ISSN: 2278 – 909X
International Journal of Advanced Research in Electronics and Communication Engineering (IJARECE)
Volume 2, Issue 11, November 2013

An Accurate Model for Optical Burst Switching Core Node Equipped with Wavelength Converter Pool

Ahmed Nabih Zaki Rashed[1*], Abd El–Naser A. Mohammed[2], and Osama M. A. Dardeer[3]
[1,2,3]Electronics and Electrical Communication Engineering Department, Faculty of Electronic Engineering,
Menof 32951, Menofia University, Egypt.

***Abstract*— This paper pays a great attention to resolving the contention problem in Optical Burst Switching (OBS) networks using wavelength converters. Not only the traffic load that leads to burst collision, but also other factors are incorporated. In order to calculate the blocking accurately, a time-slot analytical method is presented. Numerical results for the steady state throughput and the average burst loss probability are presented under different traffic scenarios. Due to the high cost of the wavelength converters, optimum values for the wavelength conversion capability in the node are reached which provide minimum burst loss probability.**

***Index Terms*— Optical Burst Switching (OBS); Just-In-Time (JIT); Just-Enough-Time (JET); Time Slot; Blocking; Wavelength Conversion.**

1. INTRODUCTION

Optical Burst Switching (OBS) represents an intermediate solution between Optical Circuit Switching (OCS) and Optical Packet Switching (OPS), and combines the best of both techniques while avoiding their drawbacks [1—5]. OBS can support bursty traffic generated by upper layers. The burst is the basic switching unit in OBS networks. All optical internet will be realized by implementing IP software over WDM optical layer (IP/WDM) [6]. The main idea in the OBS paradigm is the separation between the data and control planes. Therefore, the control packet (header) is sent on a dedicated control channel, and after a prespecified offset time, the data burst (payload) is sent on a data channel [5]. This offset time should be sufficient in order to avoid the need for optical buffers in OBS core nodes. As a consequence, the data burst is transferred in a cut-through manner towards its destination [7]. Just-In-Time (JIT) and Just-Enough-Time (JET) are the two most common reservation protocols for OBS networks [8—10]. The major difference between them is in the resources reservation time. The reservation process is immediately in JIT, while it is delayed process in the case of JET. In order to make the proposed model valid for both JIT and JET, a virtual increase in the burst length is assumed in the case of JIT whereas no increase to the actual burst length is considered in the case of JET protocol [6].

The contention problem is considered the major problem in OBS networks. Resource contention arises whenever two or more bursts, overlapping in time, arrive at a core node and require the same wavelength at the same output fiber. Various techniques are introduced for contention resolution in the literature such as wavelength conversion [11], fiber delay line [12], burst segmentation [13], and deflection routing [14]. The focus of this paper is on resolving the contention problem using wavelength converters based on time slot analysis. Various architectures exist for OBS core node depending on the distribution of the Tunable Wavelength Converters (TWCs). The Share-Per-Node (SPN) architecture comprises a single converter pool for converter sharing across all fiber lines [15]. The Share-Per-Line (SPL) architecture allows separate TWCs per output fiber [16]. The mathematical model introduced in this paper is based on the Dedicated-Per-Input-Line (DPIL) architecture; that is, each TWC is dedicated to a certain wavelength channel [6]. Of course, the OBS core node doesn't support Full Wavelength Conversion (FWC) capability due to its unaffordable cost. Instead, Partial Wavelength Conversion (PWC) is implemented which reduces the burst dropping probability compared to No Wavelength Conversion (NWC). Recalling that when a resource contention occurs between two or more bursts, only one burst can be forwarded successfully [17]. This means that the traffic load is not the only reason for burst collision, but there are other factors such as the arrival and service rates, burst length, time slot length, and so on [18]. It can be illustrated from Fig. 1 that there is a probability for a contending burst to arrive and is completely served before the slot S_v starts, as will be explained later. This scenario depends mainly on the size of the slot S_i , and this assumption makes the proposed model more accurate than previous models. Two performance measures are evaluated; namely, the steady state throughput and the average burst loss probability. Also, optimum values for the number of wavelength converters are obtained at different traffic scenarios in order to achieve minimum burst dropping probability. In order to make the proposed model tractable mathematically, the probability that the contending burst arrives in the slot S_i and is not completely served before S_v starts is not considered.

The rest of the paper is organized as follows. In section II, a description of our proposed model is presented. Section III is devoted to the numerical results of the derived performance measures. Finally, our conclusion is given in section IV.

2. MODEL DESCRIPTION

Generally, the core nodes represent the major contribution in the burst loss in an OBS network, in contrast to the edge nodes in which cheap electronic buffers can be used. For simplicity, the burst blocking case of two channels is considered. The following notation is used (B_{ij}), where i is the channel number and j is the burst number. For example, B_{21} represents the 1st burst coming on the 2nd channel. Lets denote S for the inter-arrival time between B_{11} and B_{12} [19]. Fig. 1 illustrates the period S which is divided into two slots; valid slot S_v and invalid slot S_i, where $S = S_v + S_i$.

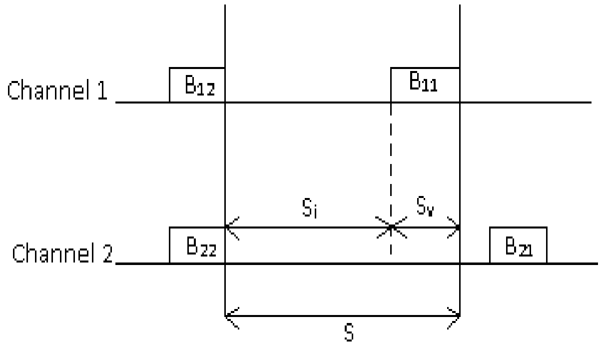

Fig. 1. Burst blocking model for 2-channels.

