doi:10.3788/gzxb20144307.0706019

基于流量门限的提前预留竞争解决机制

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摘　要:基于小尺寸缓存的提前预留机制是有效的竞争解决方案.为支持区分服务，本文研究了两优先级提前预留机制的阻塞模型，分析了变化缓存尺寸与载荷比率条件下光突发交换网络核心节点的阻塞性能.为降低两优先级提前预留机制的突发丢弃率，提出一种基于流量门限的提前预留机制.数值分析确定了合理的缓存尺寸与流量门限，实现了高、低优先级间的缓存使用平衡.仿真结果表明:与原有提前预留机制相比，基于流量门限的提前预留机制保持了全流量状态范围内的阻塞性能，并明显降低了中、低流量状态内的突发丢弃率.

关键词:光突发交换；竞争解决；提前预留；流量门限；缓存

中图分类号:TN919.2　　　**文献标识码**:A　　　**文章编号**:1004-4213(2014)07-0706019-6

Pre-reservation Based Traffic Threshold for Contention Resolution in Differentiated Optical Burst Switching Networks

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Abstract: Pre-reservation based small buffers is an efficient method for contention resolution in optical burst switching networks. In this paper, the blocking model of pre-reservation with two-class state was studied in order to provide differentiated services, and a comprehensive analysis on the blocking performance was exhibited by varying buffer size and traffic ratio. In order to reduce the total loss probability of pre-reservation with two-class state, a novel scheme named pre-reservation based traffic-threshold was proposed by constraining the buffered right of low priority within the specific traffic states. Additionally, through the detailed numercial analysis, the reasonable values of buffer size and traffic-threshold were gained, and the balance of buffer usage between high and low priority was achieved. The simulation results show that comaparing with the conventional pre-reservation schemes, pre-reservation based traffic-threshold maintains the total blocking performance in all traffic states and obtains a obvious reduction of burst loss probability in light and moderate traffic states.

Key words: Optical burst switching; Contention resolution; Pre-reservation; Traffic-threshold; Buffers

OCIS Codes: 060.4510, 060.6719, 060.4259, 060.1810, 060.4250, 060.1155

0 Introduction

Optical Burst Switching (OBS) has received much attention in the latest 15 years since it combines the merits of optical circuit switching and optical packet switching[1]. Aiming to drive the development of future optical internet, lots of proposals based OBS are proposed to provide high efficiency of transmission and

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Foundation item: The National Natural Science Foundation of China (Nos. 61302075, 61205071, 61177079), the Science Foundation of Heilongjiang Province (No. F201009) and the China Postdoctoral Science Foundation Funded Project (No. 2012M520779)

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Received: Oct. 23, 2013; **Accepted**: Dec. 18, 2013

bandwidth-usage. Nevertheless, owing to the behavior of one-way reservation, higher loss probability is always one of the key problems in OBS. Researchers have contributed many solutions to avoid burst contention by use of Tunable Wavelength Convertors (TWCs) and Optical Buffers (i. e. , Fiber Delay Lines, FDLs), such as deflection routing, scheduling, buffering, segmentation, preemption, load balance, cloning, and so on[2-5]. But the expense is at the increase of cost and energy consumption.

Currently, compared to the cost penalty, energy consumption of optical network is becoming one of the new and hot topics due to the astonishing rise in traffic, many literatures devote to develop the operating mechanisms with the nature of low energy[6-8]. Under such background, the schemes based small buffers (the length about tens of packets) are concerned because FDLs is a cheap, passive and colorless device[9]. Wherein, Pre-Reservation (PRR) is viewed as a efficient technology based small buffers for burst contention[10-11]. However, one of the shortcomings of PRR is that the burst loss probability is critically dependent on buffer size[12]. To improve the blocking of PRR, Yang introduced segmentation into pre-reservation to lessen the packet loss probability[13]. Sivaraman mitigated the degradation from small buffers by smoothing traffic burstiness at edge nodes[14]. It is worth noting that, to date, the existing studies on pre-reservation are limited in the single-class state. In this paper, we extend the blocking model of pre-reservation to support differentiated services and propose an improved scheme named Pre-Reservation based Traffic-Threshold (PRR-TT) to reduce the burst loss probability by constraining the buffered right of low priority within the specific traffic states. And the blocking model with two-class state is analyzed through the continuous-time markov process analysis. The key parameters such as buffer size and traffic-threshold are determined, the performance evaluation and comparison on blocking of the proposed scheme is conducted by simulation.

