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ORIGINAL ARTICLE

Node dimensioning in optical burst switching networks

JungYul Choi · JinSeek Choi · Minho Kang

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Abstract Network dimensioning should be progressed for pursuing the ultimate efficiency of network system resources in order to satisfy target performance. This article studies node dimensioning as a method of resource optimization in optical burst switching (OBS) networks. OBS is a new switching technology for pursuing bufferless transparent optical networks by sending control packets prior to data burst in order to provision resources for the burst. However, the basic assumption of a bufferless node implies burst contention at a core node when more than two bursts attempt to move forward the same output simultaneously. Thus, burst contention is a critical performance metric and this article takes it into account as a constraint on node dimensioning and target performance. In this article, we first present node dimensioning issues for OBS networks. Two constraints from the transport plane and the control plane which affect burst contention are then introduced. The effect of the burst assembly process on node dimensioning is also presented. From numerical analysis, the optimal number of wavelengths in a link, which provides the lowest blocking probability, is obtained to suggest a guideline for node dimensioning.

J. Choi (✉) · M. Kang
Optical Internet Research Center,
Information and Communications University,
119 Munjiro, Yuseong,
Daejon, Korea
e-mail: passjay@icu.ac.kr

M. Kang
e-mail: mhkang@icu.ac.kr

J. Choi
Department of Computer Science Education,
Hanyang University,
Seoul, Korea
e-mail: jinseek@hanyang.ac.kr

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Introduction

Network systems are required to efficiently transmit a large amount of traffic and to guarantee various demands for quality-of-service (QoS). To pursue these requirements, optically transparent end-to-end transmission technology is solicited. Optical networks based on wavelength division multiplexing (WDM) technology have been deployed to supply a cost-effective and efficient infrastructure that delivers incoming data traffic into the optical signal level. On the other hand, various QoS supporting mechanisms and resource reservation schemes are solicited for increasing diverse service demands of customers. For supporting these requirements, an intelligent control and management protocol is indispensable. Recent development for control protocols in heterogeneous networks has proposed generalized multiprotocol label switching (GMPLS), which enables to support multi-layer switching, such as packet-based, TDM-based, lambda-based, and space-based switching [1].

Optical burst switching (OBS) technology has been proposed to support aforementioned requirements for transparent optical networks [2–4]. In order to regulate bursty input traffic and increase transmission efficiency, an ingress edge node aggregates incoming input traffic as a big-sized data burst. Then, the node transmits a corresponding control packet through a separate control wavelength in advance of data burst with offset time in order to provision resource for the burst. The offset time compensates the control packet processing time for resource provisioning. It enables to get rid of optical buffers and optical–electrical–optical converters for temporarily storing data burst during processing control packets. Thus, at core nodes, a data burst is transparently switched to the next node through the provisioned route. An egress edge node de-aggregates the bursts and forwards each packet to its destination node.

On designing network systems, resource optimization is a crucial mission for constructing cost-effective and efficient network. Therefore, dimensioning of network systems should be progressed for obtaining the ultimate efficiency of network resources, in terms of the required number of wavelengths, wavelength bandwidth, wavelength converters, optical buffers, and control packet processing power, and so on. Among dimensioning issues, this article studies node dimensioning, which deals with the number of wavelengths in a link and burst assembly parameters. As a constraint on node dimensioning and performance measure, burst blocking is taken into consideration at both the transport and the control plane. Since the traffic characteristics of a generated data burst affect blocking performance, the burst assembly process has a key role in a linkage between the transport and the control plane. Based on the assembly process, this article presents a node dimensioning methodology, which gives a guideline for node design.

The remainder of this article is organized as follows. In the next section dimensioning issues in OBS networks are presented. Two constraints on node dimensioning from both the transport and the control plane are introduced in the following section. The effect of the burst assembly process on node dimensioning, dimensioning methodology, and results of node dimensioning in terms of the optimally required number of wavelengths which provides the lowest burst blocking probability, are described in the ensuing three sections. The last section summarizes this article.

Dimensioning issues in OBS networks

This section introduces key dimensioning issues in OBS networks in order to satisfy given network performance with limited resources. Figure 1 illustrates an ingress edge node and a core node architecture including several dimensioning areas, such as the burst assembly process, optical buffers, wavelength converters, required number of wavelengths per link,[1] and the control packet process. This section surveys the first three areas and the last two issues are dealt with in the following section.

Aggregated input traffic, so-called data burst, at the burst assembler is the basic transmission unit. There are two parameters that regulate the release time of data burst and the generated burst size. The two parameters directly affect the traffic characteristics of data burst, so that these values should be carefully decided by taking into account network performance. In [5], the boundary values of the parameters are suggested to guarantee the target burst loss rate and delay time at the control plane.

