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Time Delay Analysis in Wavelength Router Optical Burst Switching (WR-OBS) Networks

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Summary

The concept of wavelength router optical burst switching (WR-OBS) aims to allow the access of the bandwidth without using wavelength for routing, instead, it provides guaranteed delivery of optical data bursts to the destination. However, there are some inherent "wasting" times at edge router which influence negatively on some delay sensitive applications. This paper presents a comprehensive analytical study for all significant latency aspects. It can be considered as a guide line to network designer to make the required optimization. The main latency sources are investigated through two different network sizes.

1 Introduction

Next generation all-optical networks require protocol, bit-rate, and efficient network design for format transparency to achieve efficient routing of data packets to their appropriate destination. Recently, optical burst switching (OBS) networks bas emerged as a promising paradigm to deal with the exponential growth rate of Internet Protocol (IP) traffic volume [1, 2]. However, there are still several issues remained to be overcome, such as high burst loss rates at high traffic loads, and quality of services (QoS) mechanisms [3]. To overcome these problems, a wavelength-router OBS (WR-OBS) was emerged [4]. In WR-OBS, the wavelengths are not used for routing, instead they are used to provide point-to-point connections. The highlight features of WR-OBS are the acknowledged wavelength reservation with guaranteed latencies. However, reserving a free channel and waiting to receive an acknowledgment need some time because the packets must stay at edge router. Waiting for "long" time may be not accepted by some delay-sensitive applications like video conference services, for example. As a result, this paper is aimed to study influence of delay sources on the performance of WR-OBS. We analyze the main characteristics of latency through investigating two different network sizes. We give an analysis to the most significant time parameters through illustrating two methods to aggregate the bursts. Delay at edge router is the key parameter for design any edge router, so it has received much attention in this paper. The remainder of this paper is organized as follows: Section II includes a description for WR-OBS model, and then we turn to focus on the two methods of burst aggregation process in Sec. III, where the analysis is separated into two parts. The first studies the Limited-Size Bursts (LS-Bs) method. The second part describes the not Limited-Size Bursts (NS-Bs) methods. A detailed analysis for burst blocking probability with delay at edge router is given in Sec. IV. Section V presents our simulation results and discussions, and finally a summarization is drawn in Sec. VI.

2 The model

2.1 Network edge router architecture

Figure 1 shows schematically the edge router set up which is considered in this work. Packets received from several sources are firstly presorted according to their destination and class of services (CoS) and sorted in separate queues. Each type of these sorted packets is then aggregated to form a burst. Length of these bursts is specified in one of the two designable methods [5]: Limited-Size Burst (LS-Bs) or not Limited-Size Bursts (NS-Bs). A wavelength request is sent to a control node after a time-out signal indicates that packets have to be transmitted to meet application specific latency requirements. Then, control node sends an acknowledgment and the bursts are dynamically assigned to free wavelength. In case of no free wavelength channel available, the packets do not discarded and, instead, are stored in the buffers of edge router. However, store in buffer could be subject to additional delay.

A uniform destination address distribution is assumed throughout this paper. Therefore, the electronic switch provides statistical multiplexing. Unlike the conventional IP router architecture, packets are forwarded to buffer queues within the edge router. Recently, random access

