第 41 卷第 2 期
2012 年 2 月

光 子 学 报
ACTA PHOTONICA SINICA

Vol. 41 No. 2
February 2012

doi:10.3788/gzxb20124102.0127

A Deflection Routing Mechanism Based on Priority and Burst Segmentation in Optical Burst Switching Networks

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Abstract: To effectively reduce the packet loss probability (PLP) and guarantee quality of service (QoS) of different priority bursts, a deflection routing mechanism is proposed based on priority and burst segmentation in optical burst switching networks. In the core node, contention is resolved through incorporating prioritized burst segmentation with deflection routing scheme. The burst segmentation scheme allows the head of contending bursts or the tail of original bursts to be segmented. The segmented burst is scheduled on the optimum deflection path by the parameter-tunable deflection routing scheme. An analytical model is proposed to evaluate the contention resolution scheme through calculating PLP and the normalized end-to-end delay. Results show that high-priority bursts have significantly lower PLP and the delay than low-priority. So the deflection routing mechanism based on priority and burst segmentation can effectively resolve the issue of the burst contention, and improve the performance of OBS networks.

Key words: Optical communications; Optical Burst Switching (OBS); Contention resolution; Burst segmentation; Deflection routing; Quality of Service (QoS)

CLCN:TN929.11 **Document Code**:A **Article ID**:1004-4213(2012)02-0127-6

0 Introduction

OBS is a promising solution for the next generation internet backbone which could exploit the huge bandwidth of dense wavelength division multiplexing (DWDM) technology[1-2]. In OBS networks, a data burst consisting of multiple packets is switched through the core network without being examined and processed at each core node. A control packet is always transmitted ahead of the burst in order to configure the switches along the burst′s route between the ingress and the egress node. One of the challenging issues in OBS networks is contention resolution[3]. Existing contention resolution techniques include optical buffering[4], wavelength conversion[5], deflection routing[6] and burst segmentation[7]. Deflection routing is the effectively contention resolution schemes for not requiring extra hardware and can be rather effective under light or medium traffic load. When contention occurs on primary routing path, a contending burst can be sent to a different output link and then follows an alternative route to the destination. Burst segmentation is the process of dropping only those parts of a burst which overlap with another burst. Burst segmentation can significantly reduce the amount of data that is lost due to contention events by dropping only the portion of a burst that overlaps another contending burst. In this paper, contention resolution scheme which incorporate burst segmentation with deflection routing is evaluated.

1 A defection routing mechanism based on priority and burst segmentation

The burst which arrives at a node first is referred to as the original burst data packets (OBDP) and the burst which arrives later is referred to as the contending burst data packets (CBDP) when the contention occurs. Only one OBDP and one CBDP are considered in this paper. Let *s* and *d* denote the source node and destination node. *i*, *j*, $(i+1)$, and *h* are core nodes. P_o and P_c refer to the priority of the OBDP and CBDP,

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Foundation item: The Young Junior Faculties Programme of Education Department of Henan Province (No. 2011GGJS-081) and the Project in Natural Science Research Foundation of Education Department of Henan Province (No. 2010A510002)

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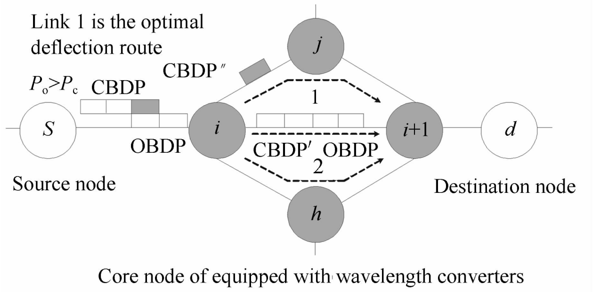
Received date:2011-08-29 **Revised date**:2011-10-25

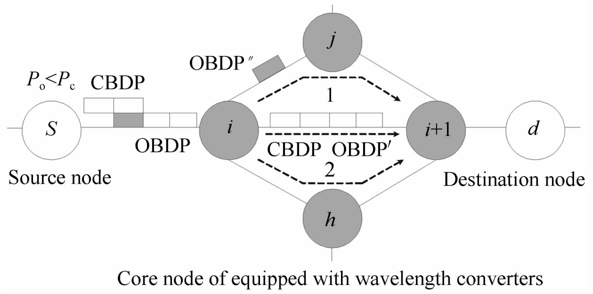
respectively. To simplify the model, we assumed link $i-(i+1)$ is the reserved route, which has the optimal free fiber link resource; link $i-j-(i+1)$ (link 1) and link $i-h-(i+1)$ (link 2) are the alternative deflection routes, which have the second optimal free fiber link resource. The shadow part of the burst is the segmented or deflected part. Two approaches are given following, which considering the priority of bursts in burst segmentation.