If B_{11} succeeded in reserving a specific wavelength, any contending burst with it will be discarded. However, after dividing the period S into 2-slots, only the contending bursts coming during the valid slot S_v will be discarded. Therefore, this slot is called valid because it is valid to consider these contending bursts for calculating the burst loss probability.

It is probable for a burst to arrive and is completely served before the slot S_v starts. As a consequence, this period is called invalid slot S_i. That is due to the fact that it is invalid to consider these bursts when calculating the burst loss probability. The probability of occurrence for this scenario depends on the average traffic arrivals (λ), the size of the slot S_i, and the length of the contending burst (L).

Assume both the service time and the inter-arrival time between any two bursts are negative exponential distribution. For T_i is the inter-arrival time between $B_{(2)(i)}$ and $B_{(2)(i+1)}$, we set T_M the mean value of T_i. Also, the burst length (L) is assumed to be fixed (L=50 time units). In OBS network, it may be non-convenient with the bursty nature of the traffic at all time scales, but actually it may be logic to deal with the burst length by its Gaussian distribution [20].

The number of arrivals (k) within the S period can be calculated by applying the following conditions on each arriving burst:-

a) $(T_M - L) \geq S$:- no arrivals within S, as depicted in figure (2).
b) $(T_M - L) < S$:- an arrival within S, and this arrival may be within S_v or S_i depending on the following conditions:-
   i. $(T_M + L) > S$:- an arrival within S_v, as depicted in figure (3).
   ii. $(T_M + L) < S$:- an arrival within S_i, as depicted in figure (4).

The probability of k-arrivals within S is given by [19]:-

$$P_S^k = \Pr.\{(T_M - L) < S\} = 1 - e^{-\frac{\rho}{k}\mu S} \quad (1)$$

where ρ=λ/μ is the traffic load of a channel, λ is the mean arrival rate, and μ=1/L is the service rate. Depending on the results obtained in [19], and by fitting the values of $P_{S_v}^1$ on ρ yields:-

$$P_{S_v}^1 = -0.1786\rho^2 + 0.5893\rho - 0.007143 \quad (2)$$

From the regression analysis, the norm of residuals equals $1.3\text{X}10^{-16}$.

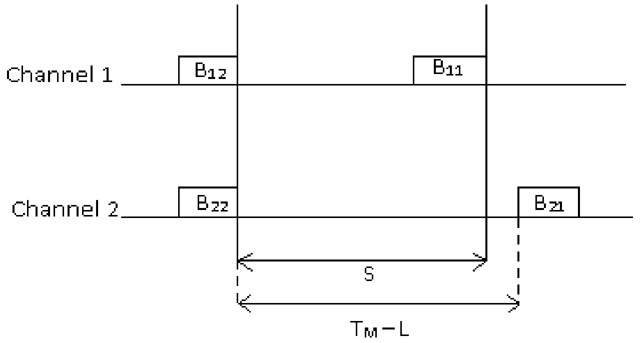

Fig. 2. No arrivals within S.

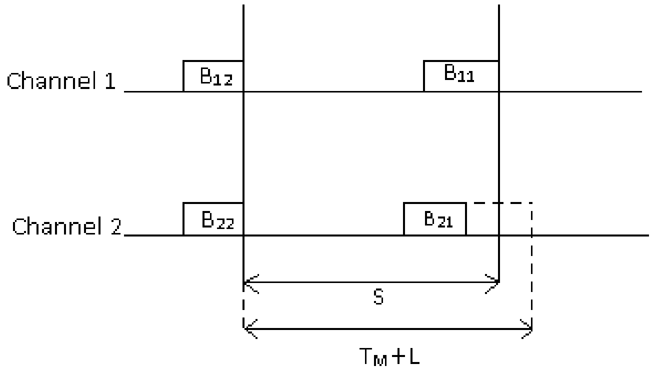

Fig. 3. An arrival within S_v.

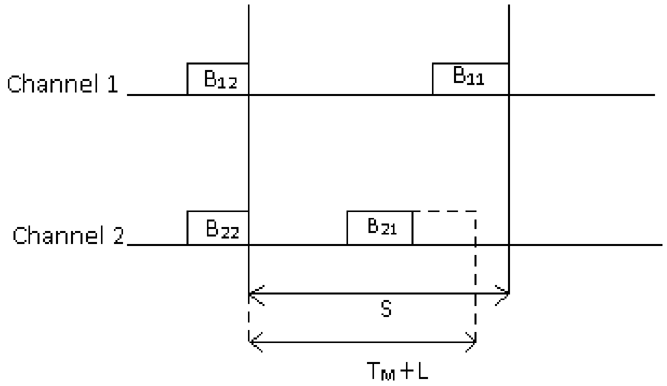

Fig. 4 An arrival within S_i.

In order to deal properly with the DPIL core node architecture, only u wavelengths, from the set of available wavelengths w, can be converted to any other free wavelength. The remaining (w–u) wavelengths are nonconvertible. The node conversion capability can be defined as $\gamma = \frac{u}{w}$. If γ=0, the incoming burst will be blocked if it arrives within the S_v slot and of course the required wavelength is busy. The incoming burst will succeed if it requires a free wavelength or it arrives within S_i slot i.e. completely served before the required wavelength is occupied again. On the same way, when (0<γ<1), the incoming burst will be blocked if it arrives within S_v slot and the required wavelength is nonconvertible. If the node has full wavelength conversion capability (γ=1), the w wavelengths are fully accessible. It is important to note that it is not a practical case due to the unaffordable cost of having w wavelength converters at the core node. Due to the lack of optical random access memory, there is no buffering capability at the core node, and consequently the queue length equals zero. This means that the maximum number of users in the system is w.

