

A Performance Study on Optical Burst Switched Networks: Ring Topology

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Abstract

Existing performance studies on optical burst switched (OBS) networks have been focusing on *channel blocking, i.e.*, when the required wavelength is not available on a link along a burst's route. However, we identify another type of blocking as the *receiver blocking, i.e.*, when the receiver at a burst's destination node is occupied by another burst. Receiver blocking may account for the much larger part of total burst blocking. *Receiver blocking* has been largely ignored in existing research. In this paper we propose using multiple receivers or fiber delay lines (FDL) in front of the receivers in order to reduce the receiver blocking probability. Extensive simulation results on bi-directional OBS rings are presented to illustrate the problem and the performance of our proposed approaches.

The results indicate that receiver blocking can be almost eliminated by using as little as three receivers and can be reduced by using FDLs of small length. To our knowledge, this is the first performance study that covers both channel and receiver blocking for OBS networks.

1 Introduction

As a promising candidate for next-generation IP-over-WDM networks, optical burst switching (OBS), a technology bridging between optical circuit-switching and pure optical packet switching, has been extensively studied [1]. A burst, the transmission unit in an OBS network, is constructed at the edge node by assembling several data packets together. A data burst (DB) transmission in the optical domain is always preceded by a burst control header packet (BCHP), which is electronically processed at each hop along the route in order to set up the lightpath for the actual DB transmission. The time between the DB and the BCHP transmissions is usually called *offset*.

Design options that affect the performance of an OBS network are: *a)* Burst assembly process (burstification); *b)* Channel scheduling mechanism with limited number of wavelengths per link; *c)* Offset time calculation; *d)* Routing, wavelength assignment and switch output port contention resolution; *e)* Tunable receiver reservation mechanism.

Most burstification algorithms are based on two thresholds: *Time threshold* and *Size threshold*. For the time-threshold based algorithm, a burst is created and transmitted at periodic time intervals and the burst size varies; the size-threshold based algorithm puts a bound on the size of a burst to be transmitted. These two thresholds can be combined together and the burst duration is decided by the first parameter that reaches the threshold given the burst time threshold T , the minimum burst size B_{min} and the maximum burst size B_{max} [2].

The majority of previous OBS studies have been focused on different scheduling algorithms in the burst layer with different *offset* time computation schemes to make better use of the bandwidth. These schemes include: *a)* Immediate Reservation (Just-in-time, JIT) [3]; *b)* Delayed reservation without void filling (Horizon) [4]; *c)* Delayed reservation with void filling (JET) [5]. In order to reduce the lightpath setup time and therefore increase the resource utilization, the above schemes use a one-way reservation scheme without acknowledgment of successful lightpath setup before the DB transmission. As a result, without special treatment, OBS is expected to have relatively high burst loss probability due to contention at the OBS switch ports, comparing to a two-way resource reservation scheme. A general comparison of the JIT, JET and Horizon protocols can be found in [6]. Various techniques to reduce the burst contention have been studied to reduce the burst contention, including wavelength conversion, deflection routing, fiber delay lines (FDL) used as buffers, or a combination [7].

Some scheduling schemes have also been shown effective to reduce the burst contention. Reference [8] improves the delayed reservation scheme by assigning a burst to the available channel in the order of burst arrival, rather than in the order of BHP's. In [9], a DiffServ-based burst-scheduling algorithm is proposed to control the offset time by the BHP arrival time and the service classes. Reference [10] studied a centralized Earliest-Deadline-First (EDF) scheduling algorithm for wavelength-routed OBS networks [11] with traffic of different classes of service (CoS).

All above schemes can be regarded as channel scheduling mechanisms, in which the limited number of wavelengths per fiber and the OBS switch output port contention are considered the causes of burst losses. However, they all ignored the receiver blocking by implicitly assuming unlimited receivers with ideal tunability at the destination nodes. The optical burst receiver, especially the tunable receiver would be one of the most expensive components in an OBS network, not to say that the fast tunable receivers are still under lab investigation. So it is not possible to deploy as many receivers as the number of available wavelengths. If there is only one fast tunable receiver at an OBS node, bursts from different

sources may arrive at the same time or within the receiver tuning period. In this case all bursts, but the one being served, would be dropped until the receiver is released and tuned to receive another burst. In this paper, we will show that the *receiver blocking* may account for the larger part of the total burst blocking.

Reference [12] proposed several access scheduling protocols for OBS rings and studied the burst blocking, end-to-end delay, and fairness issues. The ring is an uni-directional ring and the OBS node is equipped with a transmitter fixed to a unique home wavelength and the receiver is tunable. Therefore, there is no channel blocking, but only receiver blocking. A token-based scheme is showed as having zero blocking probability but long delay. All other schemes result in pretty high blocking probability. The assumptions are that the total number of wavelengths is at least equal to the number of OBS nodes and the tunable receiver are fast.

In this paper, we propose using a small number of tunable receivers or small fiber delay lines (FDLs) at the destination node to achieve better overall blocking performance. We also propose a simple burst receiving scheduling scheme by making efficient use of the FDLs. To quantify our findings and solution approach, extensive simulation studies were conducted on general OBS bi-directional rings. We believe that the conclusions are valid to other more general network topologies.

The paper is organized as follows. The OBS ring model, signalling protocol, and a general analysis are described in Section 2. The simulation study is presented in Section 3. Section 4 concludes the paper.

