Performance Evaluation of Optical Burst Switching with Assembled Burst Traffic Input

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Abstract—**This paper studies loss performance of optical burst switching (OBS) with assembled burst traffic input by exploring the characteristics of assembled burst traffic. We analyze the smoothing effect of assembly algorithms, which changes the statistical properties of packet flows, and find that assembly algorithms smooth the short range burstiness in packet traffic and thus enhance the loss performance in OBS. Based on the characteristics of such assembled burst traffic, an accurate loss model for OBS is provided, which works much better than traditional loss models in packet switching networks.**

I. INTRODUCTION

As the demand for transmission bandwidth in networks increases dramatically, optical networks are going to replace the traditional SONET backbones. Optical burst switching(OBS), which takes the advantages of both packet switching and circuit switching, is considered as a promising protocol for all-optical networking. There are two kind of nodes in an OBS network: assembly node and core node. At the assembly node, packets with the same destination are assembled together into bursts using various assembly algorithms [1], [2], and the bursts are then sent to the OBS core nodes, which forward the bursts using certain burst scheduling schemes.

OBS improves link utilization over optical circuit switching via statistical multiplexing. In addition, by assembling a number of packets into a burst and using Just-Enough-Time (JET) [3] algorithm, the processing efficiency can be increased and the loss rate can be reduced. Recent work [1] studied the characteristics of assembled burst traffic from a simple assembly algorithm via simulation and pointed out that burst assembly reduces the long range dependency (LRD), which is not accurate according to our analysis [2], the assembled burst traffic is less "bursty" in short range than the input packet traffic. However, how this smoothing is achieved and especially the impact of this smoothing effect on the loss rate in an OBS core node has not been analyzed. For example, [4] gives an analysis on the loss performance in an OBS core node, where the $M/M/k/k$ model was used which assumes that the input traffic to OBS core node is Poisson. Similarly, most of the existing OBS evaluation work has assumed Poisson or LRD traffic input, without considering the effect of burst assembly algorithms. Our analysis in [2], has shown that the assembled traffic, which is the input to an OBS core node, approaches Gaussian distribution rather than Poisson, and thus the loss performance can be different from that obtained using the $M/M/k/k$ model or other traditional models for packet switching networks.

In this paper, we explore the smoothing effect on the input packet traffic of the assembly algorithms in OBS networks, which contributes to the performance enhancement. Based on our analysis, we propose an accurate model for the loss performance in OBS. And finally, simulation results are provided to validate our analytical results and the proposed loss model.

The remaining of this paper is organized as follows. Section II describes analytically why existing models fail to predict the performance of an OBS core node with assembled burst traffic as input. An improved loss model is then proposed. In Section III, simulation results are given to verify the theoretical results. Finally, Section IV concludes this paper.

II. PERFORMANCE ANALYSIS OF OBS CORE NODE WITH ASSEMBLED TRAFFIC INPUT

This section gives analysis on the performance of an OBS core node based on both its service model and its input traffic characteristics, which are different from those of electronic switches or routers.

More specifically, in electronic packet switched networks, switches (or routers) have buffers for the input traffic, where the packets can be stored and wait to be served. A buffer in a switch can obviously decrease the packet loss and smoothes the input traffic in short range when the link capacity is low. However, it is well known that optical buffer does not exist. Although Fiber Delay Line (FDL) may be used, they do not have the random access capability as electronic buffers do. These limitations make a general optical switch a bufferless service model. When data arrives at such a bufferless switch, it will either be serviced immediately or be discarded (or deflected). Based on this bufferless server model for optical switches, we study its performance with assembled burst traffic input in the following subsections.

A. Smoothing Effect of Assembly Algorithms

A main purpose of burst assembly is to increase the switching efficiency at OBS core nodes. At the same time, it has been shown that assembly algorithms can also smooth the input packet traffic and reduce the data loss to some extent. More specifically, it is shown in [2] that the assembled traffic will follow a Gaussian distribution if the number of independent input traffic sources is large enough.