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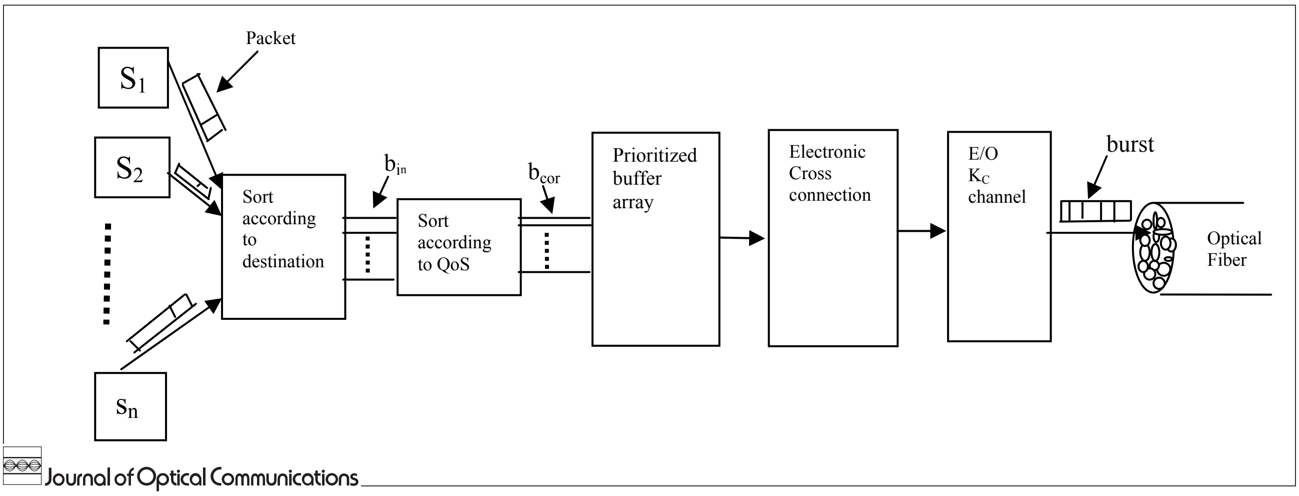

Fig. 1: Edge router diagram

memory (RAM) is used to provide sufficient buffering of 107.4 ms or 214.7 ms for 128 MB or 256 MB, respectively, for traffic at bit rate 10 Gbit/s. For nondelay-sensitive traffic, such as data, there is an advantage of large buffer in this architecture; packets are held in the buffer until a free wavelength is available, instead of released into the network to be lost on propagation.

2.2 Timing and burst aggregation

The edge delay, t_{edge}, is quite significant factor in the performance of routers. t_{edge} represents the elapsed time between the time of the arrival of the first bit of the first packet and the buffer queue until the entire burst is released into the network, $t_{edge} = L_{burst}/b_{in}$. It depends on the burst size, L_{burst}, and the input bit-rate to the buffer, b_{in}. The wavelength holding time, which is the time necessary to empty the buffer and transmit the data between edge routers, is:

$$t_{WHT} = t_{RTT} + \frac{L_{burst}}{b_{core}} = t_{RTT} + \frac{t_{edge}}{A}$$

where $A = b_{core}/b_{in}$ is the bit rate ratio between the core network, bcore, and b_{in}. The round-trip time, t_{RIT}, is the time required for the lightpath to setup. This period equals to the time required to propagate across the network, i.e. $t_{RIT} = t_{prop,ack} + t_{prop,net}$ where $t_{prop,net}$ is the time delay for the first bit to arrive at the destination edge router, and $t_{prop,ack}$is the propagation time required to receive the acknowledgement from the destination.

3 Analysis of flow aggregation

To design a fast transmission network, as demand by many applications, all types of latencies should be investigated carefully. Many efforts [5, 6] have been conducted to analyze some characteristics of delays. The edge delay is the key parameter to determine the end-to-end delay. It is determined by the arriving packet statistics and the mechanism of burst aggregation used. There are two methods for the burst aggregation that have a different effect on the edge delay. These two methods are as follows:

3.1. The limited-size bursts (LS-Bs) method

This method based on the concept that the arrival of the acknowledgment to the edge router determines the end the aggregation process of the packets into a burst. As a result, the new packets arriving during the burst is transmitting are not aggregated into this burst, but must wait for another lightpath to set up for their transmission within a new burst. Thus, when the lightpath is deleted there may be some data in the buffer. That could be a challenge to some applications adapting this method. The delay at edge router, t_{edge}, depends on the network traffic load, υ, as well as the round-trip time, t_{RIT} as:

$$t_{edge} = \frac{t_{idle} + t_{RTT}}{1 - \nu} .$$

In addition, the edge delay depends on the lightpath load (Ψ), which is the average number of lightpaths established in the network, through: $t_{edge} = t_{WHI}T/\Psi$ Under the assumption of zero blocking probability, we can formulate the time delay with number of routers, N, as follows:

$$t_{edge} = t_{WHT} \Bigg/ \left\{ \frac{1}{N(N-1)} \left(\frac{t_{WHT}}{t_C} \right) \left[\frac{\sum_{i=0}^{N(N-1)-1} \frac{\left(t_{WHT}/t_C \right)^{i}}{i!}}{\sum_{i=0}^{N(N-1)} \frac{\left(t_{WHT}/t_C \right)^{ii}}{i!}} \right] \right\}$$

where t_c is the processing delay at the control node. Minimization of $t_c$can be achieved by applying fast dynamic routing and wavelength assignment algorithms processing delay in the control node. And, the maximum network traffic load is: $\nu_{max} = \Psi_l - t_{RIT}/t_{edge}$, where Ψ_l represents the limiting average normalized lightpath load. It means the values of Ψ for which the wavelength gain is equal to one.

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3.2. The not-limited size bursts (NS-Bs) methods

This method overcomes the sort of limitations in the LS-Bs method that the lightpath is only deleted when the buffer is completely empty. Unlike the LS-Bs, in NS-Bs the new data arriving at the buffer after receiving the acknowledgment are considered as a part of the current burst. The lightpath is only deleted when the buffer is completely empty. In this scenario, control node can not estimate the rate and the length of burst size. However, the average edge delay depends on the propagation time to the control node $t_{prop,ctrl}$ and average normalized of linghtpaths in addition to the wavelength holding time as: $t_{edge} = (t_{WHT}/\Psi) - t_{WHT} + 2t_{prop,ctrl}$. Then, the maximum network traffic load in this method is:

$$\upsilon_{max} = \Psi_1 - \left(\frac{E\left[t_{RTT}\right]}{E\left[t_{dege}\right] - E\left[t_{RTT}\right]} \right) \left(1 - \Psi_1\right),$$

where $E[t_{edge}]$ and $E[t_{RIT}]$ are the average values of edge delays and round trip time, respectively.

4 Analysis of burst blocking probability

After the packets arrive at the buffer and wait for t_{wait}[1], a control packet is sent to reserve one of available channels for the burst currently being assembled. If it successes to reserve a channel, then after the round trip propagation delay the burst is sent through the channel. As we noted in Sec. 3, each packet subject to one or more of the delays; assembly delay, queuing delay, and transmission delay. If there are two or more requests to reserve a specific free channel one of these requests is accepted and the others are discarded. Hence, the burst blocking probability is:

$$P_{b,burst} = 1 - \frac{\sum_{j=0}^{N_C} j\gamma_j}{Q \sum_{j=0}^{N_C} \left(N_b - j\right)\gamma_j}$$

where:

$$Q = \frac{2t_{RTT} + t_b}{t_{p,int\,v} - t_{wait}}$$

Here, t_b represents the busy period which is also depends on the mean packet length, t_{Pckt} and the mean packet interarrival, $t_{p,intv}$, as:

$$t_b = t_{pckt} + \left(t_{pckt}/t_{p,int\,v}\right)\left(t_{wait} + 2t_{RTT}\right)$$

and γ_j is:

$$\gamma_j = \frac{Q^j}{\left(N_b - j\right)! \sum_{q=0}^{N_C} \frac{Q^q}{q!\left(N_b - q\right)!}}.$$

1 Note that t_{wait} is different from t_{edge}, which represents the maximum total latency (delay) a packet can withstand to satisfy QoS requirements.