1.1 Approach 1: $P_o>P_c$

For the case of $P_o>P_c$, the head of CBDP is segmented. CBDP is divided into CBDP′ and CBDP″. The unaffected parts CBDP′ and OBDP directly are routed on the reserved link $i-(i+1)$, as shown in Fig. 1 (a). The overlap part CBDP″ is deflected on the optimal route by deflection routing mechanism. The optimum deflection path is determined in terms of the packet loss probability and the deflection path length. The packet loss probability of the kth priority burst and the overall bursts and length of the deflection path are the minimum in the optimal deflection route. At the same time, the control system produces the corresponding burst control packets for every BDP when the head of CBDP is segmented. The information of BDP should be consequential changed according to the original BCP and the proceeding situation.



(a) $P_o>P_c$



(b) $P_o<P_c$

Fig. 1 Sketch map of contention resolution mechanism

1.2 Approach 2: $P_o<P_c$

In this approach, the tail of OBDP is segmented. OBDP is divided into OBDP′ and OBDP″. The unaffected parts CBDP and OBDP′ directly are routed on the reserved link $i-(i+1)$, as shown in Fig. 1 (b). The shadow part OBDP″ is deflected. Similarly, the corresponding BCP for every BDP is produced by the control system when the tail of OBDP is segmented. The information of BDP should be consequential changed according to the original BCP and the proceeding situation. Finally, the OBDP″ is transmitted to the destination node on the optimum deflection link.

2 Analytical model

In this section, an analytical model for evaluating the packet loss probability (PLP) and the normalized end-to-end delay with a deflection routing mechanism based on priority and burst segmentation is developed. The segmented burst is scheduled on the optimum deflection link (i, j) by the core node scheduler after bursts are segmented. While the unaffected bursts are transmitted to the destination node on the reserved link $(i, i+1)$. All bursts have the same offset time. This implies that BCP of the original burst always arrives before BCP of the contending burst.

In this paper, just-enough-time (JET)[8] one-way resource reservation mechanism is adopted, and bursts arrive to the network according to a Poisson process. First, the average amount of the segmented burst is analyzed when bursts are segmented. The notations are defined as following: α is the transition rate of the burst states; β is the transition rate of the gap states; b is the length of a burst; g is the length of a gap; c is the sum of the duration of a burst and the duration of a gap; n is the amount of the segments; $1/\sigma$ is the length of a segment; X is the amount of the segmented burst; μ_X is the expected amount of the segmented burst; $\mu_{X|n,g}$ is the expected amount of the segmented burst conditioned on values for n and g.

A two-state (burst and gap) Markov system is proposed[9]. Burst/gap cycle model is adopted in the data channel, as shown in Fig. 2.

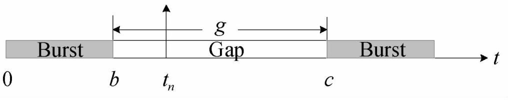


Fig. 2 The structure of a burst/gap cycle

Each burst is divided into n segments whose length, $1/\sigma$, is deterministic. The number of segments in each burst can be deterministic or random. The length of a given burst is $b=n/\sigma$; when n is random, b has probability density f_b and mean $1/\alpha$. g is the length of the gap between bursts; an assumption is made that it is exponentially distributed with mean $1/\beta$. the expected value of c is $1/\alpha+1/\beta$. Let t_n be the failure notification time at which the switch is notified by its downstream neighbor that a link failure has occurred. The failure notification time t_n is uniformly distributed over the interval $[0, c]$, the conditional probability density for t_n is

$$f_{t_n|n,g}(t)=\begin{cases}1/(g+n/\sigma) & 0\leqslant t\leqslant c\\ 0 & \text{other}\end{cases} \tag{1}$$

If t_n occurs in the lth segment. Two analytical model of calculating $\mu_{X|n,g}$ are given following, which considering the priority of bursts in burst segmentation.