There are both assembled burst flows and bypass flows which are from other core nodes at an OBS core node, To simplify the study in this paper, we only focus on the loss among the assembled burst traffic flows. The loss performance of an OBS core node with both bypass flows and assembled burst flows can be treated by examining one more loss stage, whose inputs are based on the loss results obtained in this paper.

Since an OBS network operates in an asynchronous fashion and is bufferless, if all the packet traffic sources send their packets directly into the OBS network, the number of independent traffic flows can be quite large at the OBS core node resulting in a high probability of contentions among different flows and heavy data loss.

When an assembly algorithm is implemented at the edge of OBS networks, a number of traffic flows with the same destination will be aggregated together and a certain number of packets is assembled into a burst. Since the assembly queue at the edge of OBS network will hold the packets for a given assembly period, the contentions among the packets from these sources are reduced (with the tradeoff being some additional queuing delays). In other words, the short range burstiness in the input packet traffic is smoothed by the assembly buffer with the smoothing range comparable to burst sizes.

Although assembly algorithms smooth the input packet traffic flows in one assembly node, loss of assembled bursts at an OBS core node still exists simply because there may be several assembled burst traffic flows as input at an OBS core node, and the conflicts between these assembled traffic flows will lead to burst loss at the OBS core node.

Note also that the assembly algorithms only have a smoothing effect in the short range with a finite burst size, and the long range dependence in the input packet traffic will keep unchanged [2]. However, as we will see in the following sections, the long range dependence in the assembled burst traffic will not affect burst loss performance at the bufferless core node and thus can be ignored in OBS networks.

B. Effect of Long Range Dependent Traffic in OBS

In a single server queue system, the buffer overflow probability is denoted by $P\{Q(t) = B\}$, where $Q(t)$ is the queue length at time t, and B is the buffer size. For an SRD traffic input, the overflow probability has the following exponential distribution [5]:

$$P\{Q(t) > B\} = Ce^{-\eta B} \tag{1}$$

where C is asymptotic constant, and η is the decay rate for the queue length distribution. Both of them are related to the short range variance and traffic load ρ ($\rho = \lambda/\mu$, where λ is the average traffic arrival rate and μ is the link speed)

For an LRD traffic input, the buffer overflow probability follows a heavy tailed distribution, e.g., Weibull Distribution [6]:

$$P\{Q(t) > B\} = Ce^{-\eta B^{\nu}} \tag{2}$$

where the additional parameter ν is equal to $2(1-H)$ and $0.5 < H < 1$ is the Hurst parameter. Because of this parameter $\nu (0 < \nu < 1)$, the distribution in (2) decays slower than that in (1), and the buffer overflow probability of LRD traffic will be much larger than that of SRD traffic especially when the buffer size B is large in both cases.

In a bufferless server system, the packet loss ratio is decided by the empty buffer probability $P\{Q(t) = 0\}$. From (1) and (2), it is clear that this probability is only decided by C for both SRD and LRD traffic:

$$P\{Q(t) > 0\} = C \tag{3}$$

which will not be affected by the parameter ν, or the long range dependence in LRD traffic.

From the above analysis, we can see that the long range dependence will not affect OBS loss performance, and thus can be ignored.

C. Loss Model for OBS Core Node

Clearly the $M/M/k/k$ model used in [4] does not take the non-Poisson property of assembled burst traffic into consideration, and thus we need to provide a more accurate loss model. Since the input traffic to an OBS core node is in fact the aggregation of many assembled burst traffic flows from different assembly nodes, one may be attempted to derive the the loss probability from the following model [7] for n of aggregated identical input flows as follows:

$$P\{Q(t) > B\} \approx Ce^{-\delta(n-1)}e^{-\eta B} \tag{4}$$

where C and η are as in (1), and δ is related to the traffic type and load. For on-off Markov sources, δ is strictly positive and for Poisson traffic $\delta = 0$, which makes (4) the same as (1).