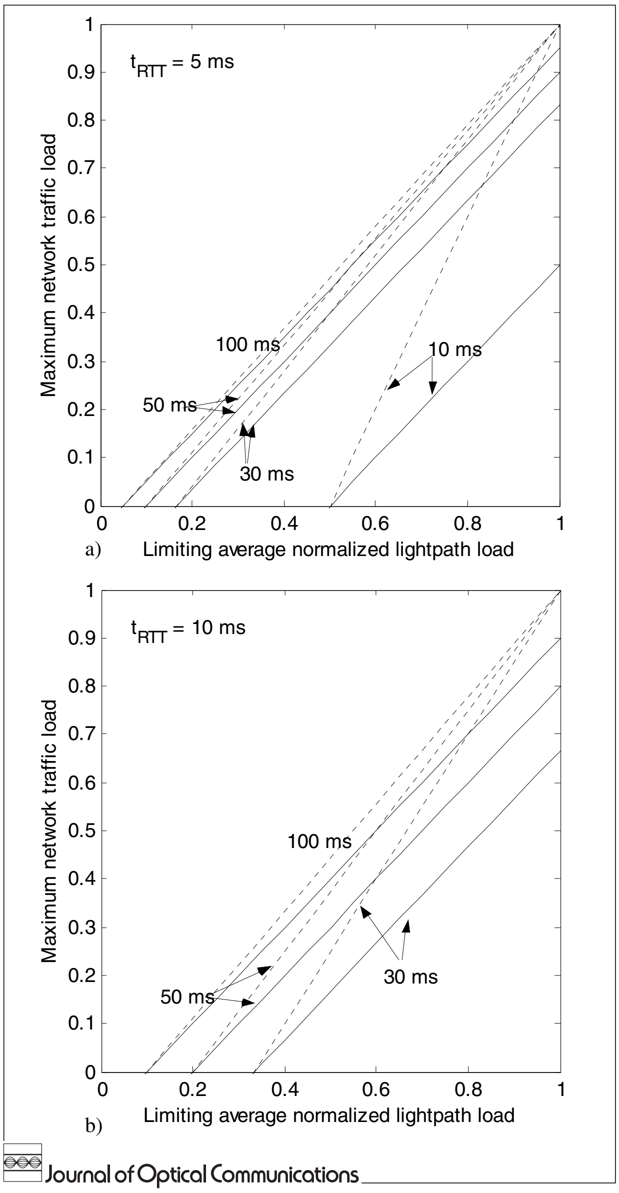

Fig. 2: Maximum network traffic load as a function of limiting average load for different average edge delays, and for round trip time = 5 ms (a) and 10 ms (b); solid lines represent the results for LS-bursts, and dashed lines those for NS-bursts

As we have seen throughout this paper that t_{edge} is a probabilistic parameter, and it is different from one edge to other. In order to control t_{edge} more precisely, Zalesky et al. [7] introduce a parameter to estimate the uncertain waiting time for packets at edge router (see [7] for more details). In section V, we will discuss influence of t_{wait} on the performance of the system.

5 Simulation results and discussions

In the simulation, we set the number of buffers $k_b = 120$ and number of wavelength channels $k_C = 80$. These values are hold throughout our calculations except results explained in Fig. 7. Also, we set the mean packet size to 400B. For simplicity, $\Psi_1 = \Psi$ and $t_{edge} = E[t_{edge}]$ are considered.

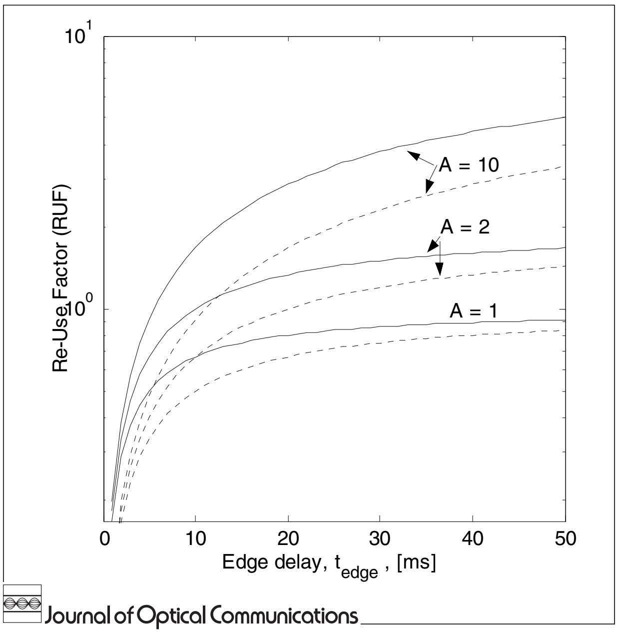

Fig. 3: Re-Use Factor (RUF) as a function of edge delay; solid lines are for t_{RTT} = 5 ms, and dashed lines are for t_{RTT} = 10 ms

