Performance Analysis of Optical Composite Burst Switching

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***Abstract*—In this letter, we introduce a queueing model to study the performance enhancement in a so-called optical composite burst switching network (OCBS). Based on our model, we develop a simple analytical method to calculate the packet loss probability and we provide numerical results to compare the performance of OCBS versus the traditional optical burst switching (OBS) technique. We then provide explanations for the performance improvement of OCBS over that of OBS.**

***Index Terms*—Burst segmentation, optical burst switching, packet loss probability, queueing model.**

I. INTRODUCTION

OPTICAL burst switching (OBS) has been proposed as an efficient switching technique to exploit the capacity provided by wavelength division multiplexing (WDM) transmission technology for the next generation optical Internet.

The idea underlying OBS technology is to decouple the data-path from the control path. In particular, IP packets are aggregated into much larger bursts before transmission through the network. This allows amortization of the switching overhead across many packets. The burst is preceded in time by a control packet sent on a separate control wavelength and requests resource allocation at each switch. There are several proposed reservation protocols in OBS; in this letter we only consider the just-enough-time (JET)-based OBS protocol [1]. In this scheme, when the control packet arrives at a core cross-connect (or switch), capacity is reserved in the cross-connect for the burst with the delay of offset time. If capacity can be reserved, the arriving burst is then switched transparently through the cross-connect. However, if the requested bandwidth is not available, the burst is said to be blocked and dropped.

Since OBS burst is an aggregation of many IP packets, one can significantly reduce the packet loss probability in OBS networks by applying a technique called optical composite burst switching (OCBS) [2] that discards only the initial part of a burst until a wavelength becomes free on the output fiber. From that instant, the switch will transmit the remainder of the burst [3]. A burst that loses a portion while waiting for a free wavelength and whose remainder is successfully transmitted will henceforth be called a *truncated* burst.

While the authors in [2] propose an analytical method to study the performance of this technique, we introduce a simpler analytical model to evaluate the benefit of OCBS and we compare it to the traditional JET-based OBS protocol.

Despite the seemingly significant improvement obtained by OCBS, we should always keep in mind that such improvement is partly due to the assumption we make that the overhead associated with truncating or switching (even without truncating) bursts is negligible. However, the reader should be aware that these overheads may be significant and must be taken into consideration in OBS design.

II. A QUEUEING MODEL FOR OCBS

We assume that for a given output port at a switch, the burst arrival process is Poisson with rate λ. The burst durations are generally distributed with mean $1/\mu$. Let k be the number of wavelengths available at each output port. If wavelength conversion is available, then k is a product of the number of fibers and the number of wavelengths per fiber at the relevant output port. Otherwise, k is equal to the number of fibers.

The OBS system behaves like an $M/M/k/k$ loss system for which burst blocking probability can be obtained using the Erlang B formula [4]–[6] as follows:

$$P_B(k, A) = \frac{\frac{A^k}{k!}}{\sum\limits_{m=0}^{k} \frac{A^m}{m!}}, \tag{1}$$

where $A = \lambda/\mu$ is the traffic load. Note that the Erlang B formula is insensitive to the service time distribution, thus (1) is also true for $M/G/k/k$ system. Since in such a model, a burst is either accepted or rejected in its entirety, the packet loss probability is equal to the burst loss probability P_B [2].

We now develop a model to analyze the packet loss probability for OCBS. There are two issues related to further wastage when the remainder of the truncated burst is transmitted [3]. The first is a switching time related to loss occurs when the output port is switched from one burst to another. And another is related to the fact that such switch may occur at the middle of the IP packet, in which case the remainder of that IP packet is lost. In this paper, we assume that these two effects are negligible. Accordingly, we assume that IP packets are small relative to the burst so that any portion of a packet lost is negligible. For the case whereby the packet size is not negligible relative to the burst size the reader is referred to [2].

As discussed before, one can model the switch in OBS networks as an $M/G/k/k$ queueing system, where k is the

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number of available wavelengths. Let us extend this queue to an $M/G/\infty$ queue with an unlimited number of pseudo-servers in addition to the original real k servers. Using the $M/G/\infty$ queue, when the system is full (i.e., all the k wavelengths are busy) and the new burst arrives, it will be accepted by the $(k+1)$th server which is a pseudo server. If more than one burst arrive to the full system, then the number of active pseudo servers increases as shown in Fig. 1(a).

In Fig. 1, the black part of a burst in pseudo servers will be dropped due to overlapping with other bursts being served by the k real servers. Once one of the wavelength among the k real servers becomes free, the remainder of the truncated burst in the $(k+1)$th server is allocated to the free wavelength at that instant and immediately starts service. This is a case in OCBS network as shown in Fig. 1(b).

On the other hand, this OCBS network is completely analogous to the system where the pseudo server becomes a real server as soon as one of the real server finishes serving and turns itself to pseudo server as shown in Fig. 1(c). Thus, the $M/G/\infty$ model is obtained from the OCBS model by a mere relabeling of the channel.