STATE DIAGRAM

Here, the state diagram representing the model is presented. Two cases exist depending on the number of wavelength converters used. The 1st case is when there is no wavelength converter (γ=0), and the other is when the core node is equipped with wavelength converters (0<γ≤1).

1st case

Figure 5 illustrates the state diagram of an OBS core node when (γ=0). The state k where k ϵ {0, 1, 2, …………, w} represents the node when it is currently serving exactly k bursts.

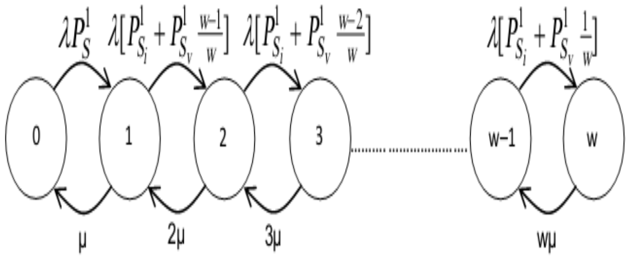

Fig. 5. State diagram of an OBS core node when (γ=0).

This state diagram represents a birth-death process of the Markovian model of M/M/w/w queue with adjusted birth rate [18]. The birth rate is adjusted as follows:-

probability that an arrival arrives in S_i slot +Birth rate = arrival rate x probability that an arrival arrives in S_v slot x

Probability that this arrival requests a free wavelength

In addition, the death rate from state k to state k-1 is set to kμ because the service rate of a burst is directly proportional to the number of busy wavelengths in this state k.

2nd case

Figure 6 illustrates the state diagram of an OBS core node when (0<γ≤1). The birth rate is adjusted as follows:-

probability that an arrival arrives in S_i slot +probability that an arrival arrives in S_v slot x

Birth rate = arrival rate x probability that this arrival requests a free wavelength + probability that an arrival arrives in S_v slot x probability that this arrival requests a busy wavelength x probability that the requested wavelength is convertible In addition, the death rate from state k to state k-1 is also set to kμ.

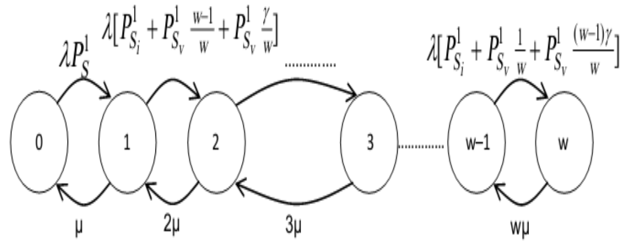

Fig. 6. State diagram of an OBS core node when (0<γ≤1).

3. MODEL EQUATIONS

In this part, mathematical analysis is performed to evaluate two performance measures from the model; namely, the steady-state system throughput β and the average burst loss probability P_b. This analysis is performed in the 2-cases explained in the previous part.

1st case

The steady state probability π_k can be evaluated in terms of π_0 by writing the cut equations for the state diagram in Fig. 5.

$$\pi_k = \begin{cases} \frac{\lambda}{\mu} P_S^1 \pi_0 \\ \frac{1}{k!}(\frac{\lambda}{\mu})^k P_S^1[(P_{S_i}^1)^{k-1} + (P_{S_v}^1)^{k-1} \prod_{i=1}^{k-1}(\frac{w-i}{w})]\pi_0 \end{cases} \tag{3}$$

The value of π_0 can be easily obtained due to the fact that the sum of all state probabilities equals one. Then, substituting by π_0 into eq.(3), the steady-state probability π_k can be evaluated as follows:-

$$\pi_k = \begin{cases} \dfrac{\lambda/\mu\, P_S^1}{1 + \lambda/\mu\, P_S^1 + \sum_{j=2}^{w} \frac{1}{j!}(\lambda/\mu)^j P_S^1[(P_{S_i}^1)^{j-1} + (P_{S_v}^1)^{j-1} \prod_{i=1}^{j-1}(\frac{w-i}{w})]} \\ \dfrac{\frac{1}{k!}(\lambda/\mu)^k P_S^1[(P_{S_i}^1)^{k-1} + (P_{S_v}^1)^{k-1} \prod_{i=1}^{k-1}(\frac{w-i}{w})]}{1 + \lambda/\mu\, P_S^1 + \sum_{j=2}^{w} \frac{1}{j!}(\lambda/\mu)^j P_S^1[(P_{S_i}^1)^{j-1} + (P_{S_v}^1)^{j-1} \prod_{i=1}^{j-1}(\frac{w-i}{w})]} \end{cases} \tag{4}$$

The steady-state system throughput β is the average number of successfully served burst arrivals by the node within a time interval equal to the burst duration, and can be calculated as:-

$$\beta = \sum_{k=1}^{w} k.\pi_k \tag{5}$$

The average burst loss probability P_b is the probability that a burst arrival is being blocked or dropped on the average, and can be calculated as follows:-

$$P_b = \pi_1 \frac{1}{w} + \pi_2 \frac{2}{w} + \text{………....} + \pi_{w-1} \frac{w-1}{w} + \pi_w = \sum_{i=1}^{w} \pi_i \frac{i}{w} \tag{6}$$