2 Network model and analysis

2.1 Network Model and Protocols

We consider a ring made up of N nodes. Two consecutive nodes are connected by a dual-fiber link, each of the two fibers supports $m + 1$ wavelengths. From the $m + 1$ wavelengths, one is reserved for the control channel and other m wavelengths are used for the data transmission channels. Each of the OBS nodes is a hub to one or more access networks and is equipped with two sets of packet burstification buffers, Optical Add/Drop Multiplexers (OADM), a pair of fast tunable transmitters and receivers, and a possible small FDL, one for each ring direction. The first pair of transmitter and receiver is permanently tuned to the control channel. There are one tunable transmitter per node per direction for burst data transmission and at least one tunable receiver per node per direction for burst data. At an OBS node, the OADM will drop the control wavelength to the control receiver and burst data wavelengths destined to this node to the data receiver(s). However, only those bursts whose BHP's reserved the receiver will be received, all other bursts will be either dropped or passed to the FDL. The length of the FDL is limited, i.e., if a burst

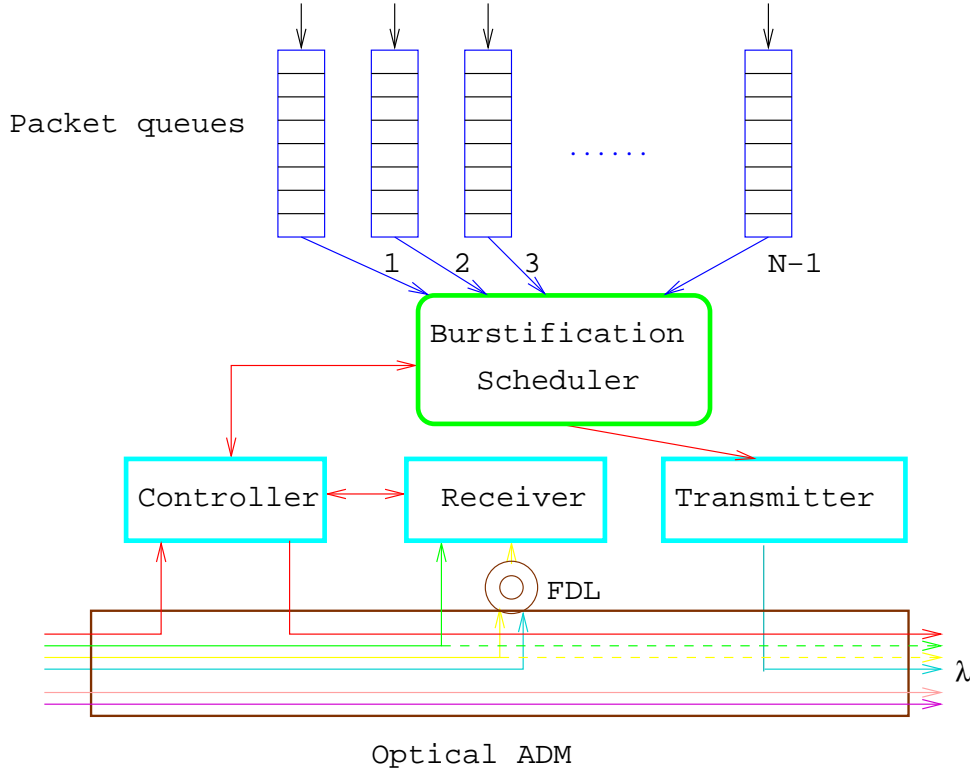


Figure 1: Node architecture of the OBS ring

traverses the FDL and can not find the available receiver at the end, it will be dropped. Since there is only one fiber per direction entering each node, we only consider one FDL per node per direction. The FDL can provide buffers for all the wavelengths with fixed delay. The architecture of an OBS node for one direction of the ring is depicted in Figure 1. The IP packets are first stored into $N - 1$ destination buffers before they are aggregated into bursts. The control wavelength is always dropped for processing. Additional wavelengths maybe dropped, depending on the number of receivers. Also, note that if the receivers are busy then the bursts may be delayed in the FDL. Each node has one tunable transmitter per ring direction.

We adopt the following design options for the OBS network under study for their good performance promise and their simplicity of implementation.

- *Burstification and traffic model:* We assume a size-threshold based burstification process for every OBS node. Thus, a burst can be of any size between a predefined minimum value B_{min} and maximum value B_{max} . Each node maintains $N - 1$ packet queues, one per OBS destination node. A simple first-fit burst transmission scheduling scheme is used, i.e., the first among the $N - 1$ burstification queues that exceeds B_{min} will generate a burst and a BCHP.

