The Effect of Burst Assembly on Performance of Optical Burst Switched Networks

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Abstract. We evaluate and compare the performance of timer-based and threshold-based assembly algorithms in Optical Burst Switching networks. Results including burst blocking probability, mean packet delay and link utilization at the ingress node are presented from both simulations and two theoretical models. The results are obtained for the full range of input traffic load so they can provide guidelines for design and dimensioning links to meet desired Quality of Service levels.

1 Introduction

Optical Burst Switching (OBS) has recently been proposed as a future high-speed switching technology for Internet Protocol (IP) networks that may be able to efficiently utilize extremely high capacity links without the need for data buffering or optical-electronic conversions at intermediate nodes [8]. Packets arriving at an OBS ingress node that are destined for the same egress OBS node and belong to the same Quality of Service (QoS) class are aggregated and sent in discrete bursts, at times determined by the burst assembly policy. At intermediate nodes, the data within the optical signal is not processed but instead, the whole burst is transparently switched according to directives contained within a control packet preceding the burst. At the egress node, the burst is subsequently de-aggregated and forwarded electronically. Unlike classical circuit switching, contention between bursts may cause blocking and make it consequent loss within the network. Jointly minimizing blocking probability and maximizing throughput is the main goal of OBS research. The aim of this paper is to explore the impact of burst assembly algorithms on this optimization objective.

Recently, several burst assembly algorithms have been introduced: timer-based [4], threshold-based [7] and hybrid [6][9][11]. Recent research into burst assembly algorithms has focused mainly on its effect on the Long Range Dependence of the traffic. The Long Range Dependence of self-similar Internet traffic was initially shown to be reduced by applying burst assembly at an ingress

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node [4]. However, it was later demonstrated that the Long Range Dependence was unaffected by burst assembly [10]. Further work showed potential link-utilization improvements by leveraging the Long Range Dependence of input traffic in choosing adaptive values of the timer and the threshold. The interaction between burst assembly and Transmission Control Protocol (TCP) has also been studied. It was suggested that the TCP performance is more sensitive to the timer value than the threshold value and that the assembly period should equal the TCP window size [2][3]. In [5], increasing burst size was shown to result in higher TCP throughput but only at low blocking probabilities.

However, as far as the authors are aware, the performance impact of different assembly algorithms from packet level input to output bursts has not yet been explicitly explored. In this paper, we compare diverse burst assembly algorithms and study their effect on blocking probability, delay, and utilization with simulations compared with two analytical models. While the impact of the timer value and threshold value on delay is reasonably straight forward, consequent network utilization and blocking probability is more complex and is the subject of the remainder of the paper.

2 Burst Assembly

Burst assembly is a mechanism to aggregate incoming input traffic to create a suitable sized burst for transmission through the optical network. This mechanism can be modelled as a queuing system with a separate queue for each egress node/QoS pair and a shared output link. Two key parameters determine how a data burst is aggregated: the maximum waiting time (timer value) and the minimum size (threshold value) of the burst. Based on these two parameters, burst assembly algorithms can be categorized as *timer-based* [4] and *threshold-based burst assembly* [7] or *hybrid* [10][11], a combination of the two.

2.1 Timer-Based

In timer-based assembly, a timer is started at the initialization of system and immediately after the previous burst is sent. At the expiration of this timer, the burst assembler generates a burst containing all the packets in the buffer at that point. Under low input offered load, this scheme guarantees the minimum delay for burst assembly. However, under high input offered load, it may generate bursts that are quite large, perhaps unnecessarily increasing delay.

2.2 Threshold-Based

In threshold-based burst assembly, a burst is generated when a number of packets in a buffer arrives at a threshold value. In terms of delay, the performance of this scheme is completely the opposite to the timer-based scheme described above. Under low input offered load, this scheme may need to wait for a long period of time until the buffer threshold is reached. However, under high input offered load, the threshold will be reached quickly, minimizing delay.