2nd case

Similarly, and from Fig. 6, the steady-state probability π_k can be evaluated as follows:-

$$\pi_k = \begin{cases} \dfrac{\lambda/\mu\, P_S^1}{1 + \lambda/\mu\, P_S^1 + \sum_{j=2}^{w} \frac{1}{j!}(\lambda/\mu)^j P_S^1[(P_{S_i}^1)^{j-1} + (P_{S_v}^1)^{j-1} \prod_{i=1}^{j-1}(\frac{w-i}{w} + \frac{i\gamma}{w})]} \\ \dfrac{\frac{1}{k!}(\lambda/\mu)^k P_S^1[(P_{S_i}^1)^{k-1} + (P_{S_v}^1)^{k-1} \prod_{i=1}^{k-1}(\frac{w-i}{w} + \frac{i\gamma}{w})]}{1 + \lambda/\mu\, P_S^1 + \sum_{j=2}^{w} \frac{1}{j!}(\lambda/\mu)^j P_S^1[(P_{S_i}^1)^{j-1} + (P_{S_v}^1)^{j-1} \prod_{i=1}^{j-1}(\frac{w-i}{w} + \frac{i\gamma}{w})]} \end{cases} \tag{7}$$

The steady-state system throughput β can be calculated also from eq.5 while substituting for the steady-state probability π_k from eq.7. The average burst loss probability P_b can be calculated as follows:-

$$\begin{aligned} P_b &= \pi_1 \frac{1}{w}(1-\gamma) + \pi_2 \frac{2}{w}(1-\gamma) + \text{………....} + \pi_{w-1} \frac{w-1}{w}(1-\gamma) + \pi_w \\ &= \pi_w + \sum_{i=1}^{w-1} \pi_i \frac{i}{w}(1-\gamma) \end{aligned} \tag{8}$$

4. SIMULATION AND NUMERICAL RESULTS

A simulation work is performed to validate the proposed model assuming Poisson traffic arrivals to the node. The throughput is measured by counting the number of successfully served bursts by the node. A constant burst length of 50 time units is assumed in all measurements. It is logic to consider the burst length fixed by dealing with the mean of its Gaussian distribution [20].

Both the steady-state system throughput and the average burst loss probability derived above have been calculated under different network parameters. Our results are plotted in Fig. (7—13). In Fig. 7, the steady-state throughput β has been plotted versus the average traffic arrivals λ at different values of node conversion capability γ representing both the results of our proposed model and that of simulation assuming the availability of 16 wavelengths. General and expected trends of the curves can be noticed. Of course, the throughput increases as the conversion capability increases. Fig. 7 illustrates a good consistency of the proposed model with that of simulation for a wide range of traffic arrivals. The proposed model presents higher values of throughput compared to previous model proposed by Morsy et. al. [6] especially for (γ=0).

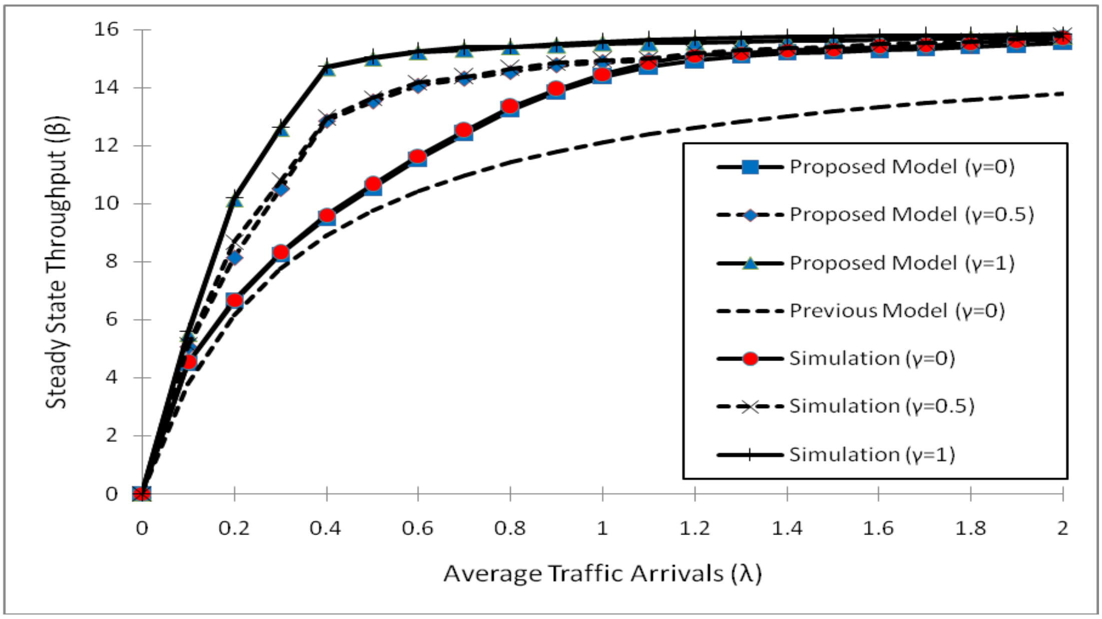

Fig. 7. Steady-state throughput versus average traffic arrivals for both proposed model and simulation at different values of node conversion capability.

Increasing the no. of wavelength converters used is not a practical solution for the contention problem due to its unaffordable cost. Therefore, this solution is not acceptable. The other way to increase the node resources is to increase the no. of available wavelengths. In order to solve the problem in a fair manner, Shalaby [21] proposed a criterion that is based on the following equation:-

$$w = \frac{2w_0}{1+\gamma} \qquad (9)$$

where w_0 is the initial no. of available wavelengths and w is the no. of wavelengths at this value of γ. As a consequence, increasing the node conversion capability will be at the expense of decreasing the available no. of wavelengths and vice versa. Depending on the above criterion, the steady-state throughput has been plotted in Fig. 8 versus the average traffic arrivals for different node conversion capabilities. The tradeoff between the degree of conversion capability and the no. of wavelengths is clearly illustrated in that figure. Increasing the node conversion capability is preferable for low traffic arrivals, while increasing the no. of wavelengths is more effective for high traffic arrivals. Therefore, for each value of average traffic arrivals, there is an optimum value for node conversion capability.