2.1 $P_o > P_c$

For the case of $P_o > P_c$, the head of CBDP is segmented. If t_n occurs in the time interval $[(l-1)/\sigma, l/\sigma]$, the segments that follow the lth segment can be deflected onto the alternate output port, as shown in Fig. 3.

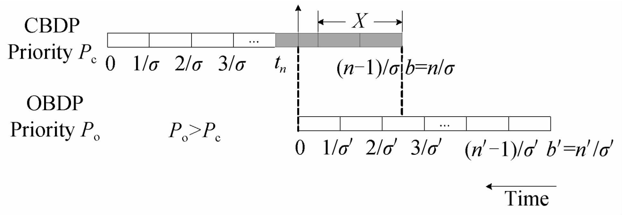


Fig. 3 Sketch map of the head of CBDP is segmented

The amount of the segmented burst that can be deflected is

$$X(n;t_n)=\begin{cases}\dfrac{n-l}{\sigma} & \dfrac{l-1}{\sigma}\leqslant t_n<\dfrac{l}{\sigma},\ l=1,2,\cdots,n\\ 0 & t_n\geqslant\dfrac{n}{\sigma}\end{cases} \tag{2}$$

According to Eq. (1) and Eq. (2), the expected amount of the segmented burst conditioned on values for n and g

$$\mu_{X|n,g}=\int_0^{\infty}X(n;t)\cdot f_{t_n|n,g}(t)\,\mathrm{d}t=\frac{1}{g+n/\sigma}\cdot\sum_{l=1}^{n}\int_{\frac{l-1}{\sigma}}^{\frac{l}{\sigma}}\frac{n-l}{\sigma}\mathrm{d}t=\frac{1}{g+n/\sigma}\sum_{l=1}^{n}\frac{n-l}{\sigma^2}=\frac{1}{g+n/\sigma}\cdot\frac{n(n-1)}{2\sigma^2}=\frac{b(b-1/\sigma)}{2(g+b)} \tag{3}$$

2.2 $P_o < P_c$

When $P_o<P_c$, the tail of OBDP is segmented. If t_n occurs in the time interval $[l/\sigma, (l+1)/\sigma]$, the segments that previous the lth segment can be deflected onto the alternate output port, as shown in Fig. 4. The amount of the segmented burst that can be deflected is

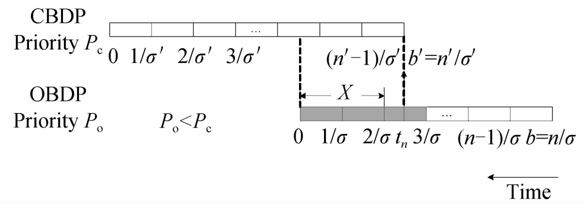


Fig. 4 Sketch map of the tail of OBDP is segmented

$$X(n;t_n)=\begin{cases}\dfrac{l}{\sigma} & \dfrac{l}{\sigma}\leqslant t_n<\dfrac{l+1}{\sigma},\ l=0,1,\cdots,n-1\\ 0 & t_n\geqslant\dfrac{n}{\sigma}\end{cases} \tag{4}$$

Using Eq. (1) and Eq. (4), the expected amount of the segmented burst conditioned on values for n and g

$$\mu_{X|n,g}=\int_0^{\infty}X(n;t)\cdot f_{t_n|n,g}(t)\,\mathrm{d}t=\frac{1}{g+n/\sigma}\cdot\sum_{l=0}^{n-1}\int_{\frac{l}{\sigma}}^{\frac{l+1}{\sigma}}\frac{l}{\sigma}\mathrm{d}t=\frac{1}{g+n/\sigma}\sum_{l=0}^{n-1}\frac{l}{\sigma^2}=\frac{1}{g+n/\sigma}\cdot\frac{n(n-1)}{2\sigma^2}=\frac{b(b-1/\sigma)}{2(g+b)} \tag{5}$$

Therefore, the expected amount of the segmented burst conditioned on values for n and g of the two burst segmentation mechanisms is consistent.