1 Blocking model

In general, the model of OBS is made up of edge nodes and core nodes. In JET-based OBS[4], at edge nodes, the incoming packets with common destination are assembled into a burst. When the assembling time (or length) reaches the predetermined threshold, Burst Header Packet (BHP) is sent in a specific out-of-band control channel and reserves the data channel for burst in advance at each core node. Then, the burst transmits transparently after its BHP by an offset time. For each core node, it includes control unit and switching unit. When more than two bursts reach the switching unit simultaneously and require to be forwarded into the same output channel, a burst contention takes place.

1.1 Single-class State

As shown in Fig. 1, assume that only the FDL with feedback configuration, no convertor, is equipped at core nodes. Then, in PRR with single-class state, the burst that arrives first (dotted line) can cut through the switching unit. In contrast, the other burst (dashed line) suffers channel congestion. Given buffer is idle, this contended burst (dashed line) can be delayed in FDL and transmits back to the input port. Meanwhile, control unit unconditionally pre-reserves the data channel and ensures this burst can be forwarded successfully. In this situation, a burst is discarded only when the data channel and FDL are in the busy states. The burst loss probability in single-class state is written as

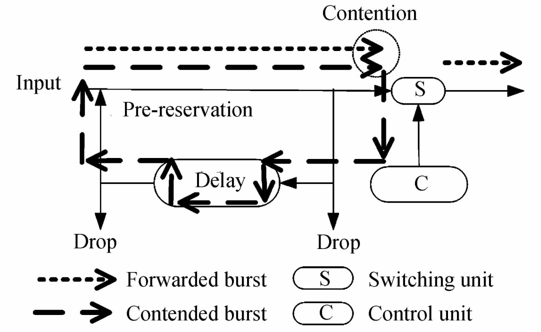


Fig. 1 Principle of pre-reservation with single-class state

$$P_{d,\sin}=uP_{\mathrm{FDL}} \tag{1}$$

where u is the probability of data channel usage, $P_{\mathrm{FDL}}=1-\mathrm{e}^{-\lambda b}$ is the probability of optical buffer usage[15]. From Ref. [10], u can be depicted as

$$u=\rho(1-P_d) \tag{2}$$

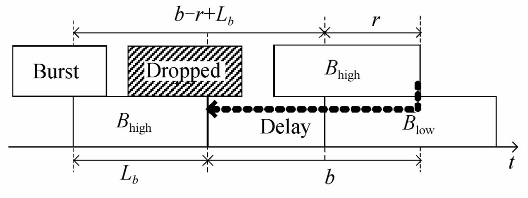
where $\rho=\lambda/W\mu$ is traffic load per data channel, λ and $1/\mu$ are the mean arrival rate and service time of bursts, W is the number of wavelength channels in each fiber link. Next, we denote the burst length by L_b, the FDL length by b, and the blocking length between two contended bursts by r. Hence, combine Eq. (1) and (2), we get

$$P_{d,\sin}=\frac{\rho(1-\mathrm{e}^{-\lambda b})}{\rho(1-\mathrm{e}^{-\lambda b})+1} \tag{3}$$

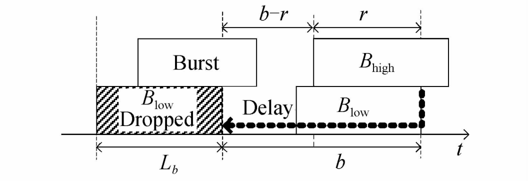
Eq. (3) shows the value of $P_{d,\sin}$ is positive proportional to b because ρ can be viewed as a constant for a given λ. Therefore an interesting result is that the larger buffer brings the aggravated burst contention in PRR with single-class state. Accordingly, the authors of Ref. [10] set the buffer size is equal to $E[L_b]$, where $E[L_b]$ is the mean burst length.

1.2 Two-class state

Here, we define both mission-critical and delaysensitive services with high priority and other bursts are with low priority. Then in two-class state, as shown in Fig. 2(a), the high priority burst B_{high} can enter the idle FDL and pre-reserves the channel $b\text{-}r+L_b$ when it encounters a burst contention. The burst loss probability of high priority will be



