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Packet loss rate of an optical burst switch with nonlinear optical loop mirrors

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Abstract: Optical Burst Switching (OBS) is designed to efficiently exploit the enormous bandwidth offered by the optical fiber. Contention is one of the major problems in the deployment of OBS networks. In this paper, a new contention resolution method is introduced. This method is based on the burst segmentation scheme and the use of Nonlinear Optical Loop Mirrors (NOLMs). The NOLMs are incorporated with SOA to provide optical buffering and ultra-fast optical switching services to the segmented bursts. Furthermore, the introduced method is evaluated in term of the packet loss rate versus various traffic loads with Pareto distributed and negative-Exponentially distributed burst length.

Keywords: burst segmentation, contention Resolution, NOLM, OBS, packet loss rate

Classification: Photonics devices, circuits, and systems

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1 Introduction

Optical Burst Switching (OBS) [1] is a switching paradigm that combines optical and electronic technologies to exploit the huge bandwidth of the optical fiber. In OBS, bursts are discarded mainly due to contentions, which occur when two or more incoming bursts compete simultaneously for the same wavelength on the same output port. In literature, several contention resolution techniques have been suggested. However, combining few of those techniques may lead to better results. Among the techniques discussed in this paper are optical-buffers, burst segmentation, and retransmission of the discarded segments. Under burst segmentation scheme [2] each burst is divided into several segments. The segments are discarded according to a head-dropping or tail-dropping strategy, i.e., when two bursts contend, only the overlapping tail segments of the original burst or the overlapping head segments of the contending burst are discarded. The control packets of the segmented bursts are updated accordingly. Thus, the segmented bursts will be recovered at the following switch [3]. The main idea behind the burst segmentation is to reduce the packet loss probability and to improve the network resource utilization. In this study, only the tail-dropping strategy is considered. Tail-dropping is more advantageous as it maintains the correct order of the data when the discarded segments are retransmitted. It is clear that, instead of dropping the segments, the overall network throughput will be improved if the overlapping segments (tail segments) are buffered at the core nodes and transmitted following the forwarded segments (head segments) whenever the switching resources permit. In this paper, to provide an efficient all-optical switching and buffering system, the use of Nonlinear Optical Loop Mirror (NOLM) is proposed. The rest of the paper is organized as follows: section 2 introduces the suggested switch block diagram. In section 3, the theoretical analysis is presented. Results are discussed in section 4. Finally, section 5 concludes the paper.

2 Switch block diagram

Figure 1 illustrates the OBS switching node with NOLM that enables the retransmission of the discarded segments. The optical nonlinearity of the device is due to the changes in the refractive index with optical power. This phenomenon is known as the Kerr effect in which the changes in input pulses will change the refractive index. Additionally, optical nonlinearity may be also caused by the gain saturation of the Semi-conductor Optical Amplifiers (SOAs) that are attached to the NOLM [4]. NOLM incorporated with SOA will offer low latency all-optical processing, low switching energy, and high-speed operation at rates approaching 100 GHz [5]. Thus, this device represents an ideal buffering system for the discarded segments that will be retransmitted once the appropriate wavelengths become available. The number of input ports for the model is either: 16, 32 or 64.

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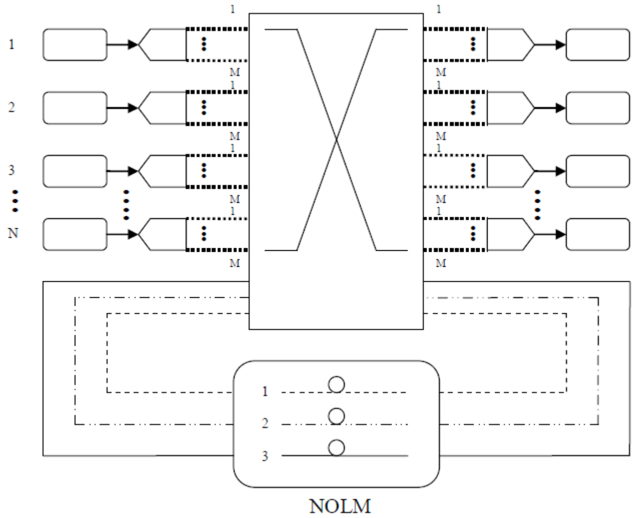

Fig. 1. OBS switching node structure with various units of NOLMs.

