQ/ACK and ON-THE-FLY reservation schemes for a client-server model with a single ATM switch. As results, we showed that the performance of FRP schemes is highly dependent on the peak rate-to-link speed ratio irrespective of the reservation method. For a given burst length (in bits), the delay performance of REQ/ACK scheme showed to be more sensitive to increase in the peak rate than ON-THE-FLY scheme. For low propagation delay-to-burst duration ratio, the performance difference between the REQ/ACK and the ON-THE-FLY schemes appeared insignificant. However, for moderate propagation delay-to-burst duration ratio, the performance of REQ/ACK scheme exhibited limited achievable throughput for fast reservation traffic due to unused bandwidth during the REQ-ACK cycle. In this case, therefore, the ON-THE-FLY scheme is more desirable in terms of fast reservation traffic performance.

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