In the next section, we use the latter $M/G/\infty$ model in our analysis to study the gain in performance by OCBS.

III. ANALYTICAL RESULTS

The $M/G/\infty$ model provides us with a very simple way to calculate the packet loss probability under OCBS. The cases where the number of active servers in $M/G/\infty$ is k or less are equivalent to the cases of k or less wavelengths busy in OCBS with no additional truncated bursts. Thus these cases represent a period of time where no packet loss occurs.

The case of $k+1$ busy servers in the $M/G/\infty$ model represents the case of all k wavelengths being busy and there is an additional burst trying to enter. This represents a period of time during which one out of every $(k+1)$ packets is lost (for every k packets transmitted on the k wavelengths, one packet of the waiting burst is lost).

Similarity, the case of $k+j,\ j>1$ busy servers in the $M/G/\infty$ model represents the OCBS case of all k wavelengths being busy and there are j additional bursts trying to get in. This represents a period of time during which j out of every $k+j$ packets are lost (for every k packets transmitted on the k wavelengths, j packets of the waiting bursts are lost).

Thus the packet loss probability of OCBS can be evaluated as

$$P_{\text{OCBS}} = E[L]/A \tag{2}$$

where $E[L]$ is the mean loss given by

$$\begin{aligned} E[L] &= 1\cdot P(k+1) + 2\cdot P(k+2) + 3\cdot P(k+3) + \dots \\ &= \sum_{i=1}^{\infty} i\cdot P(k+i) \end{aligned}$$

and $P(k+i)$ is the probability that $(k+i)$ servers are busy in $M/G/\infty$ model. Since in that model, the number of busy servers is Poisson distributed [7] with parameter A (the traffic load), $P(k+i)$ is given by

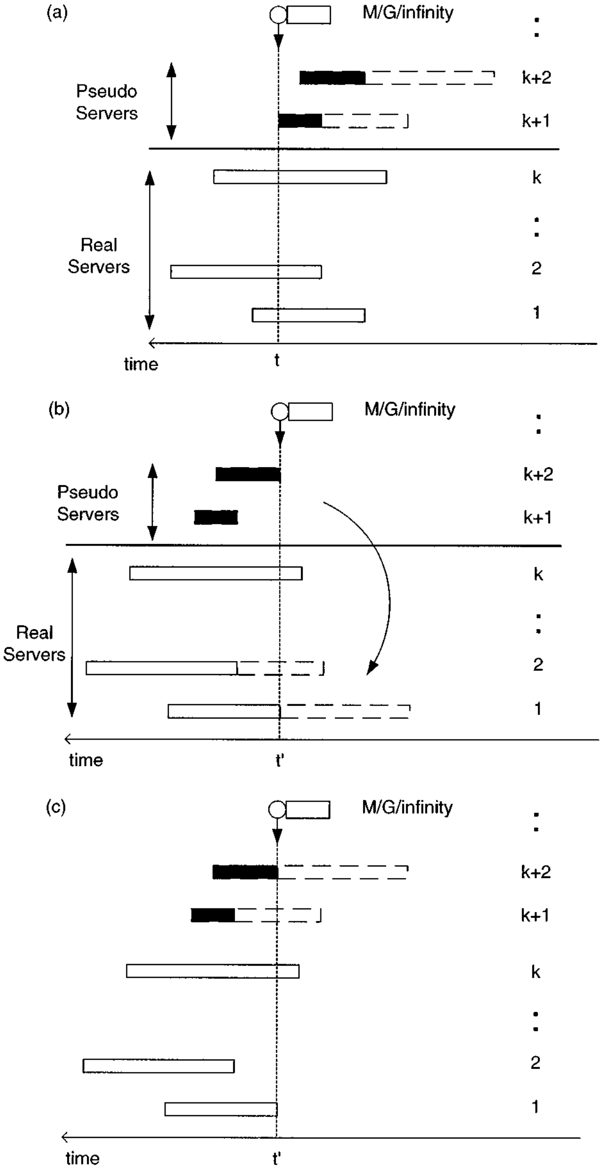

Fig. 1. (a) New burst arrives into a full OBS network at time t. (b) OCBS Model at time t'. (c) $M/G/\infty$ model at time t'.

$$P(k+i) = A^{k+i}\frac{e^{-A}}{(k+i)!},\ i=1,2,\dots$$

Note that to calculate the packet loss probability of $M/G/k/k$ and $M/G/\infty$ models using (1) and (2), we apply the following recursive formulas:

$$\begin{cases} P_B(0,A)=1 \\ P_B(n,A)=\frac{AP_B(n-1,A)}{n+AP_B(n-1,A)}, \quad n=1,2,3,\dots,k \end{cases} \tag{3}$$

$$\begin{cases} P(0)=e^{-A} \\ P(n+1)=\frac{A\,P(n)}{n+1}, \quad n=0,1,2,\dots,k,\dots \end{cases} \tag{4}$$