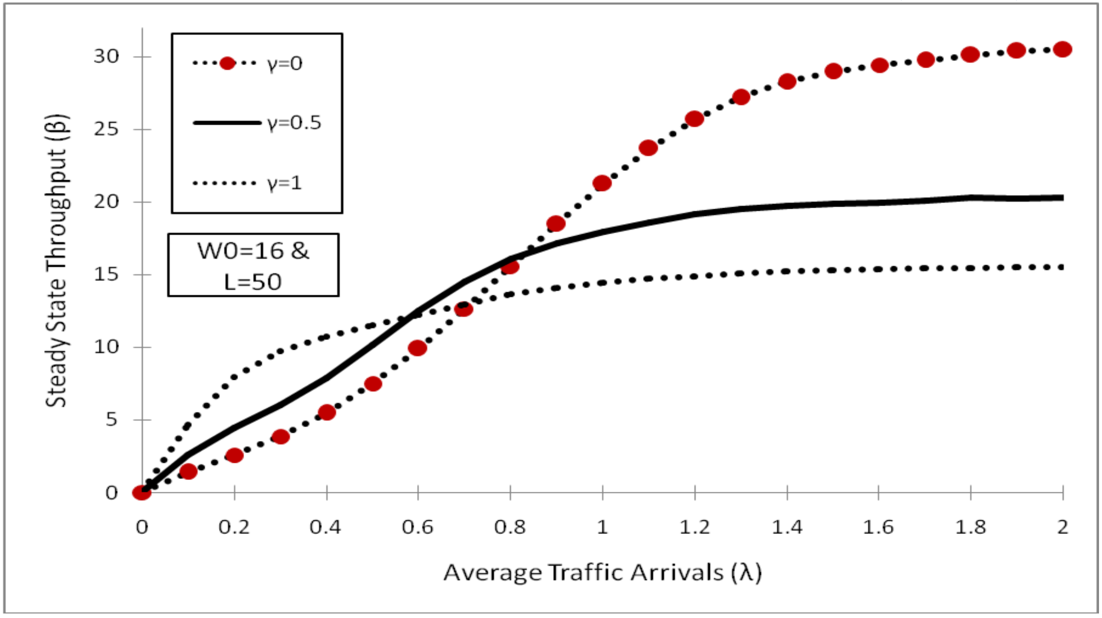

Fig. 8. Steady-state throughput versus average traffic arrivals for different values of node conversion capability and a constraint on the no. of available wavelengths and wavelength converters.

In Figs. (9, 10), the burst loss probability P_b has been plotted versus the node conversion capability at different values of average traffic arrivals. As we mentioned earlier, there is an optimum value of γ for each value of λ, which provides a minimum value of burst loss probability at the node. It is obvious that optimum values of γ decrease with the increase of λ. This is due to the fact that for high traffic, most available wavelengths are busy and the wavelength converters become quite useless. At the contrary, for low traffic, adding wavelength converters greatly solves the contention problem. This fact can be illustrated in Fig. 11.

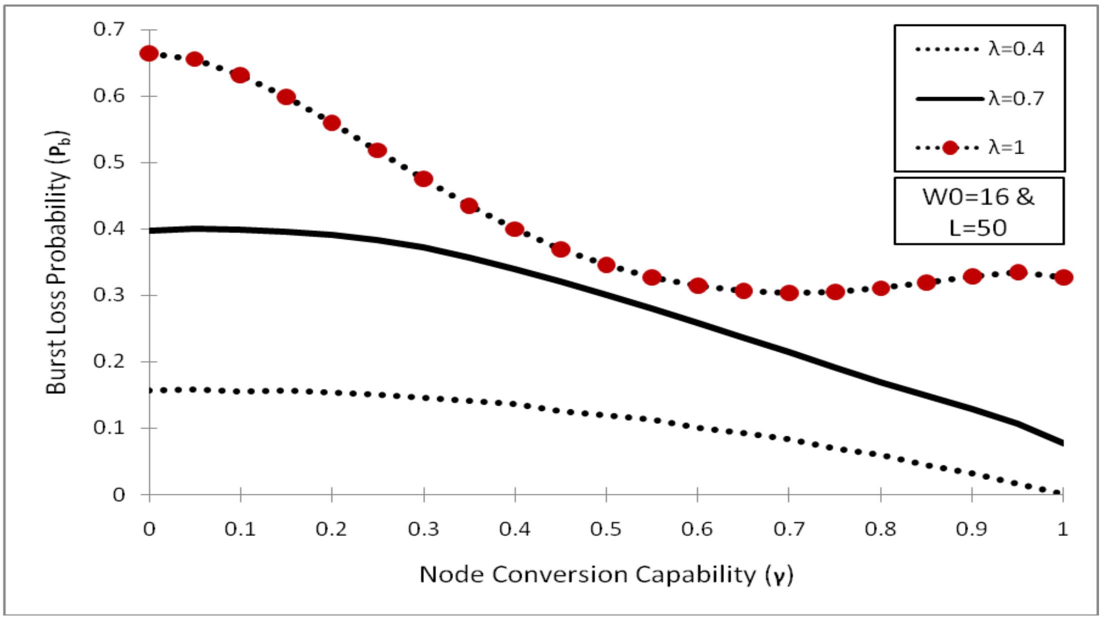

Fig. 9. Burst loss probability versus node conversion capability at λ=0.4 & 0.7 & 1 preserving a constraint on the no. of available wavelengths and wavelength converters.

