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Analytic Model for Optical Packet Switch with Output Variable All-Optical Buffers under Asynchronous Variable-Length Packet Traffic

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***Abstract*— We propose an analytic model of the output-queued optical packet switching (OQ-OPS) router using variable all-optical buffers in an asynchronous and variable length packet network scenario, and measure the packet loss probability.**

I. Introduction

Due to enormously increased data traffic, a next-generation switching system should be reliable, scalable, flexible and power-efficient. An optical packet switching (OPS) router is a strong candidate by applying wavelength division multiplexing (WDM) and optical-label switching (OLS) technologies [1].

In the OPS router, a contention resolution is a significant issue, because it has a great effect on the network performance in terms of packet loss and latency. The OPS resolves the contention in the wavelength, time, and space domains [1]. Among these three domains, the time domain solution using optical buffers is not only the simplest and most cost effective but also crucial to decide the OPS architecture [2]. Common technologies of optical buffering are based on fiber delay lines (FDLs). Several papers have shown the performance of various OPS architectures with FDL buffers through analysis and simulation under many network scenarios [2], [3], [4]. However, the FDLs can provide limited unscalable buffer capacity and coarse delay, because they have a discrete delay unit called granularity [5]. Recently, all-optical variable-length buffers are proposed by several novel technologies such as folded-path architecture [6], innovative "slow-light" all-optical buffer [7], and time-slot assignment (TSA) functions [8], etc. For a future switching system, buffering strategies applying the variable all-optical buffers might be required for better performance. Some papers propose several architectures applying all-optical variable buffers and simulate the performance [10], [11]. However, these works are limited to the simulation results, excluding analytic works even though analytic works are effective to measure the performance as well as design OSP architectures.

In this paper, we propose an analytic model of the basic and simple variable buffer-based OPS architecture, output-queued OPS (OQ-OPS) [10], and analyze packet loss probability (PLP) using the proposed model under the practical scenario which supports asynchronously arriving variable-size packets for the well-matched high-speed IP networks [9].

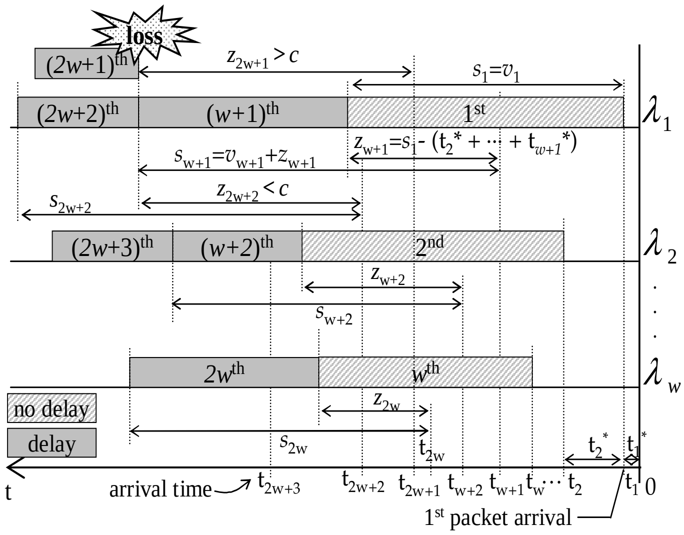

Fig. 1. An illustration obtaining the waiting time, system time, and exemplifying a packet loss occurrence of $(2W+1)^{th}$ packet.

II. Analytical Model of OQ-OPS with Variable All-Optical Buffer

The OQ-OPS architecture is composed of N input and output fibers and each fiber has W wavelengths. D is the number of output queues using variable all-optical buffers on each wavelength channel, so that the total number of output buffers per output port is DW. c denotes each buffer's maximum capacity, so that a total buffer capacity is $C = D \cdot c$. When a packet arrives at the router, a switching unit converts its wavelength to forward the desired fiber because of its routing characteristics depending on the wavelength. When a packet needs to be buffered for resolving contention, its wavelength is converted to a particular wavelength, because the variable buffer is engineered to delay the packet in a specific wavelength [10]. The variable buffer delays the packet until the desired output wavelength channel is available.

Fig. 1 describes behavior of the arrival packets. The first W packets do not need delay, because the wavelength channels are free. At t_{W+1}, $(W+1)^{th}$ packet arrived, but this should be buffered at the 1^{st} buffer since there are no free channel. We denote Z_{W+1} as the waiting time of this packet. Z_{W+1} can be calculated by subtracting its inter-arrival time between the 1^{st} packet and the $(W+1)^{th}$ packet from the 1^{st} packet length as shown in Fig. 1. Until the $2W^{th}$ packet, no packet loss occurs. Upon arrival of the $(2W+1)^{th}$ packet at t_{2W+1}, it should be buffered at the 2^{nd} buffer, because the 1^{st} buffer is occupied at that time. Z_{2W+1} is $(\nu_{w+1}+Z_{w+1})-(t^*_{w+2}+t^*_{w+3}+\ldots+t^*_{2w+1})$, where $\nu_{w+1}+Z_{w+1}$ is the system time of the $(W+1)^{th}$ packet. However, as $Z_{2W+1} > c$, this packet can not be buffered, so that a packet loss occurs.

For analytically modelling, we assume that the packet inter-arrival time is exponential distribution $f_{T*}(t^*)$ with arrival rate λ, and the packet length is exponential distribution $f_\nu(\nu)$ with an average length of $\frac{1}{\mu}$. $\overline{\nu}$ is equal to $\frac{1}{\mu}$ as the average service time of each channel. The traffic load from W-wavelength channels is assumed to be $\rho = \frac{\lambda\nu}{W}$, because W wavelengths can correspond to W servers. Through these assumptions, we can take a $M/M/W/DW$ Markov chain model whose state is the number of packets in one output port. For state $i \geq W$, the transition rate from the i^{th} to the $(i+1)^{th}$ can be expressed as $\lambda(1-\beta_i)$, where β_i is the PLP at state i in the case of $Z_i > c$. The service rate at state i is $\mu_i = min(i, W)\mu$ due to the limited number of W servers with rate μ.