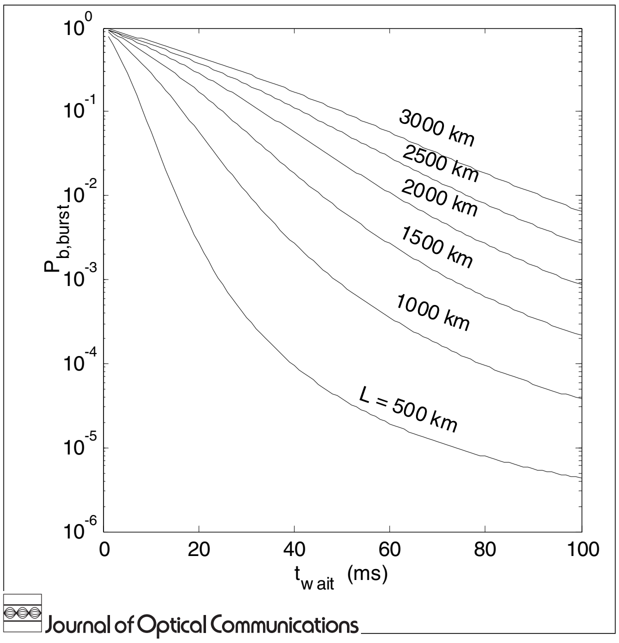

Fig. 4: Burst blocking probability $P_{b,burst}$ for different network sizes with $t_{P,intv}$ = 4 µs and $b_{in}.t_{Packet}$ = 400 B

The method used to build the burst (LS-Bursts and NS-Bursts) is illustrated in Fig. 2 a) and b). The aggregation method is important to know the maximum network traffic load that the network can support. Fig. 2 (a and b) includes a comparison between these methods for two networks diameters, 500 km and 1,000 km, respectively. Method of aggregation strongly effects on the slop of lines. In other words, network traffic load is much influenced by lightpath that can be assigned to another edge router. Thus, that leads to the increase of the wavelength reuse. This behavior can be described by a wavelength reuse factor RUF as:

$$\mathrm{RUF} = \frac{At_{edge}}{At_{RTT} + t_{edge}} .$$

Figure 3 analyses RUF as a function of delay at edge router for different values of bit rate ratios. The simulation was also performed for two different network diameters. As shown in the figure, the values RUF less than 1 occur where the total input load exceeds the network throughput. That lead to network instability and more wavelengths are required. Using core routers with high bit rates enhance to improve the network performance.

Influence of network size is directly reflected on the relationship between probability of burst blocking and waiting time, as shown in Fig. 4. More wait gives more chance to get empty channel and reduce probability of blocking.

Figure 5 illustrates the variation of burst blocking probability with different packet intervals time versus waiting time at edge router. Calculations were achieved for 1,000 km network size. It shows short packet interval should wait for more time than that for longer packets interval to get the same burst blocking probability. For example, to achieve a burst blocking probability 10^{-6} packets which have packet interarrival of 6 µs should wait for 50 ms while 32 ms, and 25 ms for packets that have interarrival 8 µs and 10 µs, respectively. The reason is that generating bursts with short packets interval need much time to create that burst, especially when first aggregation method (LS-Bursts) is used.

From Fig. 6, it can be seen that burst blocking probability is affected strongly by network load when it experienced against waiting time at edge router. The results were estimated by assuming packet length 4 µs and network size 1,000 km. Networks work with fast core router have short waiting time and extremely low burst blocking probability. For example, core router which works at 10 Gbit/s must wait 28 µs at edge router while networks with 2 Gbit/s need 63 ms.

Figure 7 illustrates influence of waiting time at edge router on the burst blocking probability when different number of buffers is used. First one, stated in Fig. 7a, uses core router works at bit rate equal to that for input into buffer unit while Fig. 7b shows behavior of network uses a core router that work on bit rate equal to ten times the bit rate at input. The difference between performances of the two networks is quite obvious. For example, to get burst blocking probability of 10^{-6} with 100 buffers, data must wait: ~61 ms and ~17 ms at edge router for the first case and the second case, respectively.