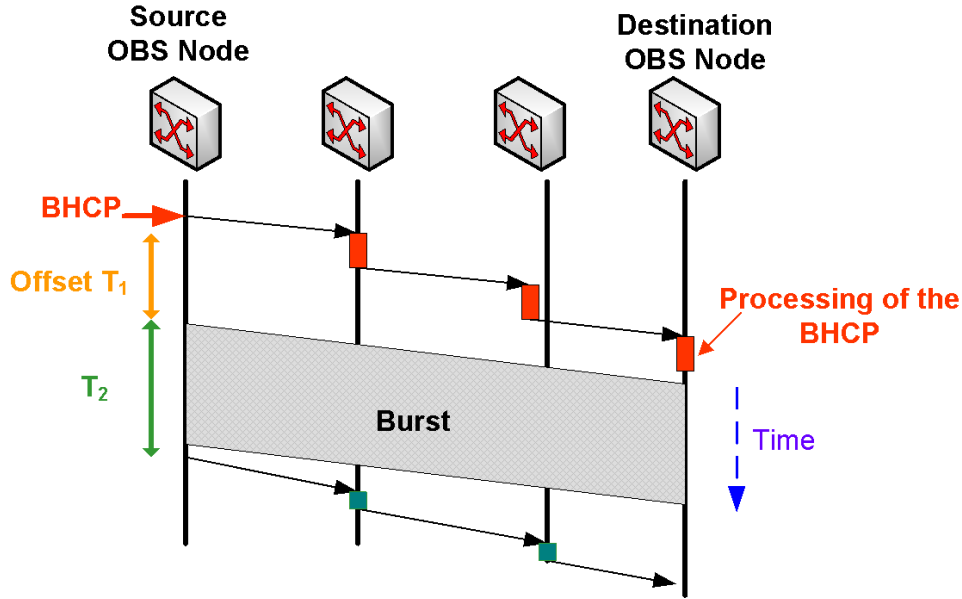


Figure 2: JIT Protocol

The burst arrival process and burst size distribution are decided by the IP packet arrival process, packet size distribution, and the burstification algorithm. Most previous performance studies have assumed that the burst arrivals can be modeled with a Poisson process [13]. Others have used a more realistic but complex burst arrival model, *e.g.*, a self-similar stochastic process, which degrades the overall network performance [14]. To simplify our analytical study, we assume that the IP packets arrive as a Poisson process, their packet size follows an exponential distribution, and their destination is chosen based on a uniform distribution. [15] showed that short-range correlation will be shaped away by a threshold-based burstification process, so we can assume the Poisson burst arrival process and exponential burst size distribution in our analytical model. This assumption is also justified by the findings in [16] that the burst blocking probability does not depend on the burst size distribution.

- *Routing and wavelength assignment:* Since we study bi-directional rings, there will be two routes for each connection request. We choose the shortest path as the route. There are several dynamic wavelength assignment algorithms, such as first-fit, random-fit, and least-used-first. We choose the random-fit algorithm since it is simple and our simulation results showed that it is at least not worse than the other mechanisms. With this algorithm, the transmission node will choose a random wavelength from the wavelengths that are still available in its output fiber.
- *Just-In-Time (JIT) protocol:* JIT is a simple protocol with competitive performance to JET [17] and Horizon [4]. As shown in Figure 2 in JIT, when a burst is generated, a BHCP is immediately

transmitted on the control channel. At each hop of the route, the BCHP chooses an available wavelength (a random one in this study) and a route (the shortest path in this study) and tries to reserve the wavelength (and the receiver) along the route immediately. This differs from *JET* and *Horizon* where the wavelength reservation would be delayed until the burst data arrival. In JIT, after an offset time period T_1 , the burst is transmitted along the route on the wavelength chosen by its BCHP without waiting for an acknowledgment of successful reservation. After another time period T_2 , a release control packet will be sent out on the control channel to release the wavelength (and the receiver) along the route. The detailed JIT signaling protocol can be found in [18].

2.2 Receiver Scheduling and Network Performance Analysis

In this section, we use analytical models to obtain some fundamental insights to our problem. For this, it is sufficient to consider just one direction in the bi-directional ring.

As mentioned previously, a burst will be blocked due to *channel blocking* or *receiver blocking*. We assume large enough electrical burstification buffers and therefore the packet losses due to buffer overflow can be ignored. Solutions for reducing channel blocking would be to add more wavelengths or more efficient burst transmission scheduling algorithms. In this paper, we focus on the receiver blocking case. We propose increasing the number of receivers or providing FDL buffers at the destination node to decrease the blocking. Generally, the bursts will be received by the receiver(s) in the same sequence as their BCHP arrival time at the destination. If we are allowed to use FDL's, we can rearrange the sequence of burst reception according to the burst arrival time instead of the BCHP arrival time. Intuitively, this scheduling algorithm will improve the receiver utilization and therefore reduce the burst blocking probability. We call this algorithm the *Earliest Arrival Burst First* (EABF) algorithm. This scheduling is possible because the BCHP knows everything about its associated data burst, including its route and the arriving time at the receiver.

Burst Blocking with multiple wavelengths and multiple receivers

In this section, we assume no FDLs at the switches and the destination nodes.

First, we look at the channel blocking case. Any OBS link with m wavelengths can be modelled as an $M/M/m/m$ loss queue. If we assume that the burst arrivals at a link follow a Poisson process with arrival rate λ and the burst size follows an exponential distribution with rate μ . The burst channel blocking can be described by the *Erlang's loss formula* as follow ($\rho = \lambda/\mu$).

$$p_m = \frac{(\rho^m)/(m!)}{\sum_{k=0}^m \rho^k/(k!)} \quad (1)$$

This blocking probability can be reduced almost exponentially with the increment of the number of servers, that is, the number of wavelengths.