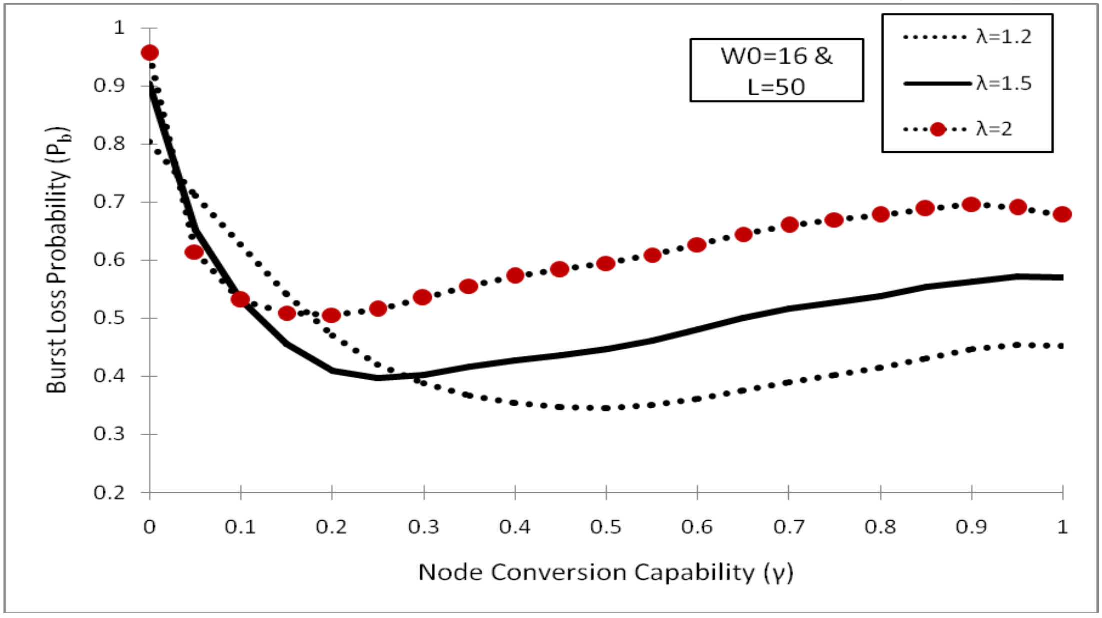

Fig. 10. Burst loss probability versus node conversion capability at λ=1.2 & 1.5 & 2 preserving a constraint on the no. of available wavelengths and wavelength converters.

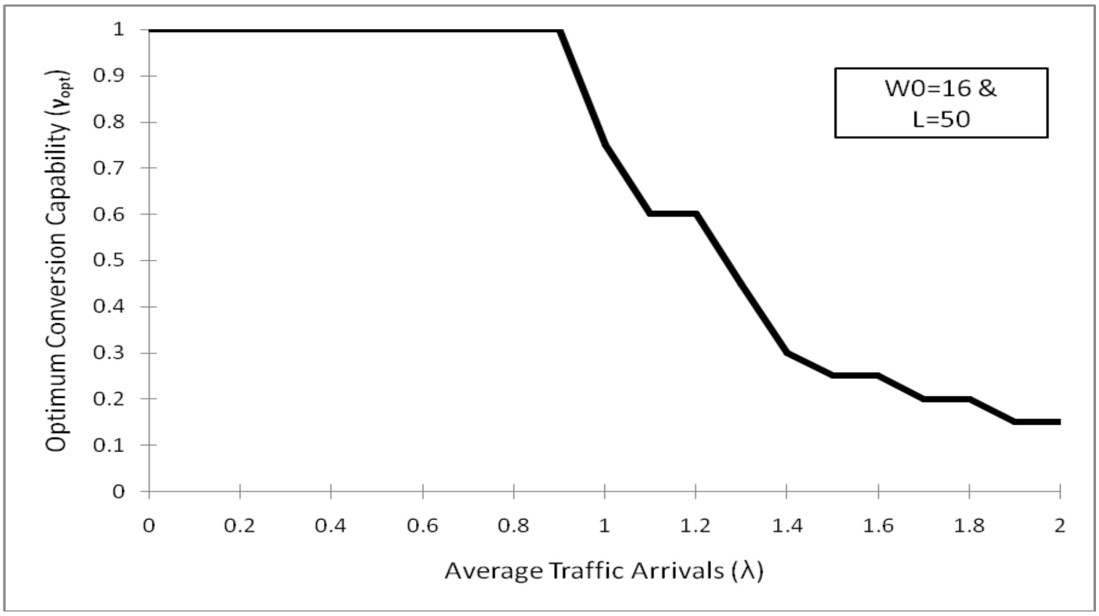

Fig. 11. Optimum values of node conversion capability versus average traffic arrivals preserving a constraint on the no. of available wavelengths and wavelength converters.

Finally, in Figs. (12, 13), we compare the burst loss probability P_b calculated from our proposed model equations those calculated in [6] by Morsy et. al. for γ=0.5 and 1 respectively. It is clear from the figures that our proposed model provides lower and more accurate values for burst loss probability. However, the discrepancy between the two models goes smaller for high traffic arrivals. In this case, the S_i slot becomes very small such that an incoming burst cannot be completely served before S_v slot begins.