3 Analysis

Using burst segmentation as contention resolution strategy, the packet loss rate versus various traffic loads with Pareto and Exponentially distributed burst length has been analyzed. The Pareto distribution with heavy-tailed characteristic refers to the gradually decaying asymptotic shape of the probability distribution. Therefore, most of the probability mass is located at the tail of the probability density function that is indicated by the α parameter in Eqs. (1), (2), and (3). The lower the value of α, the longer the tail of the Pareto distribution will be. The variance of the heavy-tailed Pareto distribution could be very high, even up to the infinite value. However, the value of α utilized in the simulation has been restricted to be only between 1 and 2. In Eqs. (1), (2), and (3), k specifies the minimum value that the random variable can accommodate. For the heavy-tailed Pareto random variable, the probability density function $f(x)$, the complementary distribution function $F(x)$, and the expected value of L are as follows:

$$f(x) = \begin{cases} \frac{\alpha}{k}\left(\frac{k}{x}\right)^{\alpha+1} & for \quad x > k,\ \alpha > 0 \\ 0 & for \quad x \le k \end{cases} \tag{1}$$

$$F(x) = \begin{cases} 1 - \left(\frac{k}{x}\right)^{\alpha} & for \quad x > k,\ \alpha > 0 \\ 0 & for \quad x \le k \end{cases} \tag{2}$$

$$L = \frac{\alpha}{\alpha - 1}k \qquad for \quad \alpha > 1 \tag{3}$$

For negative-Exponentially distributed burst length, the probability mass will be concentrated at the beginning of the probability density function. Therefore, the mean $(1/\mu)$ for the Exponential distribution will be smaller than the mean for the Pareto distribution. The probability density function $f(x)$, and the complimentary distribution function $F(x)$, for Exponential

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random variable are as:

$$f(x) = \begin{cases} \mu e^{-\mu x} & for \quad x \geq 0 \\ 0 & otherwise \end{cases} \tag{4}$$

$$F(x) = \begin{cases} e^{-\mu x} & for \quad x \geq 0 \\ 0 & otherwise \end{cases} \tag{5}$$

The data traffic in each wavelength channel can be seen as alternating ON-state and OFF-state. The ON-state is equivalent to the arrival of a burst, while the OFF-state represents an idle channel (No burst). Hence, the traffic load ρ corresponds to the percentage of the ON-state in the wavelength channel. When two bursts contend, the tail-segments of the original burst that overlap with the head-segments of the contending burst will be segmented and switched through to the NOLM; while the rest of the original burst (head-segments) is transmitted successfully through the appropriate output port. The NOLM provides buffering and switching facilities to the tail-segments. From NOLM, the tail-segments are returned as a new burst to the switching matrix through new input channels. The number of NOLM used will determine the number of extra input and output channels. The contention probability of the new burst, which is retransmitted through NOLM, is:

$$P_c = \int_0^R \frac{1}{L} f_L(x)dx - \int_0^R \left[\frac{\eta}{L}\left(1 - \int_0^{\eta x} f_L(y)dy\right)\right] f_L(x)dx \tag{6}$$

R in Eq. (6) represents the limit for X-axis; η denote the ratio of the length of the segmented tail and the length of the contending burst. Solving Eq. (6) with a Pareto distributed burst length gives:

$$P_{c\text{-}Pareto} = -\frac{\left(\frac{k}{R}\right)^{\alpha}}{L} + \frac{k^{\alpha} R^{-2\alpha}\left(2R^{\alpha} + \left(\frac{k}{\eta}\right)^{\alpha}\right)\eta}{2L} \tag{7}$$

Further, if the burst length is negative-Exponentially distributed as represented by Eqs. (4) and (5), then Eq. (6) will be amended to:

$$P_{c\text{-}Negative\text{-}Exponential} = \frac{1 - e^{-\frac{R}{\mu}}}{L} - \frac{\eta - e^{-\frac{R(1+\eta)}{\mu}}\eta}{L\,(1+\eta)} \tag{8}$$

While the probability of the bursts that are retransmitted, P_s is given by:

$$P_s = \sum_{i=1}^{M}\left[\sum_{j=1}^{i}\binom{i}{j} P_c^j (1-P_c)^{i-j}\right] \times \left[\binom{M}{i} \rho^i (1-\rho)^{M-i}\right]. \tag{9}$$

where M and ρ signify the number of data channels for each output link and traffic load respectively. The impact of the NOLM on the packet loss rate will be shown using simulations, where the model without any NOLM is compared with models with 1, 2, and 3 NOLMs. The NOLMs are connected in parallel as illustrated in Fig. 1. In the simulation model, the loss probability P_b is as follows:

$$P_b = \sum_{i=1}^{M}\left[\frac{\rho(w-i)P_b(i)}{i + \rho(w-1)P_b(i)}\right]. \tag{10}$$

where w is the number of input channels. Hence, the loss probability of the retransmitted segments is as follows:

$$P_B = P_S \times P_b. \tag{11}$$

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4 Results and discussion

Simulations have been performed in order to verify the analysis. The burst length in the simulation is either Pareto distributed or negative-Exponentially distributed as discussed previously. Results obtained from the two different distributions are analyzed and compared. Except being mentioned otherwise, the simulation parameters are as follows: The bandwidth is 10 Gbps, $\alpha = 1.2$, $k = 6.67$ ms, $L = 40$ ms, $R = 100$, $\eta = 0.038$. The traffic load (ρ), wavelength channels (w), and the number of NOLM is varied. As shown in Fig. 1, non-linear optical loop mirror (NOLM) is included in the OBS switching node in order to provide delay (optical buffering) and optical switching services to the segmented burst.