(a) Blocking of ahigh priority burst



(b) Blocking of a low priority burst

Fig. 2 Principle of pre-reservation with two-class state

$$P_{d,h}=c_1\cdot uP_{\text{FDL}} \tag{4}$$

where c_1 is the traffic ratio of high priority in a core node. Comparatively, only the buffered right is given for the low priority burst B_{low}. Therefore, besides the busy states of channel and FDL, B_{low} is possible to be dropped after buffering once there is a burst arriving within the void $b\text{-}r$ (see Fig. 2(b)). Assuming the traffic ratio of low priority is c_2, the burst loss probability of low priority is then written as

$$P_{d,l}=c_2\cdot uP_{\text{FDL}}+c_2\cdot u(1-P_{\text{FDL}})\cdot P_{b-r} \tag{5}$$

where $1-P_{\text{FDL}}$ is the probability of buffer being free state, $P_{b-r}=\text{e}^{-\lambda(b\text{-}r)}$ is the probability of burst arrival within $b-r$. Further, the total loss probability of PRR in two-class state is calculated by

$$P_{d,\text{two}}=P_{d,h}+P_{d,l}=c_1\cdot uP_{\text{FDL}}+c_2\cdot u[P_{\text{FDL}}+(1-P_{\text{FDL}})\cdot P_{b-r}]=u\cdot[P_{\text{FDL}}+c_2(1-P_{\text{FDL}})\cdot P_{b-r}] \tag{6}$$

Due to $u=\rho(1-P_{d,\text{two}})$, Eq. (6) can be written as

$$P_{d,\text{two}}=\frac{\rho(1-\text{e}^{-\lambda b}+c_2\cdot\text{e}^{-\lambda(2b-r)})}{\rho(1-\text{e}^{-\lambda b}+c_2\cdot\text{e}^{-\lambda(2b-r)})+1} \tag{7}$$

Further let $X=1-\text{e}^{-\lambda b}+c_2\text{e}^{-\lambda(2b\text{-}r)}$, Eq. (7) is simplified by

$$P_{d,\text{two}}=\frac{\rho X}{\rho X+1} \tag{8}$$

It is obvious that Eq. (8) is a monotonic increasing function of X. Comparing Eq. (8) to Eq. (3), we find $P_{d,\text{two}}\geqslant P_{d,\sin}$ because $c_2\text{e}^{-\lambda(2b-r)}\geqslant 0$. This result means the total blocking performance in two-class state is worsened. Considering the added term $c_2\text{e}^{-\lambda(2b-r)}$, the worse total blocking performance is resulted from the abundant loss of low priority. Aiming to maintain the total blocking performance, we try to discuss three methods to modify the two-class model. Firstly, deprive the pre-reserving right of high priority. In this method, not only high priority burst is possible to be dropped after buffering, but the total loss probability is increased to $\frac{\rho(1-\text{e}^{-\lambda b}+\text{e}^{-\lambda(2b-r)})}{\rho(1-\text{e}^{-\lambda b}+\text{e}^{-\lambda(2b-r)})+1}$. So it is an unfeasible method. Secondly, give the pre-reserving right to low priority. In this method, the blocking performance of high priority is unchanged, but the value of $P_{d,l}$ will be decreased to c_2uP_{FDL} because the second term of Eq. (5) can be ignored. However, note that, this method degrades the analytical model into single-class state. So it is an unfeasible method too. Finally, we observe the term $c_2\text{e}^{-\lambda(2b-r)}$ is negative proportional to b. This means the blocking of low priority will be reduced if we can reasonably increase buffer size. Nevertheless, we should notice that the term $1-\text{e}^{-\lambda b}$ is positive proportional to b because of the pre-reservation process of high priority. Consequently, a contradiction on blocking between high and low priority is demonstrated.

1.3 Pre-reservation based traffic-threshold

The above analysis unveils the key of maintaining total blocking performance is to balance the buffer usage of high and low priority. In order to improve the blocking performance in two-class state, a modified scheme named PRR-TT is proposed and a new parameter traffic-threshold denoted by ρ_{th} is designed. Briefly, in PRR-TT, on one hand we reasonably increase the FDL length to alleviate the loss of low priority. On the other hand, a constraining mechanism on the buffer usage is carried out. That is, being the light and moderate traffic states, we limit the buffered right of low priority, and the idle FDL is served only for high priority. When traffic load rises and reaches the predesigned traffic threshold, the blocking model is unchanged and the total blocking performance is improved although the expense is at the delay-increase.