6 Summary

In this paper a comprehensive description for WR-OBS network is given. Burst aggregation in WR-OBS networks can be done by two methods: LS-Bursts and NS-Bursts. Depending on which aggregation method is used, maximum network traffic load is influenced by lightpath load. The study has done for two network sizes of 500 km and 1,000 km. The reuse factor was investigated to characterize OBS networks with dynamic wavelength assignment. Influence of data at edge router on the reuse factor was studied with different values of bit rate ratios,

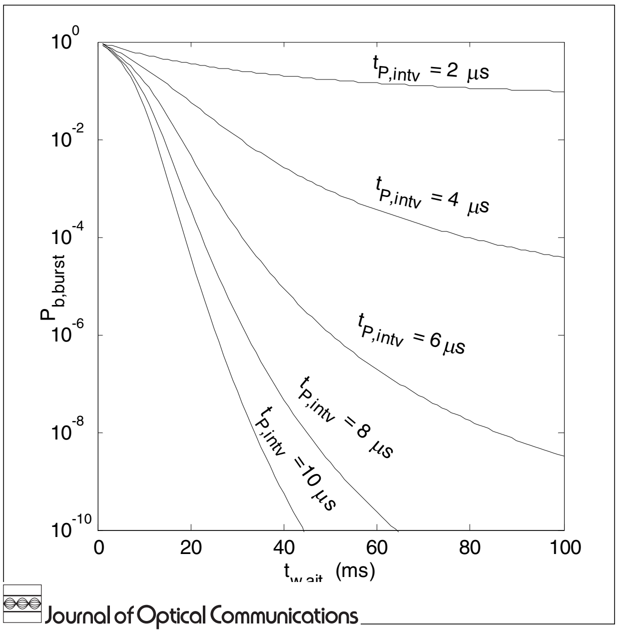

Fig. 5: Burst blocking probability $P_{b,burst}$ for t_{Packet} = 2, 4, 6, 8, 10 μs with t_{RTP} = 10 ms and $b_{in}.t_{Packet}$ = 400 B

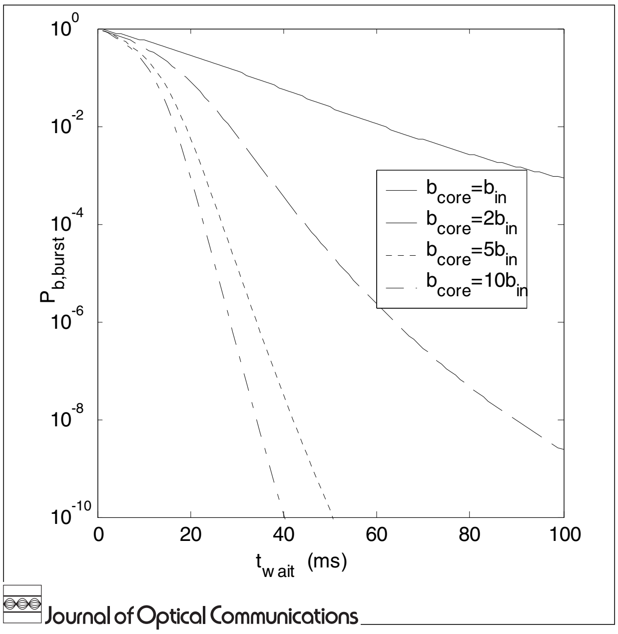

Fig. 6: Burst blocking probability $P_{b,burst}$ for t_{RTT} = 10 ms, t_{Packet} = 4 μs and $b_{in}.t_{Packet}$ = 400 B