For the receiver blocking case, let's suppose that we have K receivers, where $K < m$. Assume the burst arrival at a source node follows Poisson process with rate λ_b and at most $\lceil (N-1)/2 \rceil$ sources will send $1/(N-1)$ of all their bursts to a certain destination i , due to the assumption of uniform destination distribution. A burst will encounter channel blocking on each link along its route with blocking probability p_m . The average number of hops of all shortest path in the bi-directional ring is $l = \lceil (N-1)/4 \rceil$. Therefore the average burst arrival rate at a destination node can be approximated as:

$$\lambda_r = \frac{\lambda_b}{2}(1 - p_m)^l \quad (2)$$

A more accurate approximation can be obtained through a reduced load Erlang loss model [13].

Given the state of the technology, the receiver tuning time, say γ , is not ignorable. Therefore the average receiving time would be $\frac{1}{\mu_r} = \frac{1}{\mu} + \gamma$. Again we can describe the receiver blocking using an $M/M/K/K$ loss queue and the receiver blocking probability p_r will follow the *Erlang's loss formula* described by the expression (1) with $\lambda = \lambda_r$, $\mu = \mu_r$, and $m = K$. The blocking probability will be reduced almost exponentially with the incremental number of servers, *i.e.*, the receivers in this case.

So it is possible to use a small number of receivers to achieve good receiver blocking performance. Of course, reducing the average service time by reducing the tuning time γ will reduce the blocking probability too. However the possible tuning time reduction is limited and very costly. Therefore, we set γ as a constant in the remainder of this study.

Blocking probability with FDL

Even though using multiple receivers may reduce the receiver blocking probability, we hope to find alternative ways because fast tunable receivers are very expensive. Therefore, we consider to use of FDL as the optical burst buffer to improve the receiver blocking. A burst will go to the FDL instead of being dropped if the receiver is not ready when it arrives at the destination. Previous related theoretical studies focused on the use of FDLs at the OBS switches as conventional buffers to resolve the burst contention. Their drawback is that they usually did not consider that the delay provided by a FDL is limited and fixed. Reference [19] took the fixed delay limit into consideration and modelled the output port of an OBS switch with FDL's as an $M/M/m$ queue with balking. In this model, an FDL can provide ideal delay

for a burst from 0 to at most B time units. A burst will be blocked if there is no available FDL or the maximum delay time B is not enough. The Latest Available Unscheduled Channel (LAUC) scheduling was used. This $M/M/m$ queue with balking model is also suitable for the analysis of the OBS receiver with FDL. We can see, with a receiver as the server and a FDL per receiver with maximum delay B , the proposed Earliest Arrival Burst First (EABF) scheduling algorithm is equivalent to the LAUC model. A burst arriving at its destination would be lost if it could not be assigned the receiver within time B . Therefore the receiver blocking probability p_f with FDL can be calculated by:

$$p_f = \text{BALK}(1, \rho_r, 1, B) \quad (3)$$

where $\rho_r = \lambda_r / \mu_r$. The detailed expression can be found in [19].

The main observation made from their analytical computation and simulation results is that longer FDL (larger B) leads to smaller blocking probability. However they assumed an ideal arbitrary delay time between 0 and B for a burst entering the FDL, i.e., the burst will get out of the FDL as soon as its BHP grabs the receiver. In the reality, a burst could not get out of the FDL until it has travelled the whole FDL. In this case, too long delay time in the FDL may increase the blocking probability as the receiver holding time by the BHP for a burst may increase.

It is possible to use multiple FDL's with variable discrete lengths but that requires complicated scheduling algorithm. We do not consider this scenario in this paper.

End-to-end IP packet delay

From the point of view of IP packets, the end-to-end delay D incorporates three parts: the burstification delay D_b , the burst offset T_1 , and the burst transmission delay D_t .

$$D = D_b + T_1 + D_t \quad (4)$$

For JIT, T_1 is decided by the BHP processing, switch setup and receiver tuning time along the route. When the switching time, receiver tuning time and BHP processing time at each node are fixed, T_1 only depends on the number of hops along the route of the burst.

Because of the nature of the size-threshold based burstification algorithm with B_{min} and B_{max} , D_b depends on the packet assembling time when the burst size reaches B_{min} . The larger B_{min} is, the more burstification time and therefore the larger packet delay would be. Obviously D_b will also depend on the packet arrival rate λ_p and average packet size μ_p . The larger λ_p and μ_p are, the faster B_{min} will be reached and therefore the less the average packet delay would be. D_t depends on the line transmission