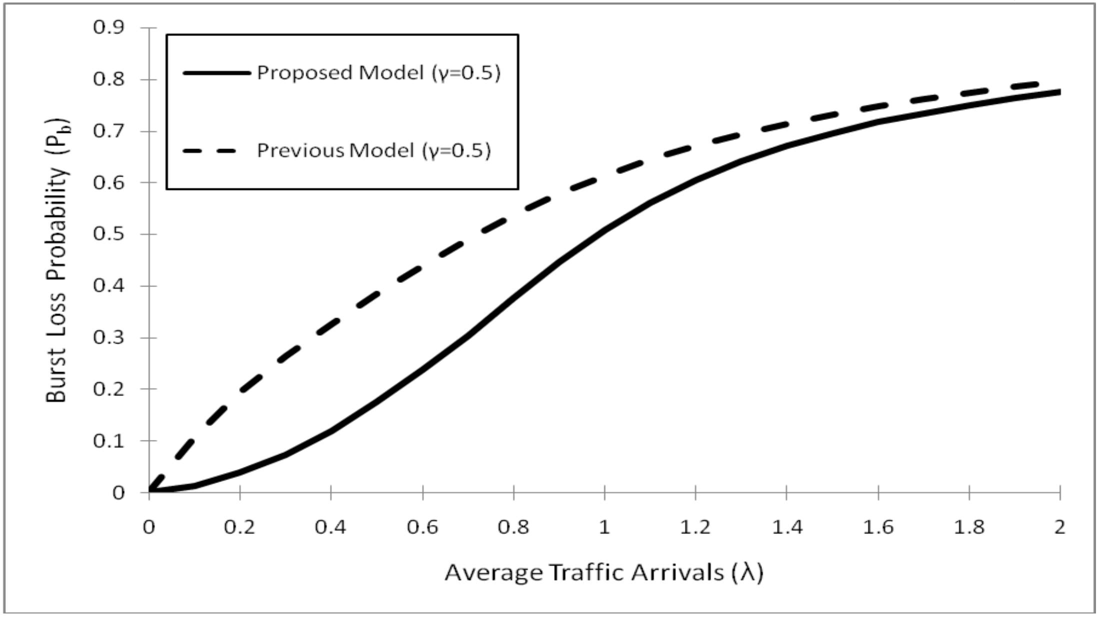

Fig. 12 Burst loss probability versus average traffic arrivals at γ=0.5 for both proposed and previous models.

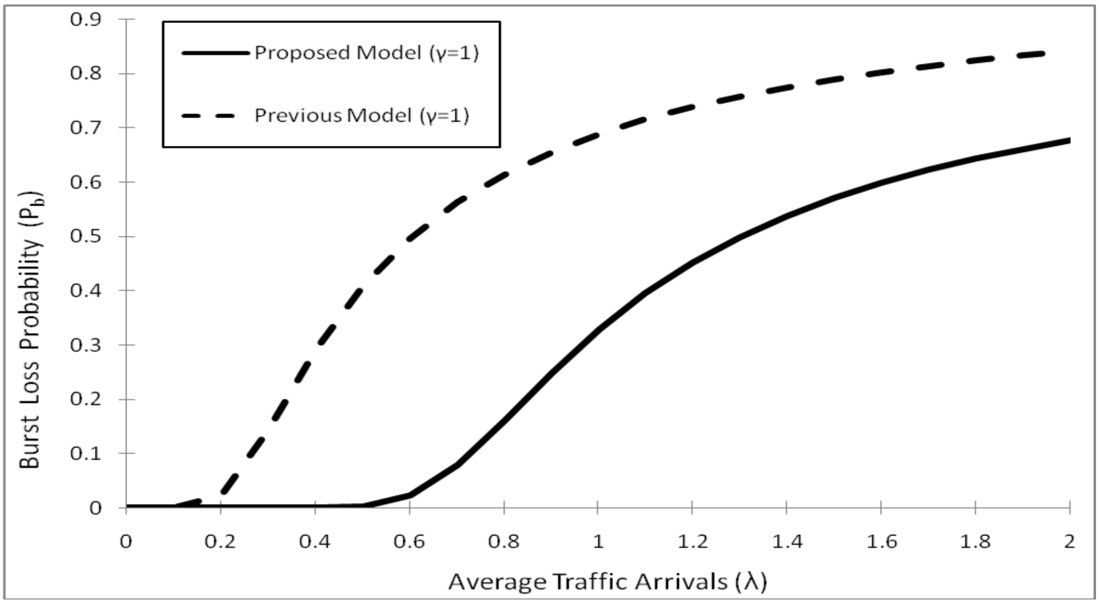

Fig. 13. Burst loss probability versus average traffic arrivals at γ=1 for both proposed and previous models.

4. CONCLUSION

A new accurate mathematical model has been proposed to evaluate the performance of a core node equipped with wavelength converter pool in optical burst switched networks. Two performance measures have been calculated; namely, the steady-state throughput and the burst loss probability. Numerical results are presented at different network parameters. Better performance and more accurate values are obtained from our proposed model. Increasing the node conversion capability is preferable for low traffic arrivals, while adding more wavelengths is preferable for high traffic arrivals. For each value of traffic arrival rate, an optimum value of node conversion capability is obtained which provides minimum loss probability.

REFERENCES

1. C. Qiao; M. Yoo.: Optical Burst Switching (OBS): A New Paradigm for an Optical Internet. J. High Speed Networks. 8, 69–84 (1999).
2. Yijun X; Marc V; Hakki C.: Control Architecture in Optical Burst-Switched WDM Networks. IEEE Journal

on Selected Areas in Communications. 18, 1838–1851 (2000).