A fiber delay line (FDL) is the currently available buffering method for resolving burst contention by intentionally delaying contending bursts. The optical buffer consists of a set of different length of FDLs for buffering contending bursts during the variable contending time. The basic delay unit (so-called granularity) of FDL buffers, represented by a ratio of the burst size, considerably affects the burst blocking performance. Thus, the granularity, number, and size of FDL buffers are key issues in buffer dimensioning for reducing down high burst blocking as well as switching system scalability [6].

A tunable wavelength converter (TWC) is also used to resolve contention among more than two bursts attempting to be forwarded to the same wavelength. By forwarding one burst to a different wavelength by a wavelength converter, it can be successfully delivered without contention. Since the TWC is an expensive equipment, its usage, tuning range, and placement are hot dimensioning issues considering trade-off between performance and cost [7].

In an extension line of network dimensioning, this article studies the node-dimensioning issue as a method of resource optimization. Especially, the optimally required number of wavelengths in a link belongs to our interest in node dimensioning. The effect of the number of wavelengths in a link on the blocking performance at the transport and the control plane will be explained in the following section.

Constraints on node dimensioning

Since the OBS network uses one-way delayed reservation without acknowledgment for resource reservation [4], burst contention inevitably occurs when more than

[1] A link consisting of a group of multiplexed wavelengths through WDM technology connects two neighboring nodes. Sometimes link can be referred to port, which multiplexes and demultiplexes a group of wavelengths in a fiber.

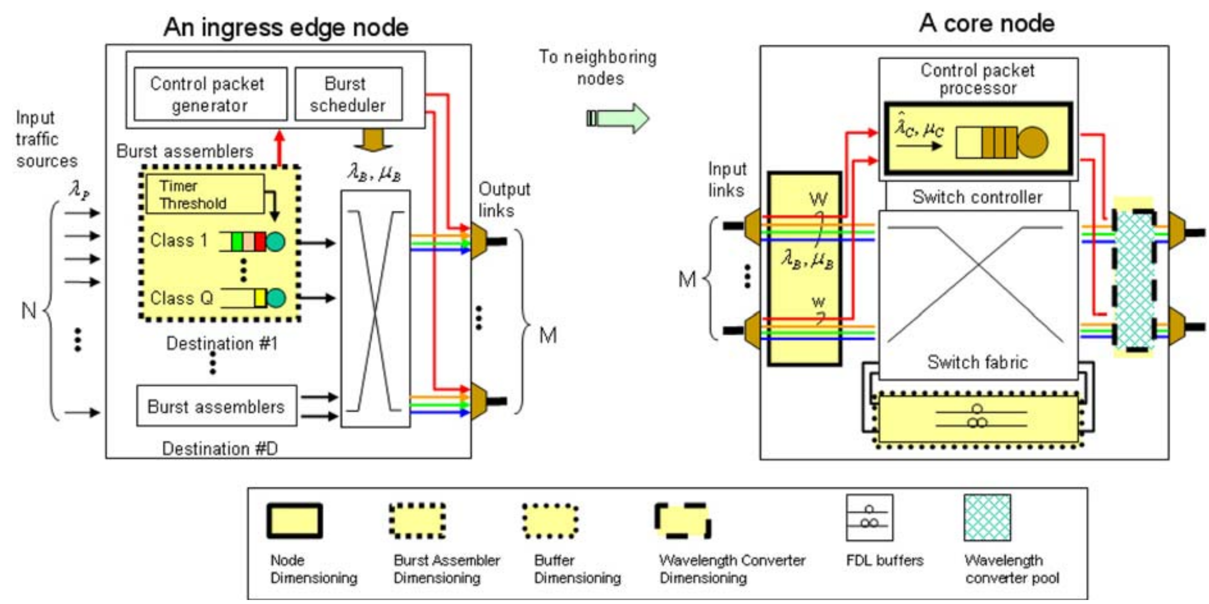

Fig. 1 Dimensioning areas in burst switching nodes

two bursts attempt to be forwarded to the same output simultaneously. A burst is also blocked when a resource is not provisioned before the burst arrives at the node. This occurs when a control packet could not be processed within the pre-calculated processing time due to congestion at the control packet processor. The former is called *burst blocking at the transport plane* and the latter is called *burst blocking at the control packet plane*. In this section, burst blocking due to the two reasons is taken into account and used for constraints on node dimensioning.

Constraint 1: Burst blocking at the transport plane

Burst contention at the output in a core node can be avoided by efficiently allocating incoming bursts from multiple input wavelengths to idle output wavelengths. There are many proposals for burst scheduling mechanisms [3,8,9]. In the *Horizon* scheduling algorithm [8], a burst scheduler chooses the earliest available output wavelength for the incoming burst by keeping and updating the last available time of each output wavelength. In the *LAUC* algorithm [3], the output wavelength that minimizes the gap among bursts in an output wavelength is selected for the data burst for allowing the next burst to have more available resources. In the *LAUC-VF* algorithm [3], the incoming burst is allocated to the inevitably generated voids among bursts in output wavelengths so that it further improves burst blocking performance. The burst scheduler may choose the minimum void between the preceding burst and the newly arrived burst or the minimum void between the newly arrived burst and the following burst [9].