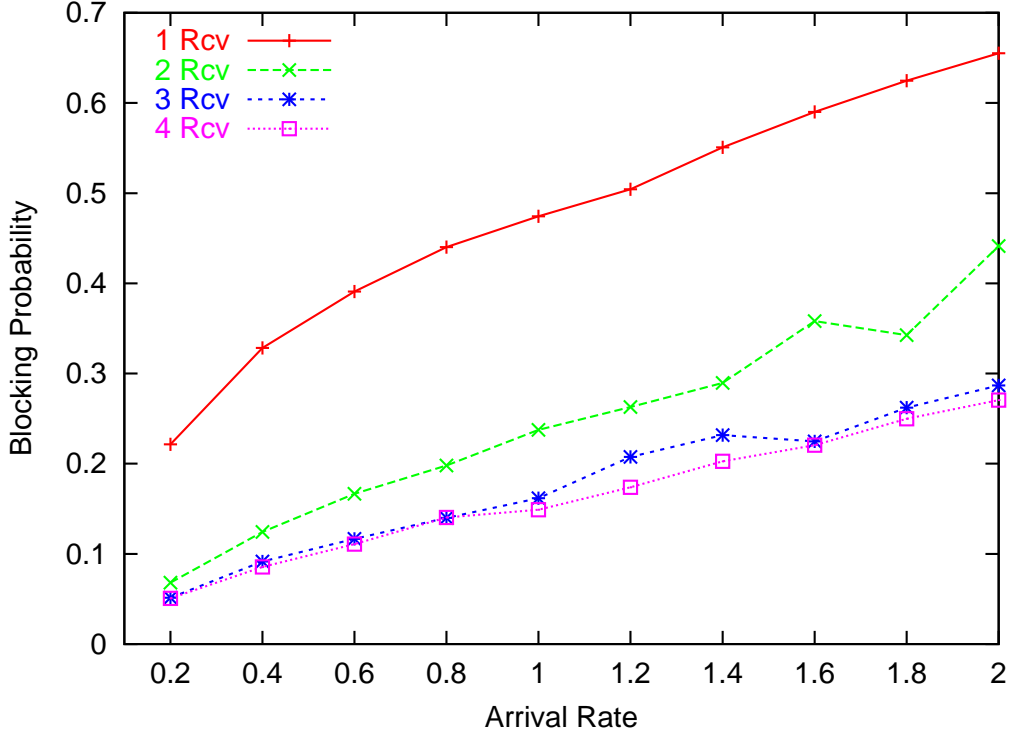


Figure 3: Burst blocking probability vs. Packet arrival rate, 16-node ring

speed.

3 Simulation study

To justify the performance of our proposed approaches, we conducted comprehensive simulation studies on bi-directional OBS rings of variable number of nodes.

In the simulation, we used time unit instead of actual time. We also defined the following parameters and their values in time units: *a*) IP packet average size: 1; *b*) Minimum burst size (B_{min}): 32; *c*) Maximum burst size (B_{max}): 200; *d*) Number of wavelengths per link: 12 + 1; *e*) BChP transmission plus processing time per hop: 5; *f*) Data burst transmission delay per hop: 1; *g*) Receiver tuning time: 2.

We varied the following parameters to see their affects on the network performance: *a*) Packet Arrival rate (λ_p): 0.2 ~ 2.0; *b*) Number of burst receivers per node per direction: $K = 1, 2, 3, 4$; *c*) Length of FDL: $n * B_{min}$, $n = 1, 2, 3, 4$.

Note, that in the simulation we model the IP arrivals with a Poisson process. The burst arrival process is depends on the EABF burstification algorithm. In other words, as an IP packet buffer reaches a B_{min} ,

the BHCP is created and sent to the destination.

Figure 3 shows the average burst blocking probability p plotted as a function of packet arrival rate λ_p and the number of receivers for a 16-node OBS ring. As expected, p increases as λ_p increases because more traffic will make the network more congested. We also observe that the impact of number of receivers on p is significant. As K increases to two, p is almost reduced in half. However, after K increases to three, p does not decrease by a lot. This is because the receiver blocking probability has almost reached to 0 for more than three receivers and therefore has little effect to the overall blocking probability.