Thus, for a bufferless server system, one might be attempted to derive the loss probability of n identical input traffic flows as follows:

$$P\{Q(t) > 0\} \approx Ce^{-\delta(n-1)} \tag{5}$$

While (5) is useful for aggregated packet traffic, it is not suitable for assembled burst traffic in OBS. More specifically, since every individual input flow to OBS core node is an assembled traffic flow, which is shaped by some burst assembly algorithms, we modify (5) as follows:

$$P\{Q(t) > 0\} \approx C' e^{\delta' n^{\alpha(n)}} = Ce^{-\delta' e^{a} + \delta'(n-1)^{\alpha(n)}} \tag{6}$$

where a is a small adjustable constant according to assembled burst traffic characteristics. And δ' is also related with the assembled burst traffic characteristics, which is different from Poisson traffic where $\delta = 0$. For the fixed traffic load and input traffic type, all the parameters in the model (6) will keep unchanged.

Since at an OBS core node, each input assembled burst flow is a smoothed flow with resolved contentions between packets, the loss can only be introduced via the conflicts from other assembled burst flows, and the more the assembled burst flows, the more likely the contention between them. This is different from Poisson packet traffic aggregation simply because the assembly algorithms interrupt the independence between arrival packets of Poisson traffic by assembling them into bursts. So, the loss probability should increase with n and (6) has a positive δ'. And such an increasing loss rate with n should be less obvious as n increases, where the assembly effect will be overridden by the randomness of the input traffic flows and the aggregated bursts also become independent in a high aggregation degree. So the parameter $\alpha(n)$ will decrease non-linearly with the increase of n. In our experiments, we find that $\alpha(n)$ is a log function of n:

$$\alpha(n) = \frac{a}{log(n+b)} \tag{7}$$

where b is also small adjustable constant according to assembled burst traffic characteristics.

From (6) and (7) we can see that when n is large enough, $\alpha(n) \to 0$ and (6) changes very little with n and the loss rate will approach a constant as that given in (4). In particular, we have:

$$\lim_{n\to\infty} Ce^{-\delta' e^{a} + \delta' n^{\alpha(n-1)}} = Ce^{-\delta' e^{a} + \delta' e^{a}} = C \tag{8}$$

This is reasonable because all the assembled burst flows are independent and when n is large they will be aggregated to Poisson traffic and the smoothing effect of the assembly algorithms is totally overridden.

Generally speaking, although there may be many packet traffic input flows to OBS networks, most of them are aggregated in assembly nodes, and the number of assembled burst input flows in OBS core node is in fact not large, and not enough to be aggregated to Poisson burst traffic. Thus, the loss performance of OBS node with assembled traffic input will be different from that with Poisson traffic input.

III. NUMERICAL RESULTS

In this section, we give numerical results for loss analysis in a single OBS core node. In our simulation, both Poisson and LRD ($H = 0.75$) traffic with average 0.1 unit inter-arrival time and fixed packet size are used as the original input packet traffic (fixed packet size is assumed to simplify the simulation, but the results are similar to that for Poisson and LRD traffic with variable packet size as analyzed in [2]). And the assembled burst traffic flows are generated from each of these two packet traffic types. The Max-Time-Min-Max-Length assembly algorithm [2] is used to generate a burst traffic which is the input to the OBS core node.