2.3 Hybrid

A hybrid scheme applies algorithms concurrently [10][11]. Both a timer and a threshold parameter are set and the burst sent at the earlier of the timer expired and threshold reached events. The two values in a burst assembly can also be varied according to the input traffic load. This extension is called *an adaptive hybrid burst assembly* [6].

3 Single Node Model

In order to make queuing networks amenable to analysis, assumptions and approximations must be employed. A popular simplified traffic model is to assume that the bursts follow a Poisson process, leading to the classical Erlang queuing system. However, in many cases, the number of input sources generating bursts, which contend for a group of wavelength channels at the output of an OXC, may be small relative to the number of output wavelengths [12]. In this case, the Poisson model overestimates the loss probability. Another simple model is the Engset loss system which has a limited number of input sources [1]. The corresponding Engset loss formula is

$$B = \frac{\binom{M-1}{K}\rho^k}{\sum_{i=0}^{K}\binom{M-1}{i}\rho^i} \tag{1}$$

where B is the blocking probability, M is the number of input links, K is the number of output links, and ρ is the average intensity of the free input links. However, as discussed in [12], the Engset model may not model OBS networks accurately.

In this paper, we consider a model of a single OXC with a finite number of sources where each generates an on/off input stream (burst). Fig. 1 shows a model of an ingress node with limited number of sources and with one burst assembler for each source. Input traffic packets arrive at the ingress node and are queued with packets destined for the same egress node. The generated data burst are scheduled in the scheduler in order to forward them to the output links. Input traffic is modelled as with λ_p and μ_p. Note that these parameters correspond to the arriving IP packet process. After an ingress node performs burst assembly, the output traffic (the generated bursts) from the burst assembler in each input link is modelled as an input source toward the scheduler with burst arrival rate λ and service rate μ. Therefore, the on and off periods of each source have means of $1/\mu$ and $1/\lambda$, respectively. Let $\rho = \lambda/\mu$.

Using the model from [12], we consider a two dimensional Markov chain assuming exponential on and off source, the output of burst assembler, in order to model the OBS networks. There are three types of customers: (1) busy (bursts that are being transmitted), (2) free (empty input link), and (3) blocked (bursts that being dumped). The sum of the three types is always M, thus the number

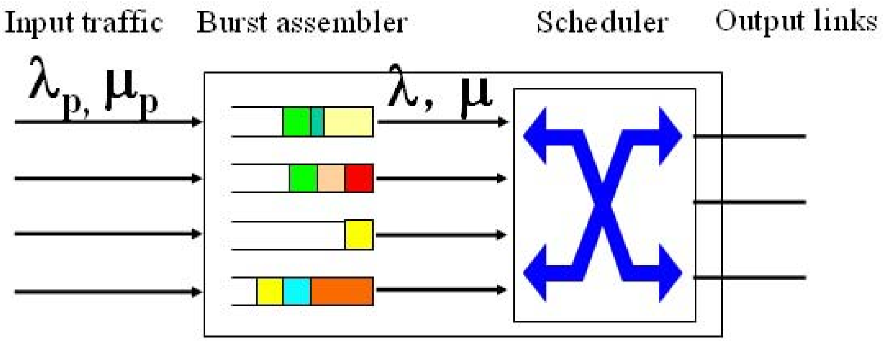

Fig. 1. A Model of an Ingress Node with Burst Assembler

of the free customers is always M minus the other two types. Accordingly, let $\pi_{i,j}$ be the steady state probability where $i(0 \leq i \leq K)$ is the number of busy customers and $j(0 \leq j \leq M-K)$ is the number of frozen customers (sources who transmit blocked bursts). We have the following steady state equations:
For $i = 0, 1, 2, ..., K-1$ we have

$$\begin{aligned}[(M-i-j)\lambda + (i+j)\mu]\pi_{i,j} &= (M-i+1-j)\lambda\pi_{i-1,j} \\ &+(j+1)\mu\pi_{i,j+1} + (i+1)\mu\pi_{i+1,j}. \end{aligned} \tag{2}$$

and

$$\begin{aligned}[(M-K-j)\lambda + (K+j)\mu]\pi_{K,j} &= (M-K+1-j)\lambda\pi_{K-1,j} \\ &+(j+1)\mu\pi_{K,j+1} + (M-K+1-j)\lambda\pi_{K,j-1}. \end{aligned} \tag{3}$$