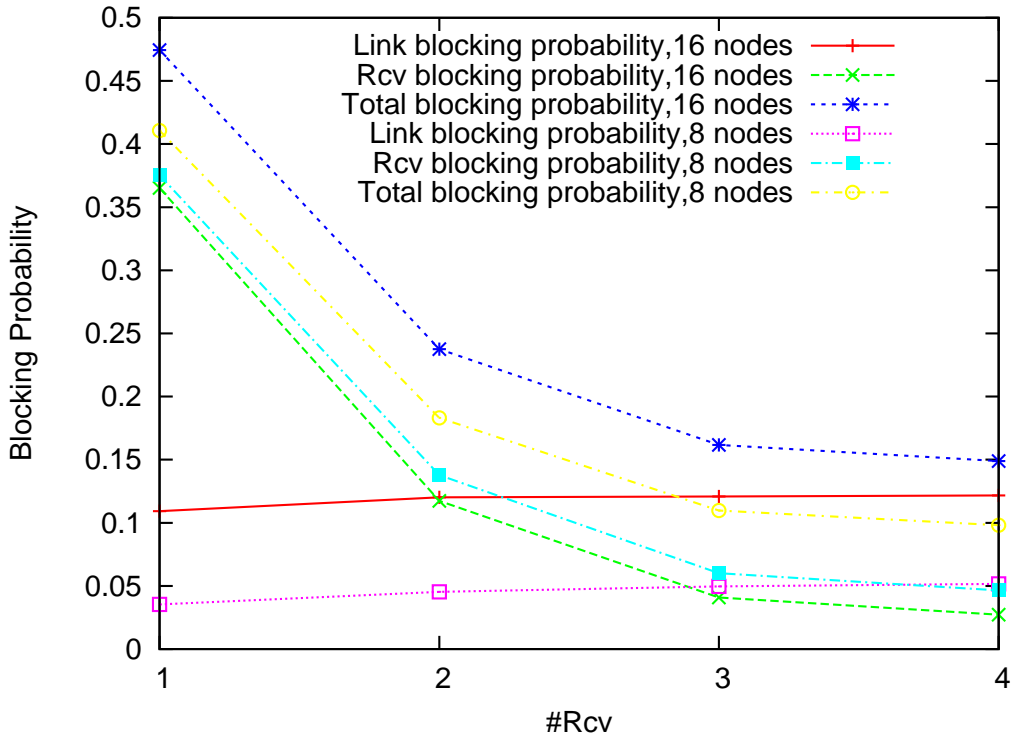


Figure 4: Burst blocking probability vs. Number of receivers

This observation is showed more clearly in Figure 4 for both 8-node and 16-node rings (the packet arrival rate is set to 1). The x-axis represents the number of receivers and the y-axis represents the value of three types of burst blocking probability: the overall blocking probability p , the part of p due to receiver blocking p_r , and the part of p due to the channel blocking p_m . We observe that p_m almost keeps constant for various K , but p_r almost reaches to 0 when $K = 3$. This result shows that a small number of receivers would be sufficient to get better receiver blocking performance. When $K = 1$, we also observe that the receiver blocking probability p_r counts for about 75% and 90% of the total burst blocking probability p for the 16-node and 8-node network, respectively. Therefore, it is much more meaningful to reduce the receiver blocking probability to improve the overall burst blocking performance. Results

for both 8-node and 16-node rings are presented to show that larger rings usually have larger blocking probability under the same traffic load from each node.

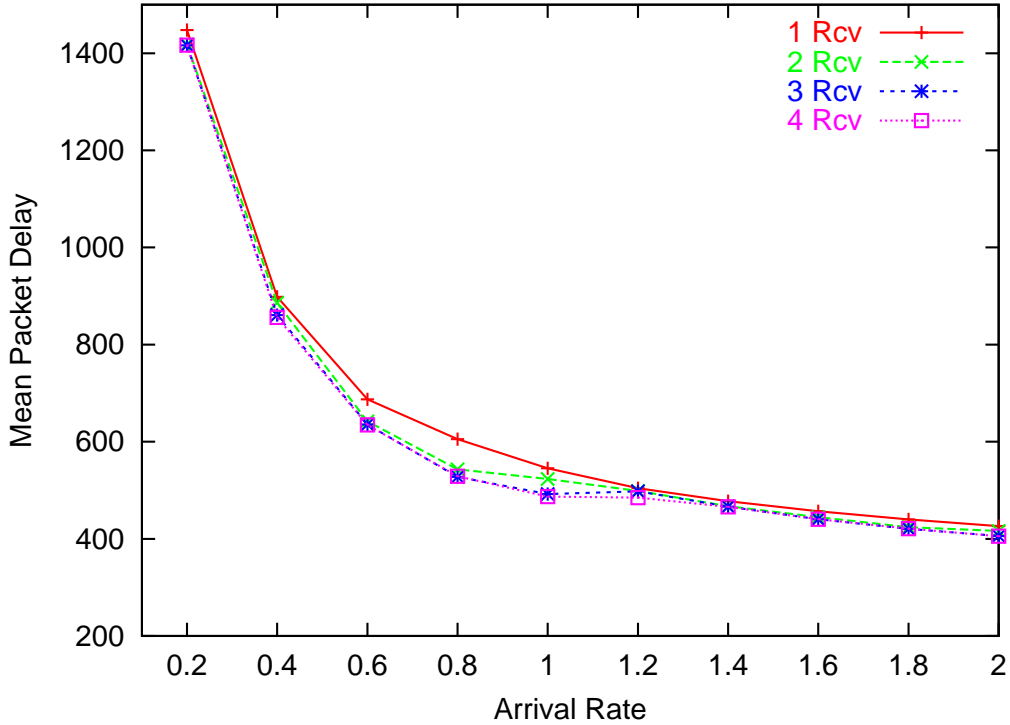


Figure 5: Average packet delay vs. packet arrival rate, 16 nodes

We also plotted the average end-to-end IP packet delay vs. the packet arrival rate λ_p under different number of receivers in Figure 5. Since the burstification delay decreases with the increment of packet arrival rate λ_p , the average packet delay will decrease with λ_p . We also observe that multiple receivers will increase the network throughput, and therefore reduce the average packet delay. However, this improvement is very limited.

Figures 6 and 7 depict the average burst blocking probability p and average packet delay vs. packet arrival rate λ_p when adding an FDL with different length for the same 16-node and 8-node OBS rings. By n FDL, we mean that the FDL length is $n * B_{min}$. Again, p will increase as λ_p increases. With the increment of the FDL length, p decreases first, but then increase after $n > 2$.

This phenomenon can be observed more clearly in Figure 8 as the three types of blocking probability are plotted as a function of the FDL length when λ_p is set to 1. We observe that the overall burst blocking probability p and the receiver blocking probability p_r hit their minimum when B is two times longer than the minimum burst size. This result is interesting since we can use FDL of small length to obtain the best performance. The average packet delay will change slightly with the blocking probability