On the other hand, several analytical models for the burst blocking performance have been proposed [4,10]. The well-known *Erlang loss formula* [11] has been applied to calculate burst blocking probability. The basic assumption of this model is that there is no available queueing space and the incoming burst can only be served if there are available wavelengths. It has been widely agreed that it fits for the burst blocking model [4]. However, in cases, there are not enough wavelengths at the node to justify the Poisson assumption [10]. The Engset loss formula [11] can be applied to the burst blocking model for a node with small number of input wavelengths. In this model, it behaves as if the blocked burst stays free and keeps attempting to transmit the burst with the same intensity. However, when a burst gets blocked at an output wavelength the input wavelength does not send burst any more until the burst gets cleared from the wavelength. Consequently, the burst blocking probability gets smaller than that from the blocking model. In [10], a blocking model reflecting the aforementioned features is proposed based on the two-dimensional Markov chain. This model assumes three types of wavelengths according to the states of input wavelengths: transmitting, blocked, and free. This model might be accurate for a node with small number of wavelengths, but it has difficulty in scalability due to the matrix computation.

Since the purpose of this article, however, is to introduce a methodology of node dimensioning, we simply use the Erlang loss formula given by,

$$\mathrm{BBP_{TRANS}} = \frac{(N\rho_{\mathrm{B}})^N/N!}{\sum_{n=0}^{N}(N\rho_B)^n/n!}, \quad (1)$$

where N is the total number of input wavelengths to a node. N is a multiplication of number of input links and the number of wavelengths for data transmission in a link. The number of input links is M, the number of wavelengths in a link is W, and the number of control wavelengths in a links is w. Thus, N is $M(W-w)$. $\rho_{\mathrm{B}} (= \lambda_{\mathrm{B}}/\mu_{\mathrm{B}})$ is the burst offered load per wavelength. In the blocking model, the burst blocking probability is a function of the number of wavelengths, the burst arrival rate (λ_{B}) and the service rate (μ_{B}). In order to satisfy the target burst blocking probability, the burst arrival rate would be limited below a specific value under the given number of wavelengths, or the number of wavelengths would be decided under the given burst arrival rate. The burst blocking model at the transport plane can be rewritten as follows.

$$\mathrm{BBP_{TRANS}} = fn(M, W, w, \lambda_{\mathrm{B}}, \mu_{\mathrm{B}}). \quad (2)$$

The upper bound of the offered load and the number of wavelengths for satisfying a specific burst blocking probability can be determined for node dimensioning.

One noteworthy thing in Eq. 2 is that blocking performance improves as the number of wavelengths increases due to the phenomenon known as *trunking efficiency*. That is, if both the total offered load to the node ($\rho_{\mathrm{T}} = \rho_{\mathrm{B}}N$) and the total number of wavelengths (N) are scaled by a factor $\alpha > 1$, then

$$\mathrm{BBP_{TRANS}}(\alpha\rho_{\mathrm{T}}, \alpha N) \to 0 \quad \text{as } \alpha \to \infty, \quad \text{if } \rho_{\mathrm{T}} \le N. \quad (3)$$

Assuming that the burst offered load per wavelength remains identical, the burst blocking probability is reduced down as the number of wavelengths in a link increases. It can also be explained that the increment of number of wavelengths implies the increment of available number of servers as applied in the Erlang loss formula.

Repeatedly, the increment of the number of multiplexed wavelengths surely helps this effect. The wavelength multiplexing, however, is restricted due to physical limitation of optical technology and system scalability. The current optical technology is reported to multiplex several hundreds of wavelengths in a fiber link [12]. However, the purpose of this article is to present a node dimensioning methodology in viewpoint of network layer. Thus, we do not take into account the physical limitation of WDM technology, but the number of multiplexed wavelengths is simply assumed not to be limited. Instead, the next section takes another effect of number of wavelengths on blocking performance at the control plane into account for node dimensioning.

Constraint 2: Burst blocking at the control plane

Intermediate nodes should take all actions to safely transmit incoming data bursts based on routing information extracted from control packets. In particular, a JET (just enough time)-based OBS node reserves resources for a data burst only for just enough transmission time [4]. Therefore, it is very important to process control packets and take actions within a specific time to successfully transmit data bursts. However, it might be possible that many control packets instantaneously arrive at the control packet processor. The late arrived control packet could be queued at the processor and even longer than the pre-calculated control processing time that is a part of the offset time. The data burst then arrives at the node before the resource is reserved. Regardless of available resources for the data burst, the arrived data burst can not be transmitted. This is called *the early arrival event* and it implies *burst blocking at the control plane* [13]. Therefore, each core node should equip enough processing power for the control packet processor in order to avoid early arrival of data burst and it is required to control the arrival rate of the incoming control packets within an allowable value. This section studies the effect of the control plane on the blocking performance by relating the burst assembly process.