For brevity, in (2) and (3) $\pi_{i,j}$ values out of the range $0 \leq i \leq K$ and $0 \leq j \leq M-K$ take the value zero.
Then we also have the normalization equation:

$$\sum_{i=0}^{K} \sum_{j=0}^{M-K} \pi_{i,j} = 1. \tag{4}$$

Since the number of frozen customers cannot be more than M-K, as a customer cannot become frozen if there are less than K busy customer, the offered load is given by

$$T_o = \sum_{i=0}^{K} \sum_{j=0}^{M-K} (M-1-j)\rho\pi_{i,j}, \tag{5}$$

the carried load is given by

$$T_c = \sum_{i=0}^{K} \sum_{j=0}^{M-K} i\pi_{i,j}, \tag{6}$$

and the blocking probability is obtained by

$$B = \frac{T_c - T_o}{T_o}. \tag{7}$$

3.1 Timer and Threshold-Based Models

The above model is burst assembly algorithm invariant and therefore is insufficient for analyzing possible differences between timer and threshold-based algorithms. In both of these two cases, there is a deterministic element not present in the probabilistic Engset model: threshold-based has a fixed burst size but random time interval, timer-based has a random burst size but fixed time interval.

Several simulations were run to evaluate the performance impact of the timer and threshold-based algorithms with the following parameter settings: Number of input links = 6, Number of output links = 3, Capacity of input and output links = 1Gbps. The packet arrivals were modelled by a Poisson process and had exponentially distributed sizes with mean = 1Kbyte. The scheduling algorithm LAUC (Lastest Available Unscheduled Channel) [8] was used to place the bursts on the output links. The simulations were run 10 times, with the number of packets in each simulations ranging from one to eight million. A range of sizes was used to ensure that simulations with longer timers and larger thresholds had similar number of bursts and therefore similar levels of accuracy. 95 percent confidence intervals, based on the Student-t distribution, are shown in the results if large enough to be visible.

As the packet sizes are assumed independent, the variance of the sum of k packet sizes is equal to k times the variance of the size of a single packet. By the central limit theorem, as k increases, the resulting queue size distribution increasingly becomes Gaussian-like with a standard deviation of the order of $\sqrt{k}$. Hence, for large k, the threshold based model can be approximated by a gaussian with small standard deviation and a mean equal to the threshold value. It was shown in [12] that models using Gaussian on and off times give slightly higher blocking probabilities than exponential, hence it was expected that packet-based simulations would also give higher blocking probabilities than the model described in Section 3.

Note that the simulations were run on only a single node. An extension to a network of nodes is currently in progress and will be the subject of a future paper.

4 Results

The two main results are presented in Fig. 2 and Fig. 5. The upper thick line is the blocking probability obtained by the Engset loss formula using (1). The