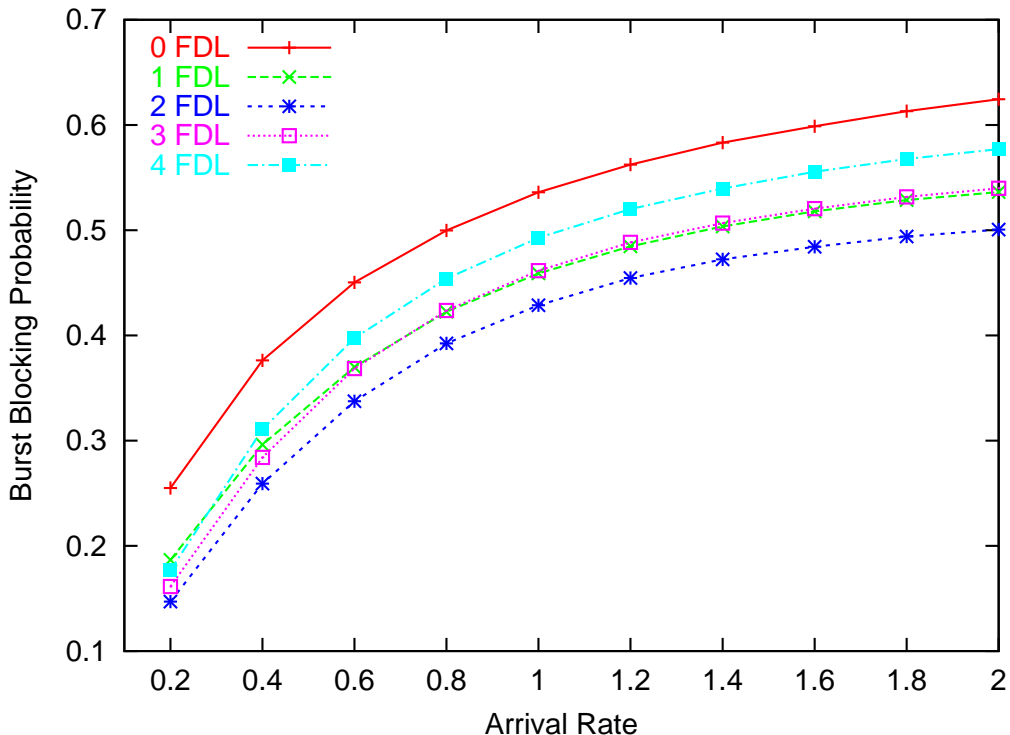


Figure 6: Burst blocking probability vs. packet arrival rate, 16 nodes

as smaller blocking may result better network throughput.

A comparison between Figure 4 and Figure 8 clearly showed that using a small number of receivers (2 ~ 3) is more efficient than adding FDLs. The comparison is showed in Figure 9 for the 16-node ring when the packet arrival rate is set to 1. While using three receivers almost eliminates the receiver blocking, using FDL can only reduce about 30% of the receiver blocking at best.

4 Concluding Remarks

In this paper, we first identify that a burst could be blocked in two cases: when the required wavelength is not available on a link along its route (*channel blocking*), or when the receiver at its destination node is occupied by another burst (*receiver blocking*). And the *receiver blocking*, which has been largely ignored by previous studies, may actually account for the much larger part of the total burst blocking. We then proposed two approaches to reduce the burst receiver blocking probability. Through analytical analysis and simulation study on OBS rings, we found that using a small number of receivers (2 or 3) would dramatically reduce the burst blocking probability. We also proposed to use an Earliest Arrival Burst First (EABF) scheduling algorithm on the receiving side with an optical buffer, FDL to improve the

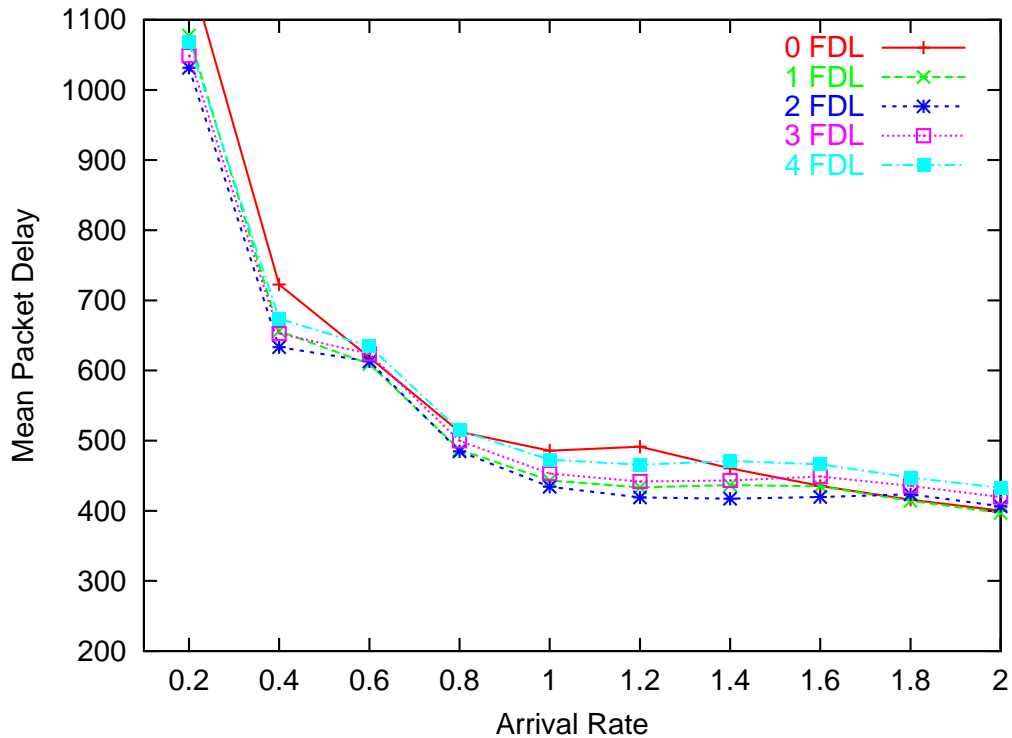


Figure 7: Average packet delay vs. packet arrival rate, 16 nodes

blocking performance. The results showed that using the FDL is useful, though not as efficient as using more receivers and more efficient scheduling algorithms are needed to make more efficient use of FDL's. Within our knowledge, this is the first performance study that covers both channel and receiver blocking for OBS networks.