Figure 2 shows a core node with the control plane that consists of the queue for arriving control packets, the control packet processor, the resource manager, the burst scheduler, and so on. Control packets from all input wavelengths waits at the queue. Data burst arrives at the node with the arrival rate λ_{B}. Thus, the total arrival rate of control packet ($\hat{\lambda}_{\mathrm{C}}$) to the node is given by

$$\hat{\lambda}_C = M(W-w)\lambda_{\mathrm{B}}. \quad (4)$$

Based on the arrival rate of control packet, we have the overflow probability of waiting time of control packet at the control packet processor as follows [14].

$$\Pr[t_{\mathrm{W}} > \xi] \approx \alpha \mathrm{e}^{-\beta\xi} = \varepsilon, \quad (5)$$

where t_{W} is the steady-state waiting time of the control packet, ξ is the target delay bound, α is the asymptotic constant, and β is the asymptotic decay rate. Thus, ε is the permissible probability that a control packet waiting time is greater than ξ. Accurate approximation of the constant and the decay rate is the key point of modeling control packet process. From [14], we have the simple approximation for α by $\hat{\rho}_{\mathrm{C}}$ and β by $\hat{\rho}_{\mathrm{C}}/\bar{t}_{\mathrm{W}}$,

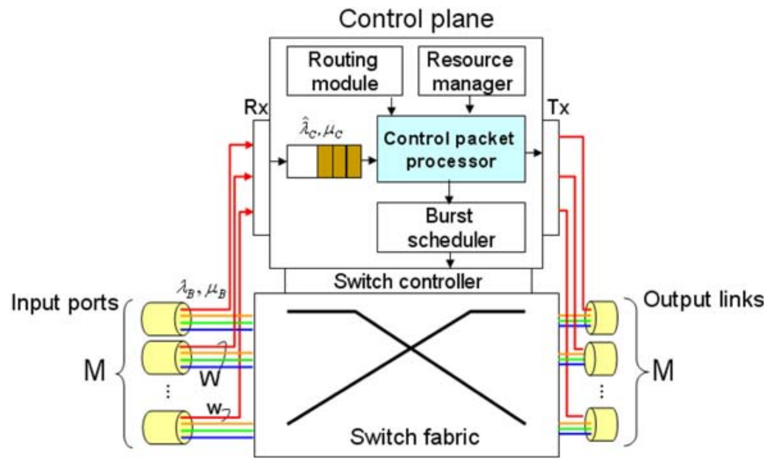

Fig. 2 Core node with the control packet processor

where $\hat{\rho}_C$ is the offered load to the control packet processor ($= \hat{\lambda}_C/\mu_C$, where μ_C is average service rate of control packet) and $\bar{t}_W$ is the average packet processing time. If we assume that the service time for each control packet is tightly bounded and the number of input traffic source is large enough, the average waiting time can be calculated by assuming M/D/1 queuing system given by

$$\bar{t}_W = \frac{\hat{\lambda}_C \bar{x}^2}{2(1-\hat{\rho}_C)}, \tag{6}$$

where $\bar{x}$ is the average service time of a control packet.

From Eqs. 4 to 6, the burst blocking probability at the control plane is known as a function of input wavelengths, the arrival rate and the service rate of the control packet given by,

$$\mathrm{BBP}_{CTRL} = fn(M, W, w, \hat{\lambda}_C, \mu_C). \tag{7}$$

As aforementioned, the arrival rate of the control packet has a close relation with the burst arrival rate and the number of input wavelengths. It is noted that the burst assembler can regulate the burst generate rate (that is, the burst arrival rate) and the burst service rate by adjusting burst assembly parameters [5]. In summary, according to the generated rate of data burst and the number of input wavelengths, the overflow probability of waiting time of the control packet can be controllable. The following section describes the burst assembly process and gives the key linkage between the burst assembly parameters and the burst blocking at the control plane.

The effect of burst assembly process on node dimensioning

The two burst blocking models introduced in the previous section Section have a close relation with the burst arrival rate and the service rate, which are regulated by the burst assembly process. In OBS networks, input traffic is not directly transmitted but aggregated to a big-sized data burst. Thus, the traffic characteristics of a generated data burst are determined by the burst assembly process. This section models the burst assembly process for introducing the burst traffic characteristics.

For data burst generation, the input traffic is first classified into destination and QoS level, and then waits at the assembly queue. The process can be modeled as a queuing system with a separate queue for different destination and QoS pairs. There are two assembly parameters to determine the release time and the size of the burst: *the timer value* [15] limiting the maximum waiting time of input packets at the assembly queue and *the threshold value* [16] that regulates the minimum size of data burst. Modeling of the burst assembler with the two parameters is performed in this section.