Accordingly, in this situation, the burst loss probability of high priority is reduced to

$$P_{d,h}=c_1\cdot uP_{\text{FDL},1},\rho\leqslant\rho_{\text{th}} \tag{9}$$

where $P_{\text{FDL},1}=1-\text{e}^{-c_1\lambda b}$ is the probability of buffer usage of high priority. Correspondingly, low priority bursts are simply discarded if a channel contention occurs when $\rho\leqslant\rho_{\text{th}}$, and its burst loss probability will be

$$P_{d,l}=c_2\cdot u,\rho\leqslant\rho_{\text{th}} \tag{10}$$

Because $c_1+c_2=1$, the total burst loss probability of PRR-TT is obtained

$$P_{d,\text{PRR-TT}}=\begin{cases}\dfrac{\rho(1-c_1\text{e}^{-c_1\lambda b})}{\rho(1-c_1\text{e}^{-c_1\lambda b})+1},\rho\leqslant\rho_{th}\\[2ex]\dfrac{\rho(1-\text{e}^{-\lambda b}+c_2\cdot\text{e}^{-\lambda(2b-r)})}{\rho(1-\text{e}^{-\lambda b}+c_2\cdot\text{e}^{-\lambda(2b-r)})+1},\rho>\rho_{\text{th}}\end{cases} \tag{11}$$

Clearly, with the motivation of gaining the lower burst loss probability in the proposed scheme, we should ensure two inequalities $P_{d,\text{PRR-TT}} < P_{d,\sin}$ and $P_{d,\text{PRR-TT}} < P_{d,\text{two}}$. Based on the first one, we obtain

$$c_1 e^{-c_1\lambda b} > e^{-\lambda b} \tag{12}$$

From Eq. (12), the calculated values of λb with the various c_1 are shown in Table 1. Now assuming $E[L_b]=1/W\mu$, the traffic load per data channel can be represented by $\lambda \cdot E[L_b]$. Therefore we find that the value of b should be not more than $3.2E[L_b]$ at the minimum c_1 (=0.1). With the rise of c_1, the buffer size is decreased and asymptotically equals $E[L_b]$ at $c_1=1.0$. This indicates the mean burst length is only the minimum value of the FDL length, and its upper bound goes to about $3E[L_b]$.

Table 1 The values of λb with various c1 under the condition $P_{d,\text{PRR-TT}} < P_{d,\sin}$

c_1	λb
0.1	<3.203 1
0.2	<2.011 2
0.3	<1.719 9
0.4	<1.527 1
0.5	<1.386 2
0.6	<1.277 1
0.7	<1.188 9
0.8	<1.115 7
0.9	<1.053 6
1.0	≈1.0

Then, we analyze the second inequality to determine the values of the other key parameter ρ_{th}. From $P_{d,\text{PRR-TT}} < P_{d,\text{two}}$, we get

$$c_1 e^{-c_1\lambda b} > e^{-\lambda b} - c_2 e^{-\lambda(2b-r)} \tag{13}$$

Substitute c_2 by 1-c_1, Eq. (13) is calculated and simplified as

$$\frac{c_1}{\lambda}\left(\lambda+\ln\frac{1}{1-c_1}\right)<\frac{r}{b} \tag{14}$$

To prevent the delayed burst from facing a second contention, b should be larger than r at least. Hence, Eq. (14) is changed to

$$\frac{c_1}{\lambda}\left(\lambda+\ln\frac{1}{1-c_1}\right)<\frac{r}{b}\leqslant 1 \tag{15}$$

It is worth that, because r presents the blocking length of two bursts, $r=0$ means the non-blocking state, and the serious channel congestion occurs at the case $r=b$. In other words, the values of r/b can partially characterize the state of channel congestion. We set $c_1 \leqslant 0.5$ in the following analysis due to the fact that high priority in networks is always the minority. The values of r/b in Eq. (15) are shown in Fig. 3 with the various c_1 and normalized λ. From Fig. 3, we find the values of r/b are monotonic increasing with c_1, but monotonic decreasing with normalized λ. Moreover, c_1 should be less than 0.25 to satisfy the condition $r/b<1$. This limitation can be regarded as a drawback of the proposed scheme. Fortunately, the current and foreseeable traffic ratio of high priority would be usually less than 30%[16].