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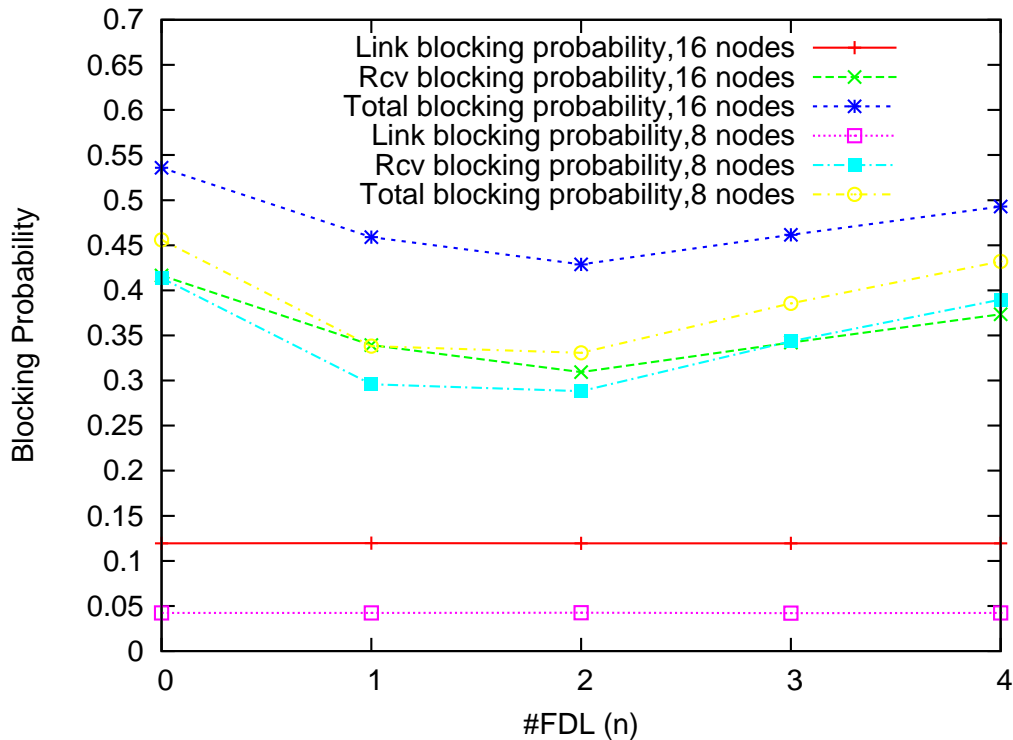


Figure 8: Burst blocking probability vs. the length of the FDL

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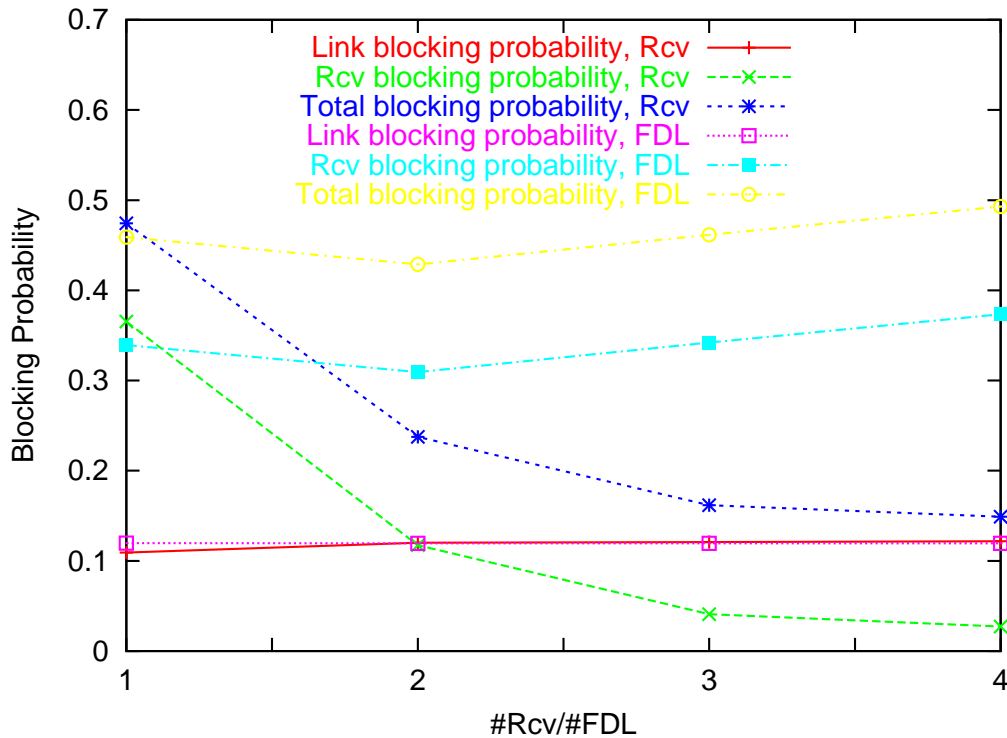


Figure 9: Burst blocking probability vs. #receivers/Length of FDL, 16 nodes

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