Figure 3 illustrates the timing diagram for the burst assembly process with the timer and the threshold value [17]. Note that the arrival process of input traffic to the burst assembler is assumed as Poisson process, and its rate (λ_P) is normalized to ensure that the burst offered load per wavelength (ρ_B) exists between zero and one, and that the input packet size is exponentially distributed with average L_P.

First, let us observe how the timer-based burst assembly process operates and is modeled. After the fourth packet arrives at the queue, the timer (T_I) expires and the proceeding four packets are assembled into a single data burst. In the figure, A_i is the random variable representing the interarrival time between the i packet and the $i+1$ packet with the normalized average value $1/\lambda (= \frac{QD}{N_P\lambda_P} \cdot \frac{M(W-w)}{QD} = \frac{M(W-w)}{N_P\lambda_P})$, where Q is the number of priority classes, D is number of destinations, N_P is the total number of input traffic sources. The timer is

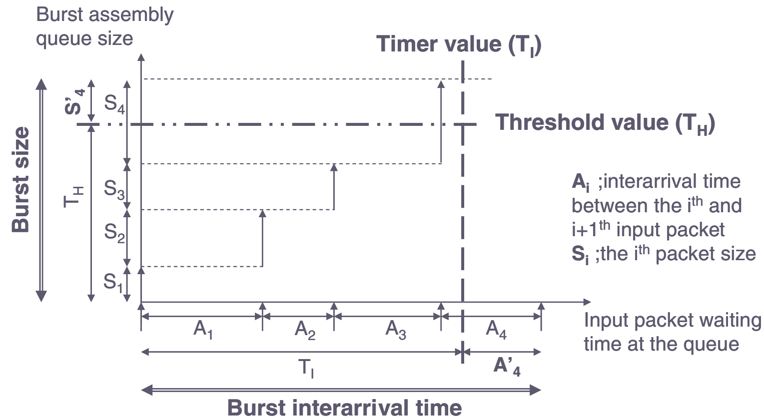

Fig. 3 Timing diagram for the burst assembly process with the timer and the threshold value

initialized when the first packet arrives at the queue after the previous burst generation. The interarrival time between two bursts is the sum of the timer value (T_I) and the interval of the timer expiration time and the new input packet arrival time (A'_4). Due to the memoryless property of the packet interarrival time with a negative exponential distribution, the interval of the timer expiration time and the new packet arrival time is equal to the interarrival time of the input packet, independent of the timer expiration time (Refer to [5] for detailed modeling). From the modeling, the average burst arrival rate (λ_{BI}) and the service rate (μ_{BI}) when using the timer-based model are given by

$$\lambda_{BI} = \frac{1}{T_I + M(W-w)/N_P\lambda_P}, \tag{8}$$

$$\mu_{BI} = \frac{C_B M(W-w)}{N_P T_I L_P \lambda_P}, \tag{9}$$

where C_B is the wavelength bandwidth in bit/second.

The threshold-based burst assembler is then modeled as in Fig. 3. When the fourth packet arrives at the queue, the queue size arrives at the pre-defined threshold value (T_H) ($\sum_{i=1}^{4} S_i > T_H$). The proceeding four packets then are assembled into a single data burst. Due to the memoryless property of exponential distribution of input packet size, the remaining part of the last packet (S'_4), which makes the queue size greater than the threshold value, is equal to the input packet size. The detailed modeling is referred to [5] and we just present the modeling results for average burst arrival rate (λ_{BT}) and the service rate (μ_{BT}) in the threshold-based model as follows

$$\lambda_{BT} = \frac{N_P L_P \lambda_P}{M(W-w)(T_H + L_P)}, \tag{10}$$

$$\mu_{BI} = \frac{C_B}{T_H + L_P}. \tag{11}$$

The burst arrival rate and the service rate obtained from the burst assembly process now can be applied to an input parameter of burst blocking at both the transport and the control plane.

Node dimensioning methodology

In previous section, we presented the burst blocking model as a function of the number of links, the number of wavelengths per link, and the arrival rate and the service rate of data burst at both the transport and the control plane. The linkage between the transport plane and the control plane was connected by Eq. 4. The linkage between input traffic and the generated burst was also established by Eqs. 8–11.

In the transport plane, the burst blocking probability decreases as the number of wavelengths increases. It is because the increment of wavelength implies the increment of available servers even though the offered load per wavelength remains identical. Meanwhile, the increment of wavelength makes the amount of incoming control packets to the control packet processor increase. This induces longer delay of the waiting control packet at the processor. It also increases the possibility that waiting time of control packet at the processor exceeds the target delay bound. Consequently, the possibility of burst contention comes to increase.