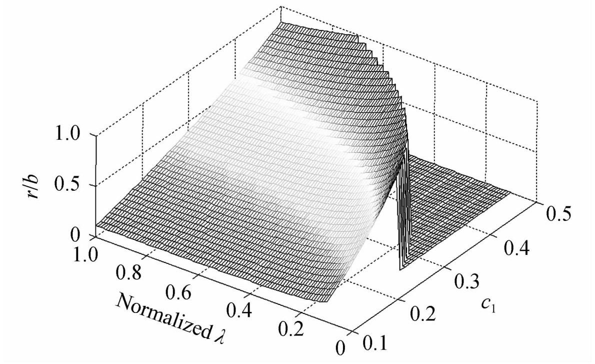


Fig. 3 The values of r/b under the condition $P_{d,\text{PRR-TT}} < P_{d,\text{two}}$

Therefore, based on a joint consideration on the increase and upper-bound of the buffer size, the value of b is designed to be equal to $3E[L_b]$. Under this condition, the advisable traffic threshold is presented as shown in Table 2. According to the obtained values, ρ_{th} becomes smaller for a larger c_1. It indicates that the blocking performance of PRR-TT would be deteriorated with the increase of high priority. In particular we find except for the minimum c_1 (=0.1), the values of ρ_{th} are in the range from 0.45 to 0.62 in the most cases.

Table 2 The advisable traffic threshold within $c_1 \leqslant 0.5$

c_1	ρ_{th}
0.1	1.071
0.2	0.622
0.3	0.581
0.4	0.506
0.5	0.462

2 Simulation and results

As shown in Fig. 4, a typical simulation scenario based on NSF network with 14 core nodes is adopted, in which the traffic states are uniform at each core node. We assume that all bursts have the same offset time, the minimum and maximum burst lengths are 20 KB and 300 KB with mean 100 KB. The transmission rates for control and data channels are 2.5 Gbps and 10 Gbps, respectively. There are 4 input/output ports in switching unit and only one circulation in FDL is allowed for all contended bursts. The FDL length b is designed as 300 KB, and $W=16$ in each fiber link. The signal processing period of control unit is 10 μs, the traffic ratio of high priority is $c_1 \leqslant 0.5$. Moreover, to be clear, we choose PRR (single-class, $b=100$ KB) as a benchmark. The performance of the proposed scheme on blocking is then evaluated. All simulated values are with 95% level confidence interval, and are demonstrated in Fig. 5.

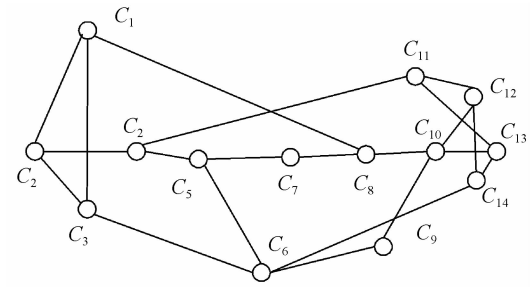
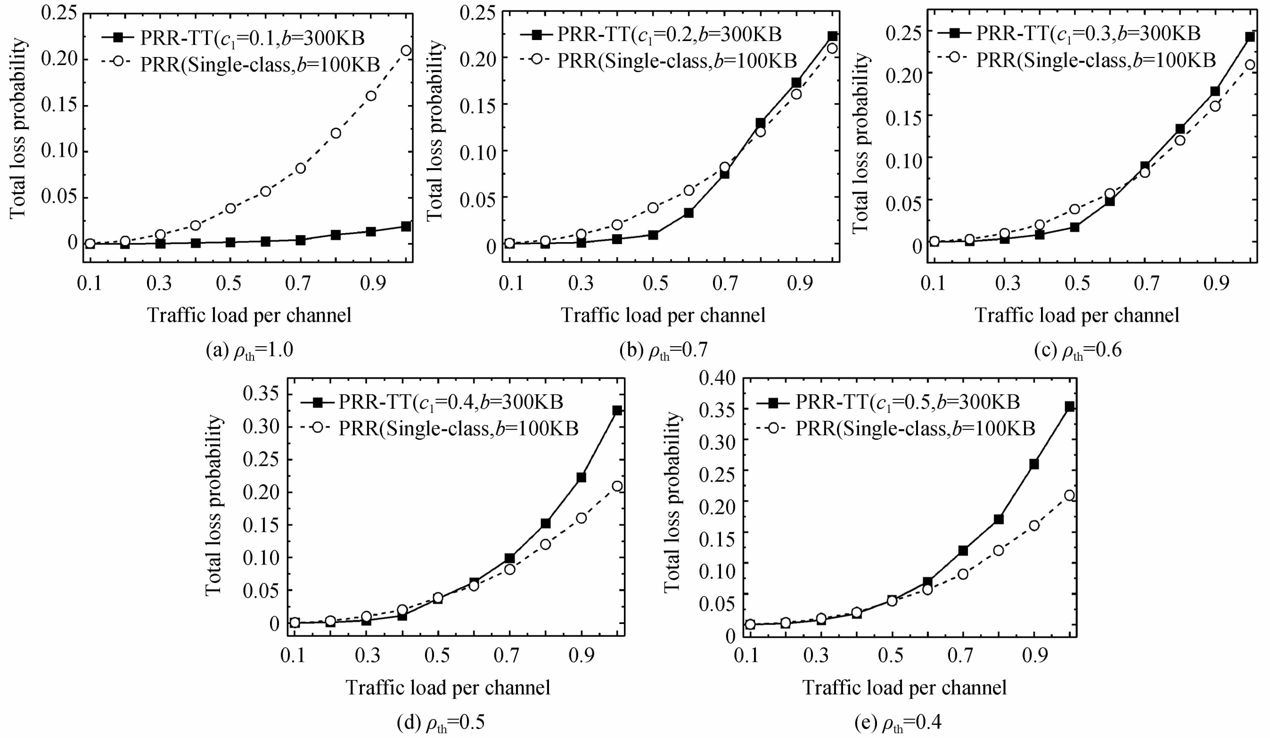