In Figs. 2 and 3, we show the improvement in packet loss probability of OCBS over that of the traditional JET-based OBS system with and without wavelength conversion using (1)

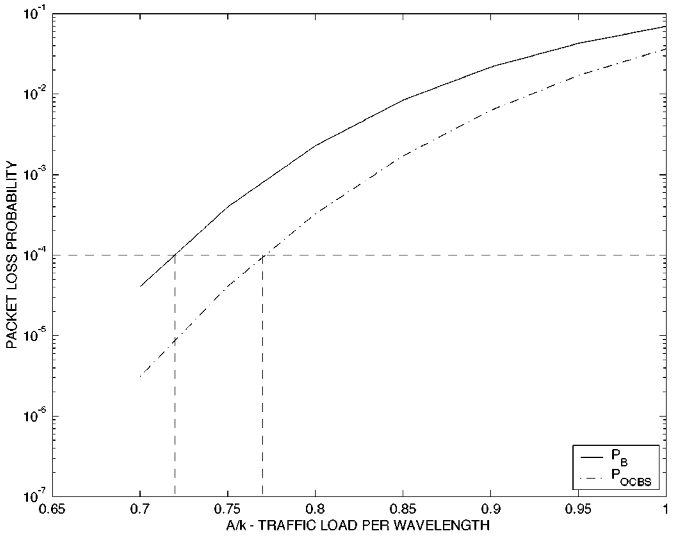

Fig. 2. Packet loss probabilities (P_B, P_{OCBS}) in OBS and OCBS (3 fibers, 40 wavelengths/fiber and using wavelength conversion).

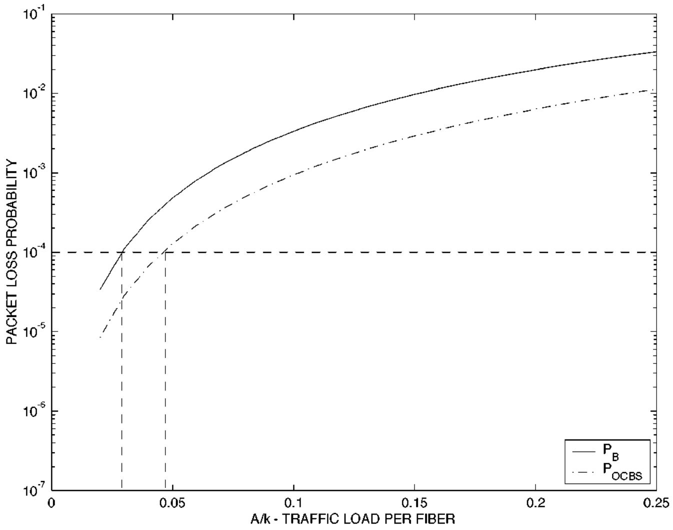

Fig. 3. Packet loss probabilities (P_B, P_{OCBS}) in OBS and OCBS (3 fibers without wavelength conversion).

and (2). Note that here we display the packet loss probabilities versus the normalized traffic load per channel (A/k), i.e., the traffic load per a relevant available wavelength. When wavelength conversion is available, all wavelengths are considered available. Otherwise, only one wavelength per fiber is considered available for the relevant traffic. Our traffic load per channel is the right measure of efficiency in both cases because it is the right indicator of channel (resource) efficiency.

In both cases (with and without wavelength conversion), our results show significant performance improvement in OCBS over OBS. In particular, when wavelength conversion is available, assuming we require 10^{-4} packet loss probability, we observe approximately a 10% increase in carried traffic per wavelength using OCBS versus OBS. Comparing Fig. 2 to Fig. 3, we can see the enormous benefit of wavelength conversion which allows a traffic increase of an order magnitude. Still, without wavelength conversion, significant benefit is achieved by OCBS over OBS. In particular, we observe that given the 10^{-4} packet loss probability requirement, OCBS only allows a traffic load of 0.047 per fiber, while OBS only allows 0.029 per fiber—a traffic increase of 60%.

The significant improvement achieved by OCBS is due to the fact that, on average, the part of the truncated burst that is lost is significantly smaller than its successfully transmitted part. Notice that under exponential distributed burst length, for the $(k+1)$th pseudo server, for example, the successfully transmitted remainder part is exponentially distributed with mean $1/\mu$, while the mean of the lost part is much smaller as it represents the time until one of many servers becomes free. Another factor that significantly affects the improvement of OCBS is the OBS traffic load for the given packet loss probability requirement. We have observed that for $k = 120$ that load is equal to approximately 0.72 per wavelength (at packet loss probability of 10^{-4}). It is already high and there is not much room for further improvement. Under the case of $k = 3$, where there is significantly more room for further improvement, the relative improvement of OCBS is greater.

IV. CONCLUSIONS

In this letter, we have introduced a simple analytical method to evaluate the packet loss probability of OCBS. We have compared it with that of OBS and we have shown that OCBS supports significantly more traffic than OBS for a given level of packet loss probability requirement.

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