One noteworthy thing is that since the burst arrival rate can be adjusted by controlling the burst assembly parameters as shown in Eqs. 8 and 10, accordingly, burst blocking at the control plane can be controlled by the assembly parameters. On the other hand, the blocking performance at the transport plane is invariant with the burst assembly parameter because the change in the burst arrival rate also proportionally affects that in the burst service. Consequently, the burst offered load remains identical regardless of the assembly parameter values.

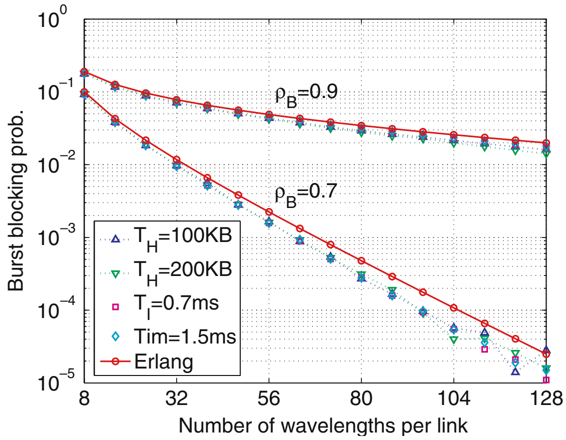

Fig. 4 Burst blocking performance at the transport plane

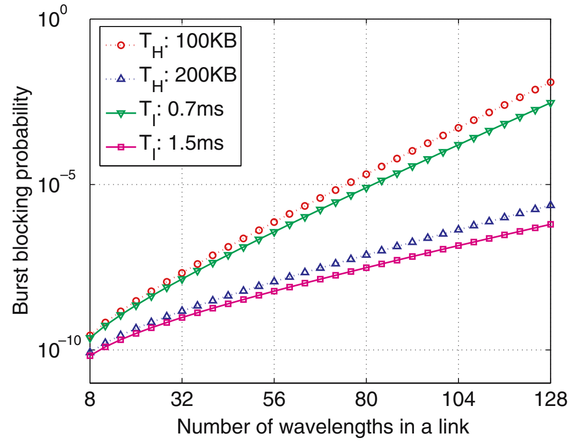

Fig. 5 Burst blocking performance at the control plane ($\rho_B = 0.5$)

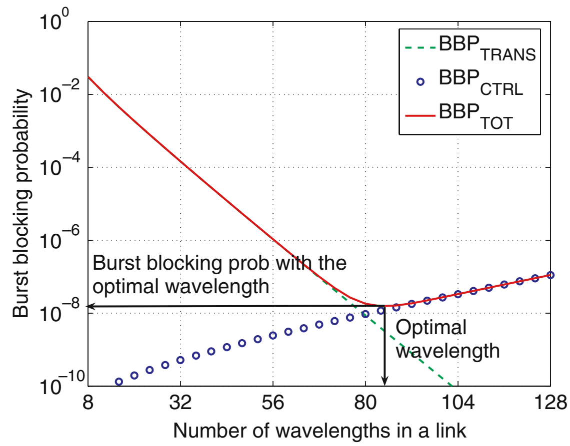

Fig. 6 Decision of optimal number of wavelengths ($\rho_B = 0.5, T_H = 300\,\text{KB}$)

Since the two planes contrarily affect the blocking performance according to the number of wavelengths, by summing up the burst blocking from both the transport and the control plane, the lowest blocking probability can be obtained as a function of the number of wavelengths and the burst assembly parameters. The used number of wavelengths producing the lowest blocking probability is the optimal number of wavelength.

Numerical results

As a result of node dimensioning, this section suggests the optimal number of wavelengths which produces the lowest burst blocking. The effect on the burst assembly parameters on the burst blocking performance is also taken into account. For obtaining numerical results, let us assume the following parameter values: number of links M is 8, processing time for one control packet is 500 ns, delay bound of control packet processing time (ξ) is 5 us, wavelength bandwidth 2.5 Gbps, average input packet size is 1 KByte.

Burst blocking performance at the transport and the control plane

Figure 4 presents the burst blocking probability at the transport plane according to the burst assembly values. The increment of the number of wavelengths in a link helps to reduce high burst contention. As explained in Sect. 'Constraint 1: Burst blocking at the transport plane' the Erlang loss formula overestimate the burst blocking probability due to no consideration of the dumping time of blocked burst from the wavelength. The overestimate on the blocking performance, however, helps to safely decide the required number of wavelengths to produce the lowest blocking probability. In addition, the burst assembly parameters do not affect the blocking performance because their changes do not affect the burst offered load.

Figure 5 presents the overflow probability of waiting time of control packets at the control packet processor, which is the burst blocking probability at the control plane. Contrary to Fig. 4, the blocking performance at the control plane is affected by the burst assembly parameters. The larger parameter values generate the smaller number of bursts and accordingly the smaller number of control packets. It directly affects the control packet congestion at a core node.