Fig. 4 NSF network with 14 nodes

First, we observe that our analytical model is consistent with the simulation results in Fig. 5(a) to (e). The smaller c_1 is, the lower total loss probability is. At $c_1 = 0.1$, the simulated values of $P_{d,\text{PRR-TT}}$ is much less than those of $P_{d,\sin}$ in all traffic states. With the rise of c_1, the blocking performance of PRR-TT is worse, and the situation $P_{d,\text{PRR-TT}} < P_{d,\sin}$ only occurs within the field $\rho < \rho_{\text{th}}$. Besides, the values of ρ_{th} are also decreased with the rise of c_1. For instance, ρ_{th} can reach 0.7 at $c_1 = 0.2$, but ρ_{th} is equal to 0.4 at $c_1 = 0.5$. These results prove that the pre-reservation process of high priority leads the increase of burst loss again. However, consider $c_1 < 0.3$ in general, PRR-TT can gain the lower burst loss probability in most traffic states. Further, a blocking comparison is conducted among PRR (single-class), PRR (two-class) and PRR-TT in the case $c_1 = 0.2$.



(a) ρ_{th}=1.0 (b) ρ_{th}=0.7 (c) ρ_{th}=0.6

(d) ρ_{th}=0.5 (e) ρ_{th}=0.4

Fig. 5 Performance evaluation of PRR-TT with various traffic-threshold

Furthermore, from Fig. 6, we observe that in single-class state a lower $P_{d,\sin}$ occurs when b = 100 KB in all traffic states. But for two-class state, the bigger b (300KB) brings a lower $P_{d,\text{two}}$ in high traffic states. It means delay-increase of the contented bursts contributes to alleviate channel congestion in a certain level. Comparatively, the proposed scheme is superior to other models and gains the lowest loss probability in light and moderate traffic states ($\rho \leqslant 0.7$) through constraining the buffered right of low priority. In heavy traffic states, by increasing delay time in FDL, the values of $P_{d,\text{PRR-TT}}$ are still smaller than $P_{d,\text{two}}$, and near to the values of $P_{d,\sin}$.

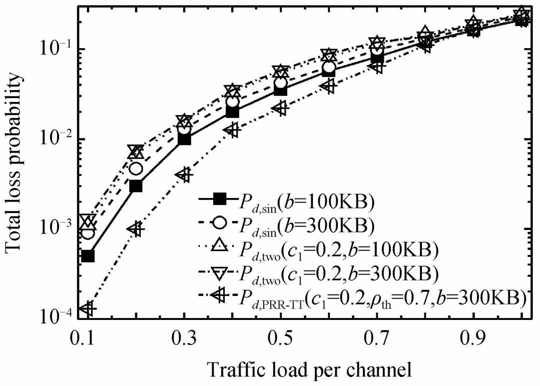


Fig. 6 Blocking comparison with the advisable traffic threshold

3 Conclusion

In two-class state, the total blocking performance is worsened due to the pre-reservation process of high priority. Aiming to improve it, we increase buffer size to alleviate the probability of burst contention of low priority, and we meet the low-loss demand of high priority by constraining the buffered right of low priority. A balance on buffer usage between high and low priority is obtained in the proposed scheme PRR-TT. Based on a comprehensive analysis, the upper bound of buffer size and the values of traffic-threshold for constraining are determined. By simulation, the blocking performance of PRR-TT is evaluated, which presents a lower loss probability in all traffic states.

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