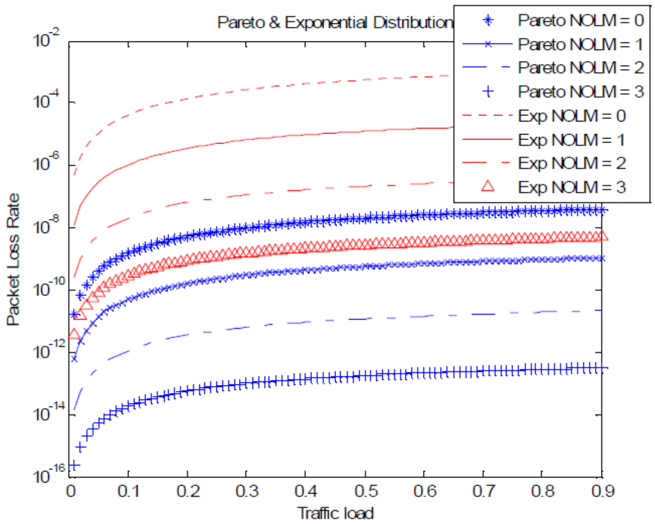

Fig. 2. Packet loss rate vs. Traffic load with Pareto & negative-Exponential distribution for 0, 1, 2, and 3 NOLMs.

The simulation results are shown in Fig. 2, where the OBS switching node with one, two and three NOLMs are compared with the model without any NOLM. The numbers of input ports are maintained at 16. As mentioned earlier, NOLM is used mainly for contention resolution. Therefore, the model without any NOLM has the highest packet loss rate and the model utilizing three NOLMs gives the lowest packet loss rate. Besides, Fig. 2 also indicates that results with Pareto distributed burst length gives lower packet loss if compared to the negative-Exponentially distributed burst length. All the graphs have almost identical shapes. The packet loss rate increases significantly when traffic load is increase from 0.01 to 0.1. When the traffic load approaches 0.8, the packet loss rate almost draw nearer to a constant value.

In Fig. 3, the packet loss rate is measured where the number of input ports is either 16, 32, or 64. As stated earlier, the burst length is either Pareto distributed or negative-Exponentially distributed. When comparing the three curves, the results clearly indicate that the switch with 16 input ports has the lowest packet loss rate, followed by 32 input ports and 64 input ports.

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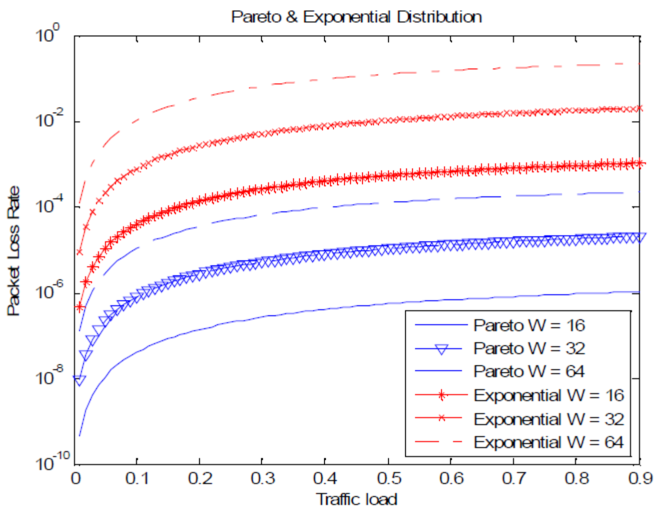

Fig. 3. Packet loss rate vs. Traffic load with Pareto & negative-Exponential distribution for 16, 32, and 64 input ports.

This result is expected, as by increasing the burst input while the amount of wavelength channels remains unchanged, will certainly causes higher blocking probability. Thus, causing even higher packet loss rate. Furthermore, the curves show that the networks simulated with traffic loads having Pareto distributed burst length perform better than all those having the negative-Exponentially distributed burst length.

5 Conclusion

In this paper, a new burst contention resolution technique is proposed. The new technique is based on the burst segmentation in order to obtain the lowest packet loss rate and improve the network throughput. Based on simulation, it is shown that Pareto distributed burst length is far more superior in terms of packet loss rate compared to negative-Exponentially distributed burst length. Furthermore, by increasing the number of input ports while the amount of output wavelength channels remain unchanged will also increase the packet loss rate. NOLM incorporates with SOA provides optical buffering and ultra-fast optical switching services for the segmented packets. This will allow the segmented packets to be retransmitted when the channels are available and, additionally, reduces the packet loss probability. NOLM proved to be a good all-optical switching device for OBS networks. Moreover, NOLM has low latency, low switching energy, and high-speed operation.

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