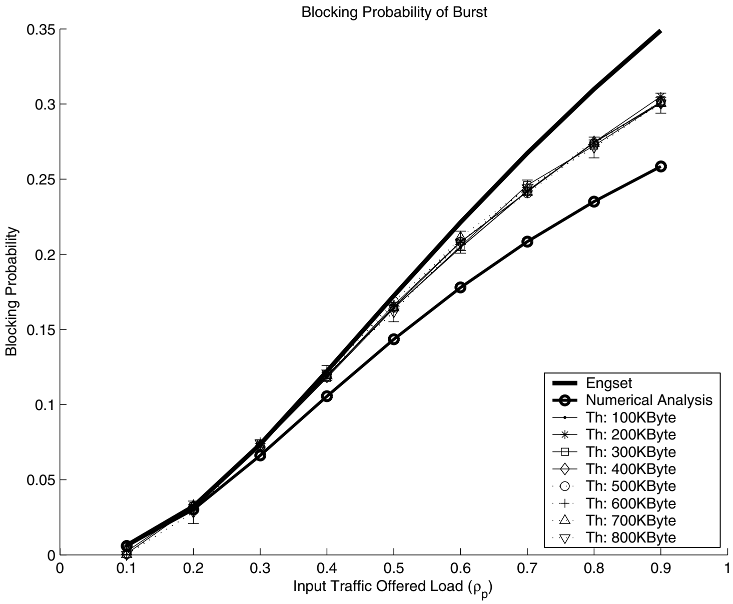

Fig. 2. Blocking Probability of Block: Threshold-based

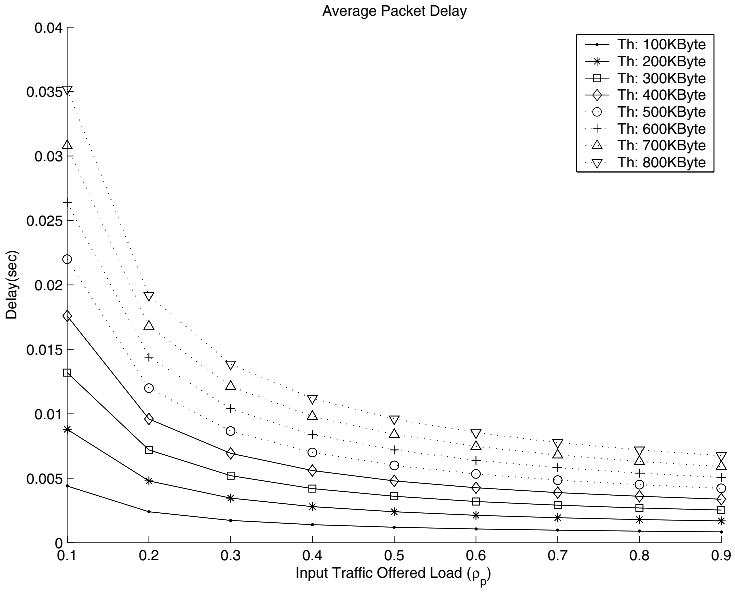

Fig. 3. Average Packet Delay: Threshold-based

lower thick dotted line is the blocking probability from the numerical analysis using (7). In general, the Engset overestimated the blocking probability and the numerical analysis underestimated the blocking probability. This is consistent with results obtained in [12] for the case where the on and off periods are Gaussian distributed. We present utilization results in Fig. 4 and Fig. 7 for completeness.

4.1 Threshold-Based

Fig. 2 shows the burst blocking probability according to threshold values of 100Kbytes to 800Kbytes. Over that range, the blocking probability was threshold size invariant. This is explained by the fact that for threshold-based systems, the parameter of interest (burst size) is deterministic, therefore scaling the system does not change the statistics of the output burst process for a constant load. For example, if we double the threshold and define the time unit as the burst transmission time, the number of burst served per time unit is still one, and the number of burst arrivals per time unit is as before. Thus, we have exactly the same system with exactly the same blocking probability. Fig. 3 shows the average packet delay. As expected from the discussion in Section 2.2, large threshold sizes and low load yield long average delays while small threshold sizes and high load yield short average delays. Fig. 4 shows link utilization that implies output link capacity occupancy of data burst. Under low load of input traffic link utilization yields low efficiency while it yields high efficiency under high load even though there are high blocking probability.