To verify the analytic model of OQ-OPS, we consider the average packet loss probability β as a performance measurement. To obtain β as well as the state probability P_i, we need to derive β_i. Aforementioned, the packet loss occurs when the waiting time is greater than a buffer capacity. When all buffers are occupied, namely state $i = (D+1)W$, the packet loss also occurs. In the case of $Z_i > c$, the packet loss probability β_i can be expressed as:

$$\beta_i = \int_c^\infty f_{Z_i}(z)dz, \tag{1}$$

where $f_{Z_i}(z)$ is the probability density function (*pdf*) of Z_i. In Fig. 1, Z_i can be express as $S_{(i-W)} - W \cdot t^*$, where S_i is system time and $i \geq W$. If n packet losses have occurred previously, Z_i is $S_{(i-W)} - (W+n)\cdot t^*$. Here the sum of t^* is distributed according to an Erlang distribution, $f_{\Sigma t*}(t) = \lambda\frac{(\lambda t)^{(W+n-1)}}{(W+n-1)!}e^{-\lambda t}$, where $n \geq 0$. Since S_i and sum of t^* are independent, $f_{Z_i}(z)$ is given by the convolution of $f_{S_{i-W}}(\cdot)$ and $f_{-\Sigma t^*}(\cdot)$ [4], where f_{S_i} is the *pdf* of S_i. f_{S_i} can also be obtained by the convolution of $f_{\nu_i}(\cdot)$ and $f_{z_i}(\cdot)$ due to the sum of independent random variables, $\nu_i + Z_i$. For $i < W$, S_i equals to ν_i, because Z_i is 0. By applying the values of β_i solved by means of iterations, the state probabilities P_i can be calculated by the queueing theory formula [2]. Finally, the average packet loss probability, β is:

$$\beta = \sum_{i=w}^{(D+1)W} \beta_i P_i + P_{(D+1)w}. \tag{2}$$

III. Numerical Results

In this section, we measure the PLP through the proposed OQ-OPS analytic model. Fig. 2 shows the PLP versus D for different numbers of wavelengths and total buffer capacities per wavelength channel with $\rho = 0.8$ and $\overline{\nu} = 400$. The 3 solid lines show the case of employing 4 wavelength channels, and the 2 dotted lines shows that of employing 10 wavelength channels.

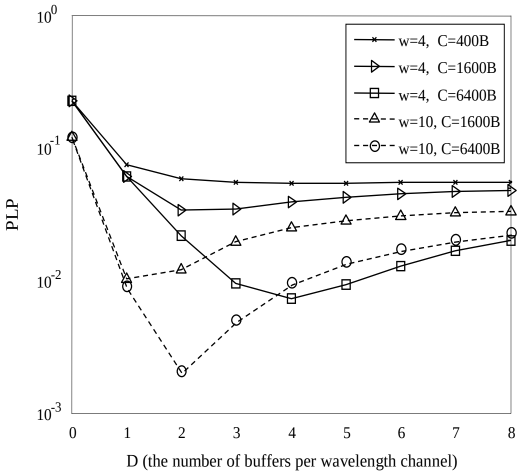

Fig. 2. PLP versus the number of buffers for different numbers of the wavelength and the total buffer capacity with $\overline{\nu} = 400$, $\rho = 0.8$.

As the shown result, increasing the number of buffers does not always have better PLP. The reason is that each buffer capacity is C/D, so that the more buffers we use, the less each buffer capacity due to a fixed total buffer capacity C. If C is enough large, the effect to increase buffers could be enhanced. Intuitively, when more wavelengths we use, we obtain much better PLP than using more buffers, because the wavelength means the server. Furthermore, the more number of wavelengths, the less effect to increase buffers. An optimum point can be different according to the average packet length, traffic load, buffer capacity and wavelength number.

IV. Conclusion

In this paper, we propose the analytic model of the OQ-OPS using variable all-optical buffers in an asynchronous network with variable length packet. Through this proposed model, we measure the PLP, and obtain an approximate optimum number of buffers. This model can be useful to analyze other performance measurements, and extend the OPS model as applying various architectures and assumptions such as burst packet arrival.

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References

[1] F. Xue, et al, *Lightwave*, 21, 11, pp2595-2604 (2003)
[2] F. Callegati, et al, *Comm Lett*, 4, 9, pp292-294 (2000)
[3] J. Yan, et al, *HPSR*, pp302-305 (2005)
[4] R. C. Almeida, et al, *Comm Lett*, 9, 2, pp175-177 (2005)
[5] P. Zhou, et al, *Digital Object Identifier 10*, 5, pp2709-2713 (2003)
[6] A. Chowdhury, *Photonics Technology Lett*, 18, 10, pp1176-1178(2006)
[7] A. V. Turukhun, et al, *Phys. Rev. Lett.*, 38, 24, pp1591-1583 (2002)
[8] Z. Wang, et al, *Lightwave*, 24, 8, pp2994-3001 (2006)
[9] L. Tančevski, et al, *Selected Area in Comm*, 18, 10, pp2084-2093(2000)
[10] H. Yang, et al, *Photonics Technology Lett*, 17, 6, pp1292-1294(2005)
[11] H. Yang, et al, *IEEE/OSA Lightwave*, 23, 10, pp3321-3330, (2005)