A. Smoothing Effects of Assembly Algorithms in OBS

Figure 1 illustrates the inter-arrival time distributions for LRD traffic and Poisson traffic, before assembly and after assembly. Here the X-axis is the inter-arrival time of packets in packet traffic, or the inter-arrival time of bursts divided by average number of packets in a burst in assembled burst traffic, where n is the number of packets in one transmission unit, and for packet traffic, $n = 1$; and the Y-axis denotes the probability density function (PDF) of inter-arrival time T. While the two packet traffic traces and their corresponding assembled burst traffic traces have the same inter-arrival time distribution, they are different from each other in their correlation structures. Such differences are shown in their R/S plots in Figure 2(a): In the R/S plot, the slope α of the line is related to the LRD degree in the traffic: $H = \alpha$. In other words, the larger the slope, the heavier the long range dependence. In Figure 2(a), the LRD traffic has a Hurst parameter 0.75 calculated from the slope, while the Poisson traffic has a Hurst parameter of only 0.5. Also from Figure 2(a), we can see that in the light traffic load scenario (1 percentile in assembly node), both assembled Poisson traffic and assembled LRD traffic keep their R/S plot slope unchanged, which means that the long range dependence in the traffic remains the same after assembly. On the other hand, Figure 2(b) shows the R/S plot for assembled LRD traffic in medium to heavy traffic load scenarios. It is illustrated that when the traffic load is 50 percentile (or 90 percentile) at the assembly node, the R/S slope is flat when n is smaller than 20 (or 1000 respectively), and then becomes the same as before assembly. From the R/S definition [8], we conclude that it is the short range variance (when n is small in R/S plot) that has been smoothed. And the heavier the traffic load in assembly node, the longer range the variance gets smoothed. In extreme scenario when the traffic load is 100 percentile, the R/S slope will become flat over all n because such assembled traffic has been smoothed to constant rate traffic and R/S plot cannot measure the LRD in such traffic any more.

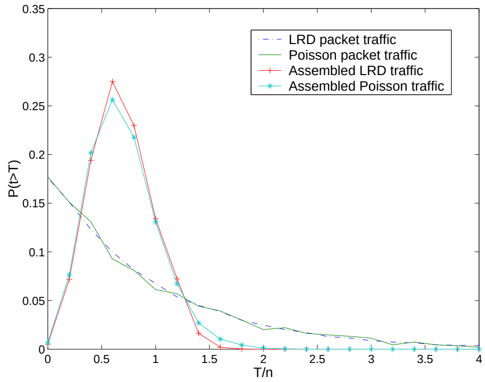


Fig. 1. Inter-arrival Time Distribution for Packet&Assembled Traffic

Figure 3 illustrates the improvement of loss performance in OBS with 10 to 100 traffic input flows, which results in different traffic load scenarios from 10 percentile to 100 percentile. The smoothness of the assembled traffic enhances the performance of OBS with either Poisson traffic input and LRD traffic input under various traffic load scenarios. In Figure 3(b) the assembled LRD burst traffic seems to result in a larger improvement in the loss performance than the assembled Poisson traffic. This is not inherent from LRD property, rather, it is mainly due to the fact that the short range variance in the LRD packet traffic generated in the simulation is higher than that in the Poisson traffic, which gets smoother by the assembly algorithm. As we look closer at the loss performance in light traffic load scenario as shown in Figure 4, it is clear that both of the loss rate are very small (approach zero) when traffic load is light , but as the number of input flows increases, the loss rate of packet traffic increases faster than that of the assembled burst traffic. This is because it is more likely for packets to conflict in n aggregated packet flows (each aggregated flow represents all the input flow to the same assembly node) than burst to conflict in the n assembled burst flows whose short range burstiness has been smoothed to some extent. From the above simulation results we conclude that assembly algorithms smooth packet traffic in the short range variance, which in turns enhances the OBS loss performance.