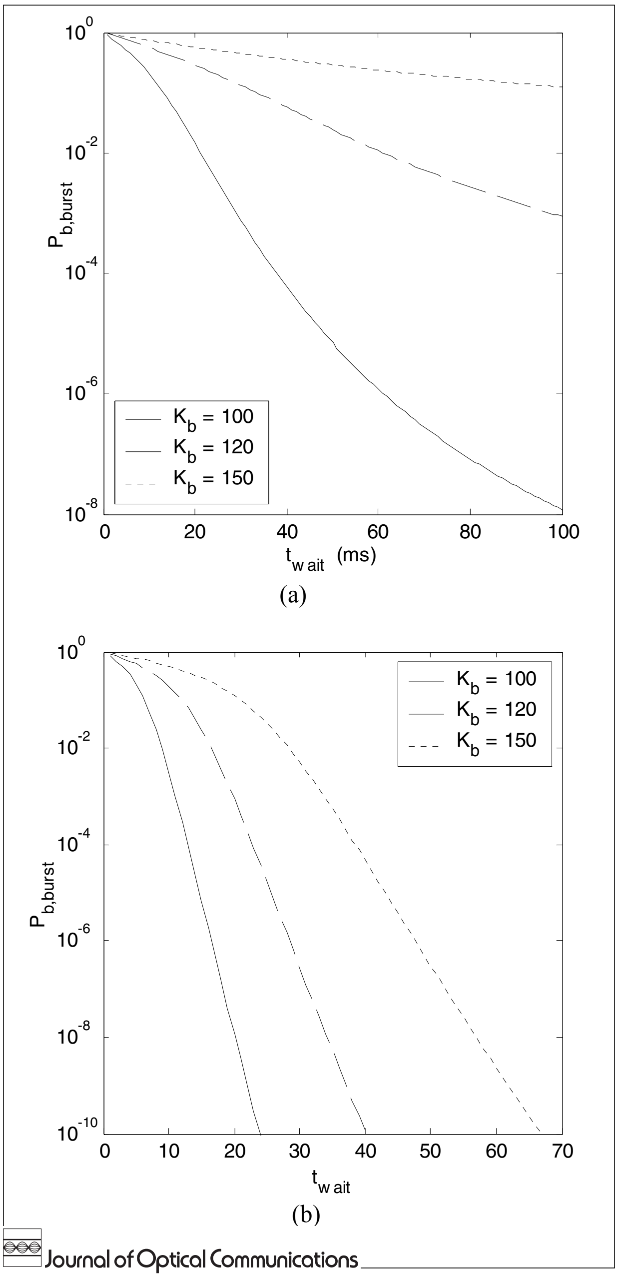

Fig. 7: Burst blocking probability with different number of buffers as a function of waiting time at edge router, (a) $b_{in} = b_{core}$ and (b) $b_{in} = 10b_{core}$

also for the two network diameters. The results show that the performance can get better with increased ratio bit rate. In other side, Delay (waiting) at edge router has significantly influences on the performance of the network. However, increasing packets interval and using fast core router can attain low probability of burst blocking. This work can be extended to investigate the influence of packets type and bit rates for the signals that received at edge router from systems that work at lower bit rates, comparatively, such as packets that received from instruments work in Wireless Local Area Networks (WLANs). By adapting the work in this paper an optimal design for edge router for different traffics can be achieved.

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References

[1] S. Sheeshia et al.: "Performance Comparison of OBS and SONET in Metropolitan Ring Networks"; IEEE Selected Areas in Commun. 22 (2004), 474–1482

[2] C. Qiao, M. Yoo: "Optical burst switching (OBS)- a new paradigm for an optical Internet"; Journal of High Speed Networks (1999), 69–84

[3] M. Düser, P. Bayvel: "Performance of a Dynamically Wavelength-Routed, Optical Burst Switched Network"; IEEE Photon Technol. Lett. 14, (2002) 2, 239–241

[4] M. Düser, P. Bayvel: "Analysis of Wavelength-Routed Optical Burst-Switched Network Performance"; Proc. Europ. Conf. Optical Commun. (ECOC 2001), 1, Amsterdam, (Oct. 2000), 46–47

[5] I. de Miguel, M. Düser, P. Bayvel: "Traffic Load Bounds for Optical Burst-Switched Networks with Dynamic Wavelength Allocation"; IFIP 5th Working-Conference on Optical Network Design and Modeling (ONDM 2001), 1, Vienna, (5th–7th Feb. 2001)

[6] M. Düser, P. Bayvel: "Analysis of a Dynamically Wavelength-Routed Optical Burst Switched Network Architecture"; J. lightwave Technol. 20 (2002) 4, 574–585

[7] A. Zalesky et al.: "Performance analysis of an OBS edge router"; IEEE Photon Technol. Lett. 16 (2004) 2, 695–697