3. Sanjeev V; Hemant C; Rayadurgam R.: Optical Burst Switching: A Viable Solution for Terabit IP Backbone. IEEE Network Magazine. 14, 48–53 (2000).
4. C. Qiao; M. Yoo.; Dixit S.: Optical Burst Switching for Service Differentiation in the Next Generation Optical Internet. IEEE Communications Magazine. 39, 98–104 (2001).
5. T. Battestilli; H. Perros.: An Introduction To Optical Burst Switching. IEEE Communications Magazine. 41, S10–S15 (2003).
6. M. Morsy; M. Sowailem; H. Shalaby.: Performance Analysis of a Core Node Equipped with Wavelength Converter Pool in an Optical Burst Switched Network. IEEE 17th International Conference on Telecommunications (2010). doi: 10.1109/ICTEL.2010.5478866.
7. Martin Maier.: Optical Switching Networks. Cambridge University Press, New York (2008).
8. I. Baldine; G. Rouskas; H. Perros; D. Stevenson.: JumpStart: A Just-in-Time Signaling Architecture for WDM Burst-Switched Networks. IEEE Communications Magazine. 40, 82–89 (2002).
9. John Y. Wei; Ray I. McFarland.: Just-In-Time Signaling for WDM Optical Burst Switching Networks. IEEE Journal of Lightwave Technology. 18, 2019–2037 (2000).
10. M. Yoo; C. Qiao.: Just-Enough-Time (JET): A High Speed Protocol for Bursty Traffic in Optical Networks. IEEE/LLEOS Summer Topical Meetings Dig. for Conf. Technologies Global Information Infrastructure. TuB2, 26–27 (1997).
11. B. Ramamurthy; B. Mukherjee.: Wavelength Conversion in WDM Networking. IEEE Journal on Selected Areas in Communications. 16, 1061–1073 (1998).
12. J. Choi; H. Vu; M. Kang.: On Achieving the Optimal Performance of FDL Buffers Using Burst Assembly. IEEE Communication Letters. 11, 895–897 (2007).
13. V. Vokkarane; J. Jue.: Burst Segmentation: An Approach for Reducing Packet Loss in Optical Burst Switched Networks. SPIE Optical Network Magazine. 4, 81–89 (2003).
14. X. Wang; H. Morikawa; T. Aoyama.: Burst Optical Deflection Routing Protocol for Wavelength Routing WDM Networks. Proceedings of SPIE Optical Network Communication Conference. 257–266 (2000).
15. V. Eramo; M. Listanti; P. Pacifici.: A Comparison Study on the Wavelength Converters Number Needed in Synchronous and Asynchronous All Optical Switching Architectures. IEEE Journal of Lightwave Technology. 21, 340–355 (2003).
16. N. Akar; E. Karasan; K. Dogan.: Wavelength Converter Sharing in Asynchronous Optical Packet/Burst Switching: An Exact Blocking Analysis for Markovian Arrivals. IEEE Journal on Selected Areas in Communications. 24, 69–80 (2006).
17. J. Kim; J. Cho; S. Das; et al.: Optical Burst Transport: A Technology for the WDM Metro Ring Networks. IEEE Journal of Lightwave Technology. 25, 93–102 (2007).
18. L. Kleinrock.: Queueing Systems I. Wiley, New York (1975).
19. J. Yang; G. Buyin; Y. Huang; H. Ye.: An Accurate Blocking Model Based On Time-Slot Analysis For Optical Burst Switching Networks Without Buffers. IEEE 9th International Conference on Optical Communications and Networks. 159–162 (2010).
20. X. Yu; J. Li; X. Cao; Y. Chen; C. Qiao.: Traffic Statistics and Performance Evaluation in Optical Burst Switched Networks. IEEE Journal of Lightwave Technology. 22, 2722–2738 (2004).
21. H. Shalaby.: A Simplified Performance Analysis of Optical Burst-Switched Networks. IEEE Journal of Lightwave Technology. 25, 986–995 (2007).

Author's Profile

Dr. Ahmed Nabih Zaki Rashed was born in Menouf city, Menoufia State, Egypt country in 23 July, 1976. Received the B.Sc., M.Sc., and Ph.D. scientific degrees in the Electronics and Electrical Communications Engineering Department from Faculty of Electronic Engineering, Menoufia University in 1999, 2005, and 2010 respectively. Currently, his job carrier is a scientific lecturer in Electronics and Electrical Communications Engineering Department, Faculty of Electronic Engineering, Menoufia university, Menouf. Postal Menouf city code: 32951, EGYPT.

His scientific master science thesis has focused on polymer fibers in optical access communication systems. Moreover his scientific Ph. D. thesis has focused on recent applications in linear or nonlinear passive or active in optical networks. His interesting research mainly focuses on transmission capacity, a data rate product and long transmission distances of passive and active optical communication networks, wireless communication, radio over fiber communication systems, and optical network security and management. He has published many high scientific research papers in high quality and technical international journals in the field of advanced communication systems, optoelectronic devices, and passive optical access communication networks. His areas of interest and experience in optical communication systems, advanced optical communication networks, wireless optical access networks, analog communication systems, optical filters and Sensors. As well as he is editorial board member in high academic scientific International research Journals. Moreover he is a reviewer member in high impact scientific research international journals in the field of electronics, electrical communication systems, optoelectronics, information technology and advanced optical communication systems and networks. His personal electronic mail ID (E-mail:ahmed_733@yahoo.com). His published paper under the title **"High reliability optical interconnections for short range applications in high performance optical communication systems"** in Optics and Laser Technology, Elsevier Publisher has achieved most popular download articles in 2013.