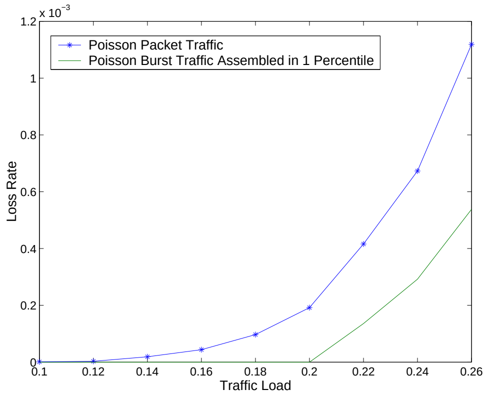
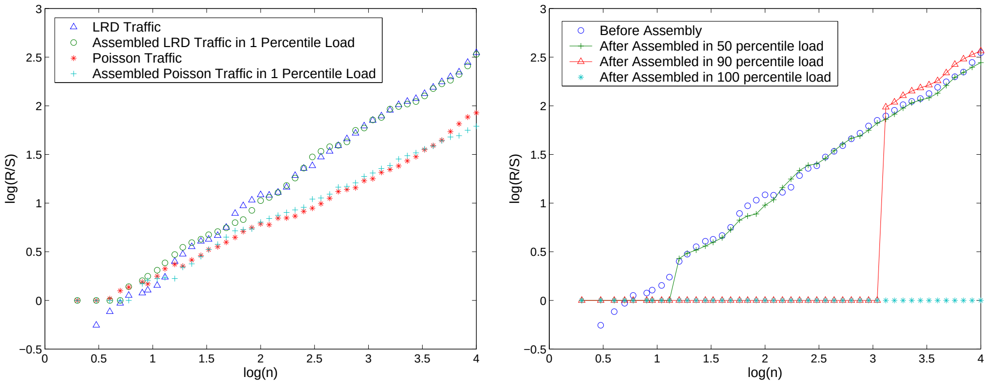


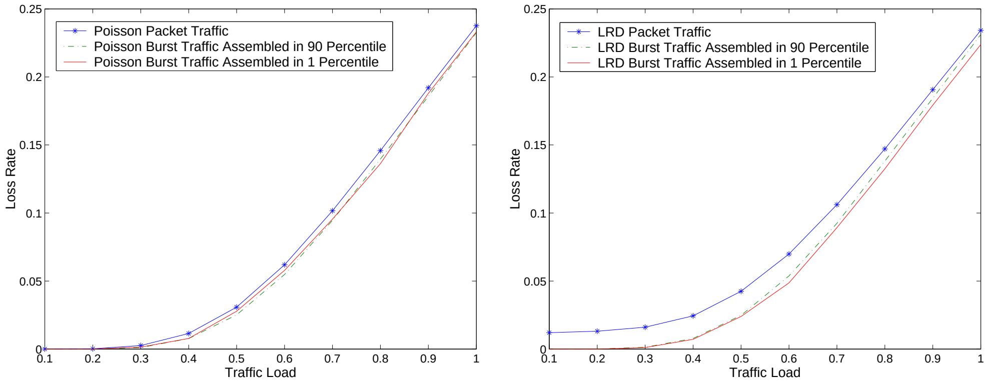
Fig. 4. OBS Core Node Performance in Low Traffic Load Scenario