Decision of the optimal number of wavelengths

Figure 6 shows how the optimal number of wavelengths that produces the lowest burst blocking probability is

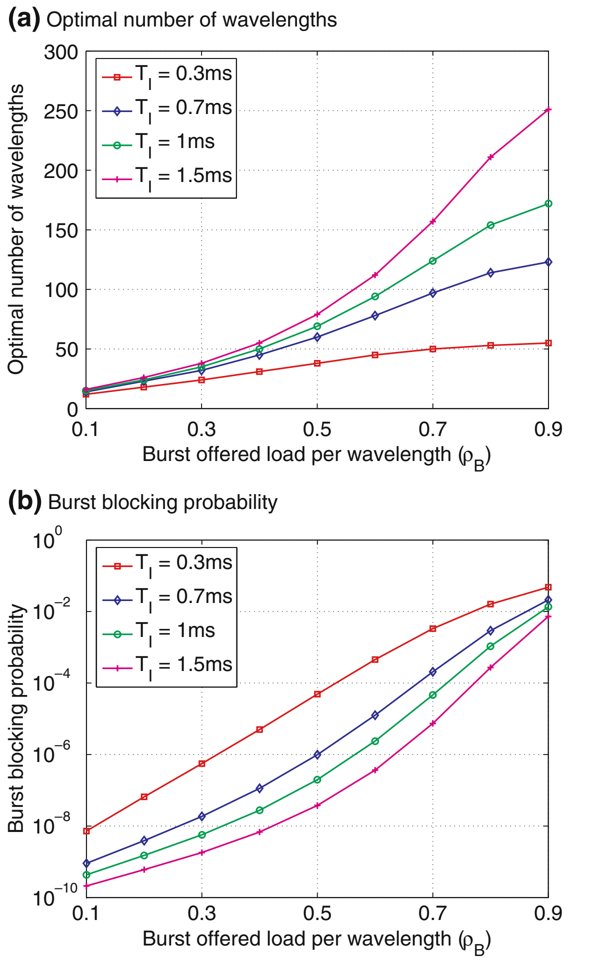

Fig. 7 With timer-based burst assembler (**a**) Optimal number of wavelengths (**b**) Burst blocking probability

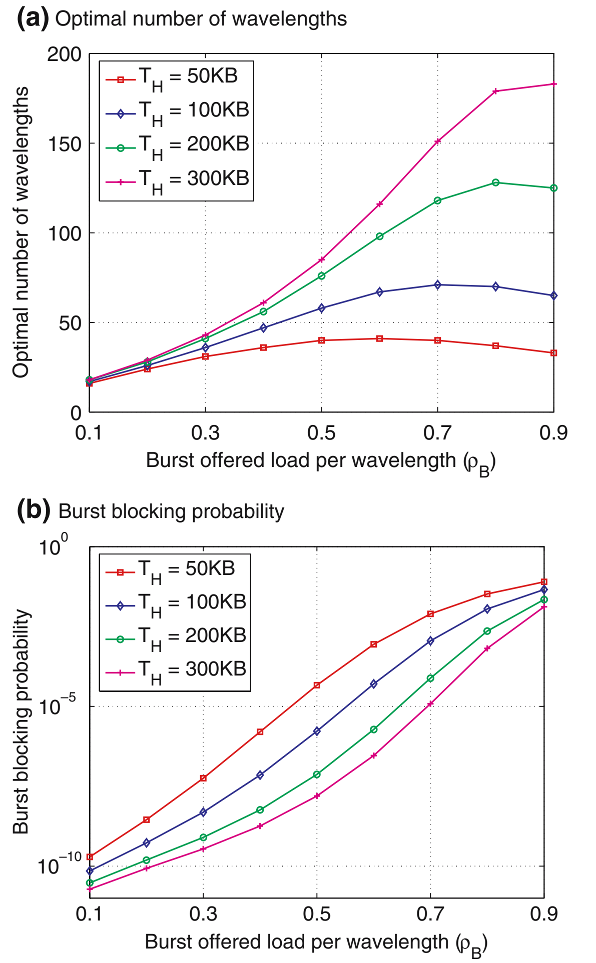

Fig. 8 With threshold-based burst assembler (**a**) Optimal number of wavelengths (**b**) Burst blocking probability

determined. The solid line implies the burst blocking probability from the transport plane and the dot line implies that from the control plane. By summing the two probabilities, the lowest blocking probability can be obtained and the used number of wavelengths, that is the optimal wavelength. As explained in Sect. ‘Burst blocking performance at the transport and the control plane’, since the analytical models for burst blocking overestimate its probability, the obtained wavelength gives the lower boundary value for the lowest blocking probability.