4.2 Timer-Based

Fig. 5 shows the blocking probability of the bursts according to timer values of 1 ms to 8 ms. Unlike the threshold-based method, changing the timer value had a substantial effect on the blocking probability: for low load, longer timers give lower blocking probabilities but for high load, longer timers give higher blocking probabilities. This suggests care must be taken to choose appropriate parameters that match the expected load into the network if a timer-based method is to be employed successfully. In contrast to threshold-based systems, in this case burst sizes are random variables, therefore scaling the system does change the statistics as the variance and higher order moments do not scale linearly, unlike the mean which was the only parameter of interest in the threshold-based system. The blocking probability of Engset loss formula shows intermediate values between that of larger timer value and that of smaller timer value. Result of numerical analysis still presents the lower bound of blocking. Fig. 6 shows the average size of the bursts as a function of the load. As expected from the discussion in Section 2.1, low load yields smaller burst sizes while high load yields larger burst sizes. The burst sizes also increase approximately linearly with timer length. Fig. 7 shows link utilization that smaller timers give high utilization over all range of offered load except only low load. It implies that smaller size of

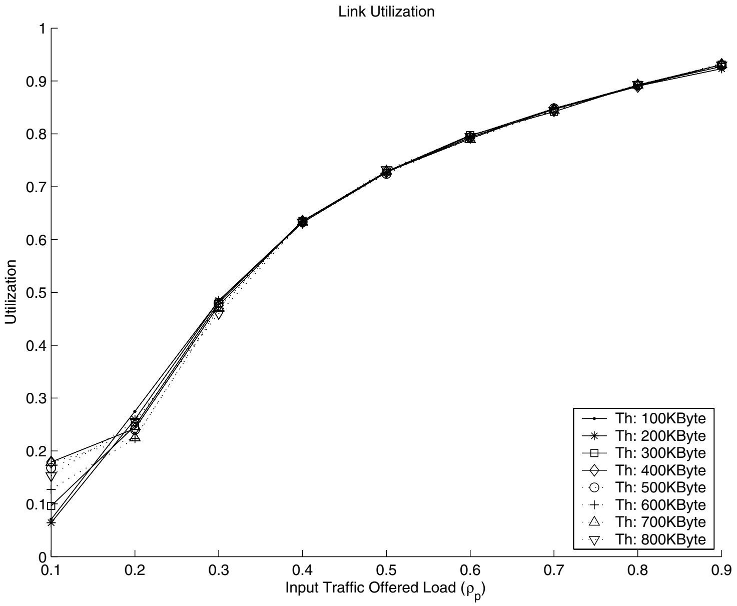

Fig. 4. Link Utilization: Threshold-based

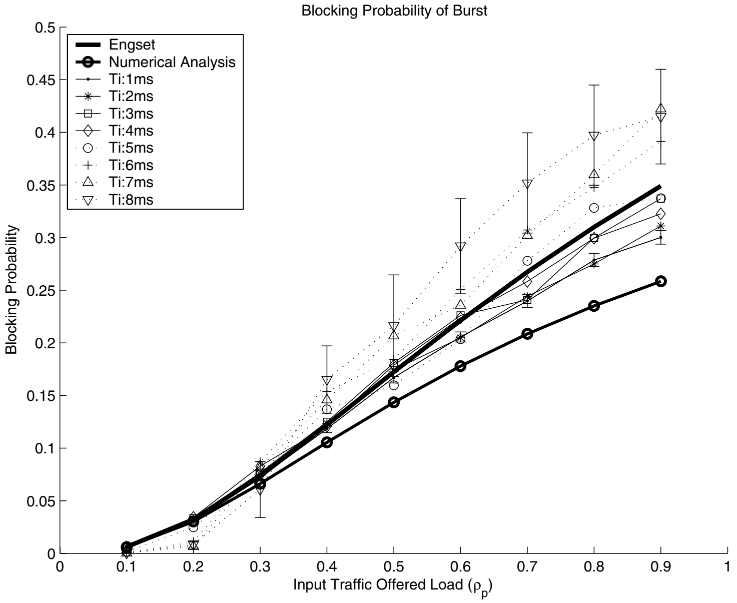

Fig. 5. Blocking Probability of Burst: Timer-based

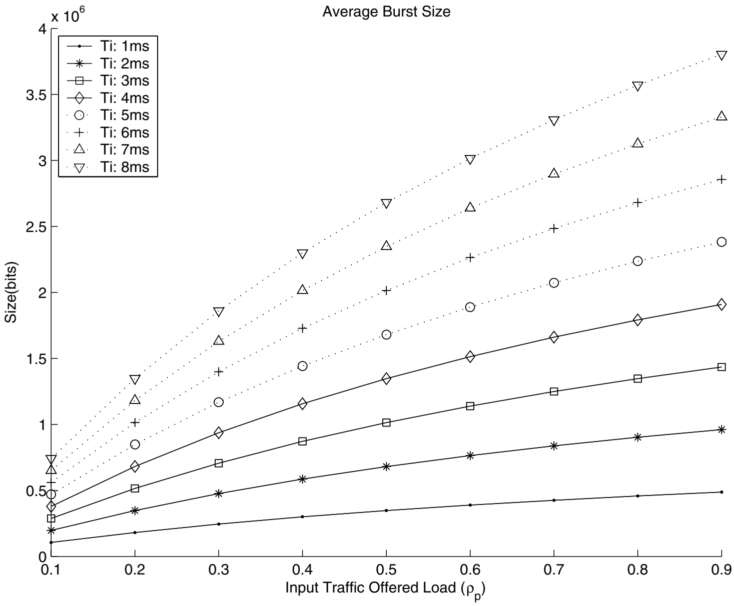

Fig. 6. Average Burst Size: Timer-based

burst is efficiently transmitted through the OBS networks in terms of blocking probability and link utilization.

5 Conclusion

In this paper, we studied the performance of timer and threshold-based burst assembly algorithms in OBS networks and compared the simulation results with two theoretical models: the classical Engset model and an analytical blocking model. The blocking probability was found to be threshold value invariant. But for low load, longer timers yielded lower blocking probabilities and for high load, longer timers yielded higher blocking probabilities. Finally, smaller size of burst shows mostly better performance in terms of link utilization and blocking probability over all range of load except very low load for timer-based burst assembler, as well as for threshold-based even through its effect is very slight.

Acknowledgements

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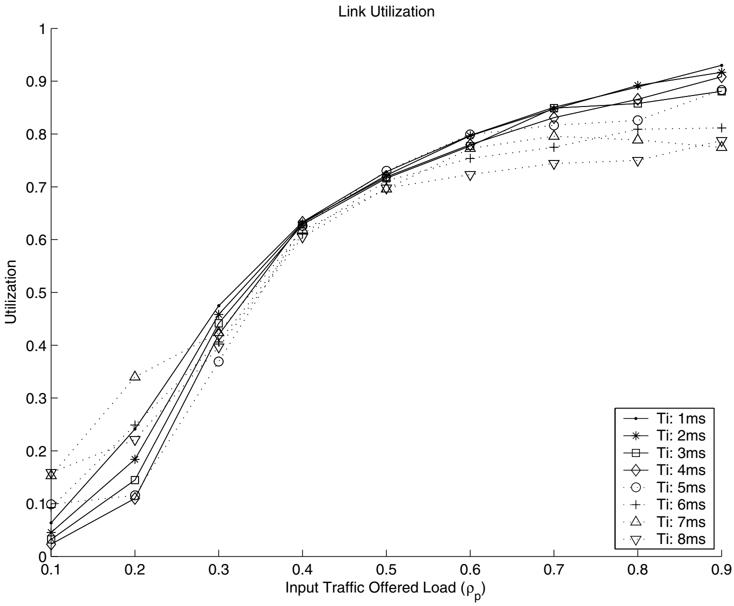

Fig. 7. Link Utilization: Timer-based

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