(a) SRD and LRD Traffic Assembled under Light Load

(b) LRD Traffic Assembled under Heavy Load

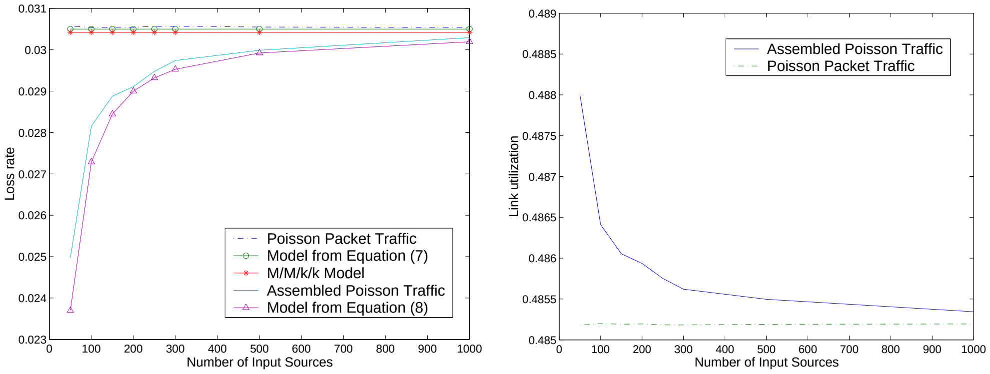
Fig. 2. R/S Plot



(a) Loss Rate in OBS with Poisson Traffic

(b) Loss Rate in OBS with LRD Traffic

Fig. 3. Loss Performance Comparison in OBS core node



(a) Loss Rate

(b) Link Utilization

Fig. 5. Performance Comparison under Different Number of Aggregated Flows

B. *Aggregation Effect to the Performance in OBS*

Figure 5 illustrates the loss rate and link utilization at an OBS core node with either assembled burst traffic (assembled under 1 percentile traffic load) or unassembled packet traffic as input. For a fixed traffic load as 50 percentile in OBS core node, the loss rate in Figure 5(a) shows that with Poisson packet traffic input, the loss rate remains almost a constant as the number of input flows increases, which fits the M/M/k/k model and the model in (4). However, with the assembled Poisson traffic as input, the loss rate increases with n, but the rate of increase becomes slower and slower. And finally the loss rate approximates that with Poisson packet traffic. Similarly the link utilization in both cases show the same trends as in Figure 5(b).

The above phenomenon can be explained as follows: with many inputs (i.e., when n is large), the multiplexing effect will override the smoothing effect of assembly algorithms in the OBS performance. More specifically, with a large n, the loss performance with assembled burst traffic input is expected to be the same as that with packet traffic input since both the aggregated assembled burst traffic and the aggregated packet traffic are Poisson traffic due to the independence between the individual traffic flows. However usually in OBS networks, there won't be so many aggregated assembled burst flows because most of the input packet flows are aggregated in assembly node and get smoothed, and the smooth effect of assembly algorithms still dominates the loss performance and makes OBS performance with assembled burst traffic input ‘better than OBS with packet traffic input. If the total number of input packet flows to an OBS node keeps unchanged, and if we aggregate more packet flows in assembly nodes, the number of assembled burst flows to OBS node will reduce, and the loss of OBS node can be reduced.

Figure 5(a) also verifies the loss model proposed in (6) for assembled traffic in OBS node, which predicts the loss to increase with the number of assembled burst traffic flows. This is different from the $M/M/k/k$ loss model which can only be applied for Poisson packet traffic input, as well as the model in (5) for aggregated packet traffic. Figure 5(a) shows that neither the $M/M/k/k$ model nor the model in (5) is appropriate for predicting the loss performance in OBS with assembled burst traffic input. On the other hand, it is clear that the loss model proposed in (6) works very well with assembled burst traffic inputs. In this simulation, we use $C = 0.000003$, $\delta' = 0.582$, $a = 1.2$ and $b = 2$ for the parameters in model (6).

IV. CONCLUSION

In this paper, we have analyzed the OBS core node performance based on the bursty characteristics of assembled burst traffic. One of our major findings is that assembly algorithms only smooth the input packet traffic in short range variance, but its long range dependence still remains unchanged in assembled burst traffic. Such smoothing effect can enhance the loss performance at an OBS core node, which is a bufferless server and hence can only be affected by short range variance instead of long range dependence. This finding is significant because for the first time it provides a theoretical explanation as to why the previous simulation studies have shown that OBS has a better performance than optical packet switching. Also, it corrects the misleading statement made in [1] that burst assembly will reduce LRD.

Another major contribution is that, based on the characteristics of assembled burst traffic, a loss model with assembled burst traffic input has been proposed in this paper and verified via simulation. According to this model, the loss rate increases with the number of assembled Poisson traffic. This is different from the loss performance in packet switching with Poisson traffic input, where the packet loss will remain constant with the number of input packet flows. As far as we know, this is the first analysis model that can accordingly predict the loss performance at a core OBS node with assembled burst traffic as input. Such a model will be extremely useful in further studies of OBS network wide (or multi-hop) loss performance.

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