Figure 7a shows the suggested optimal number of wavelengths in a link for producing the lowest blocking probability obtained in Fig. 7b, when the timer-based burst assembler is applied. By summing burst blocking probabilities from the two planes, we could obtain the lowest blocking probability and then get the required number of wavelengths for it. As shown in Fig. 7a, as the offered load increases, the optimal number of wavelengths also increases. It is because the effect of the transport plane requiring more wavelengths to produce lower burst blocking surpasses that of the control plane requiring less wavelength to produce lower blocking. On the other hand, the smaller timer value results in the less optimal number of wavelengths. The smaller timer value generates more control packets so that it results in higher burst blocking probability at the control plane. Thus, in order to reduce the burst blocking probability, it needs to decrease the arrival rate of control packet. In viewpoint of node dimensioning, decreasing the number of input wavelengths at the node results in the decrement of the arrival rate of control packet. As a result, under high offered load, burst blocking is similarly high regardless of the timer value, but the optimal number of wavelengths is diversely obtained. The timer value particularly affects decision of optimal number of wavelengths.

Figure 8a and b show the optimal number of wavelengths in a link and the burst blocking probability at that number, respectively, when the threshold-based burst assembler is applied. One noteworthy thing is that the optimal number of wavelengths first increases and later decreases as the offered load increases. Under low offered load, burst blocking usually occurs at the transport plane because congestion at the control packet process does not frequently occur. It results in similarly low blocking probability regardless of the threshold value and so does the optimal number of wavelengths. On the other hand, under high offered load, even small change of the threshold value can affect burst blocking at the control plane. Thus, in order to produce the similar rate of burst blocking, the smaller threshold requires the less optimal number of wavelengths.

Conclusion

There are many network system elements which affect network performance, such as the burst assembler, FDL buffers, wavelength converters, the control packet processor, and so on. Not only management algorithm manipulating network resources but also dimensioning of the resources are important to achieve high network performance. This article proposed a node dimensioning methodology by taking into account burst blocking at both the transport and the control plane. This article also considered the burst assembly process in computing the burst blocking at the control plane. As a result, the optimally required number of wavelengths per link was suggested in order to produce the lowest burst blocking probability. From this study, we obtained an OBS node design methodology which dimensions the supportable number of multiplexed wavelengths in a link and the burst assembly parameters for pursuing the target performance metrics.

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JungYul Choi received his BSEE from Inha University in 2000, and his MSEE and Ph. D degrees from Information and Communications University, Korea, in 2002 and 2006, respectively. He worked for the Access Network Laboratory at Korea Telecom from March to December 2000, where he researched control plane and survivability for optical networks. He also visited the Center for Ultra-Broadband Information Networks, the University of Melbourne, Australia, for an overseas exchange program from August 2003 to February 2004, where he researched optical burst switching technology. His research interests include optical internet, wired and wireless convergence, and next generation networks.

JinSeek Choi received his BSEE from Sogang University in 1985, and his MSEE and Ph.D degrees from the Korea Advanced Institute of Science and Technology (KAIST), Korea, in 1987 and 1995, respectively. He worked at Gold Star Information and Communication Co. from 1987 to 1991, where he worked on the development of Ethernet, FDDI bridge, and ISDN systems. He was with Kongju National University from 1995 to 2001, where he was a faculty member in the Information and Communication Department. He also worked for the National Institute of Science and Technology (NIST), Washington D.C., USA, as a visiting researcher from September 1998 to August 2000. He also worked as an assistant professor with School of Engineering at Information and Communications University from 2001 to 2003. He is presently an associate professor with the department of Computer Science Education at Hanyang University, Korea. He has authored more than 50 reviewed technical papers related to communication networking. His current research interests include optical Internet, QoS guaranteed high-speed switching and routing, and location management in next generation wired and wireless networks.

Minho Kang received his BSEE, MSEE, and Ph.D. degrees from Seoul National University, the University of Missouri-Rolla, and the University of Texas at Austin in 1969, 1973, and 1977, respectively. From 1977 to 1978, he was with AT&T Bell Laboratories, Holmdel, NJ. From 1978 to 1989, he was the Head of the Department Head and Vice President at the Electronics and Telecommunications Research Institute. Also from 1985 to 1988, he served as the Electrical and Electronics Research Coordinator at the Korean Ministry of Science and Technology. During 1990–1998, he was Executive Vice President at Korea Telecom in charge of R&D, quality assurance, and overseas business development groups. In 1999, he joined Information and Communications University as a professor, served as Dean of Academic and Student Affairs and is presently the Director of the Optical Internet Research Center since 2000.

Dr. Kang was awarded the Order of Merit-Dongbaek Jang by the Korean Government, and the Grand Technology Medal by the 21st Century Management Club in 1983 and 1991, respectively, for his contribution to optical communications technology development. He served as the Study Group Chairman at the Asia Pacific Tele-community of Bangkok during 1996–1999, and is a member of the National Academy of Engineering in Korea and a senior member of IEEE. He is the author of Broadband Telecommunications Technology published in 1993 and revised in 1996 by Artech House, and is an associate editor of IEEE Optical Communication and Networks Magazine.