The segment length $1/\sigma$ decreases ($\sigma\rightarrow\infty$). $\mu_{X|n,g}$ is estimated by

$$\lim_{\sigma\rightarrow\infty}\mu_{X|n,g}=b^2/2(g+b) \tag{6}$$

It is assumed that the burst length is exponentially distributed in the limit. μ_X can be obtained by computing

$$\mu_X=\int_0^{\infty}\int_0^{\infty}\mu_{X|n,g}f_{b,g}(b,g)\,\mathrm{d}b\mathrm{d}g=\int_0^{\infty}\int_0^{\infty}\frac{b^2}{2(g+b)}\cdot f_{b,g}(b,g)\,\mathrm{d}b\mathrm{d}g=\frac{\alpha\beta}{2}\left[\int_0^{\infty}\frac{1-\alpha g}{\alpha^2}\mathrm{e}^{-\beta g}\mathrm{d}g+\int_0^{\infty}g^2\mathrm{e}^{(\alpha-\beta)g}\left(\int_{\alpha g}^{\infty}\frac{\mathrm{e}^{-b}}{b}\mathrm{d}b\right)\mathrm{d}g\right] \tag{7}$$

The first integral can be evaluated directly. The double integral can be simplified by changing the order of integration, which gives us

$$\mu_X=\frac{\alpha\beta}{2}\left[\frac{\beta-\alpha}{\beta^2\alpha^2}+\int_0^{\infty}\left(\int_0^{b/\alpha}g^2\mathrm{e}^{(\alpha-\beta)g}\mathrm{d}g\right)\frac{\mathrm{e}^{-b}}{b}\mathrm{d}b\right]=\frac{(\alpha-\beta)(\beta-3\alpha)-2\alpha^2\log(\beta/\alpha)}{2\alpha(\alpha-\beta)^3/\beta} \tag{8}$$

The indeterminate form 0/0 when $\beta=\alpha$ is assumed. Applying L′ Hopital′s Rule yields

$$\lim_{\beta\rightarrow\alpha}\mu_X=\frac{1}{3\alpha} \tag{9}$$

It is assumed that the segmented burst is the kth priority burst. Let $G=(Y, Z)$ denote OBS network node structure, Y and Z are the node sets and the link sets, respectively. The segmented burst with the kth priority is scheduled on the optimum deflection path by the core node scheduler after bursts are segmented. The optimum deflection path should meet follow three conditions[10]: (a) the packet loss probability of the kth priority burst in the deflection path is the minimum; (b) the packet loss probability of the overall bursts in the deflection path is the minimum; (c) the length of the deflection path should be the minimum. In order to describe how to find the optimum deflection path for the kth priority segmented burst, the following notations are defined: $x_{i,j}(k)$ is the optimal solution of the integer linear programming; w is the number of the supporting wavelength in link $(i, i+1)$; m is the number of the burst priority in link $(i, i+1)$; $\rho_{i\to j}(k)$ is introducing the network load of the kth priority burst in link (i, j) as a result of deflection routing; $\rho_{i,j}$ is the original input network load in link (i, j); $B_{i,j}(k)$ is the kth priority the packet loss probability after the kth priority segmented burst is deflected in link (i, j); $B_{i,j}$ is the total packet loss probability after the kth priority segmented burst is deflected in link (i, j); μ_X is the expected amount of the segmented burst; $D_{i,j}$ is the transmission and processing delay from the node i to the node j; γ_k is the data loss cost factor of the kth priority packet loss probability; γ is the data loss cost factor of the total packet loss probability.

An assumption is made that the burst blocking event occurs independently from link to link. The objective function is stated as follows

Minimize: Min $\{F\}$[10]

$$F=\sum_{i,j}[x_{i,j}(k)\rho_{i\to j}(k)(D_{i,j}+B_{i,j}^{\gamma_k}(k))+x_{i,j}(k)\rho_{i,j}(D_{i,j}+B_{i,j}^{\gamma})] \tag{10}$$

In the deflection routing problem formulation, the variable $x_{i,j}(k)$ is defined as

$$x_{i,j}(k)=\begin{cases}1 & \text{link}(i,j)\in\text{link}(s,d)\\ 0 & \text{otherwise}\end{cases}\qquad \forall\, i,j,s,d\in Y \tag{11}$$

According to the flow conservative principle, the constraint condition of $x_{i,j}(k)$ is given by

$$\sum_{j\in Y}x_{i,j}(k)-\sum_{i\in Y}x_{i,j}(k)=\begin{cases}1 & i\in s\\ -1 & i\in d\\ 0 & \text{otherwise}\end{cases}\qquad \forall\, i,j,s,d\in Y,\ k=1,2,3,\cdots,m \tag{12}$$

Note that the segmented bursts are deflected in the optimum deflection path. It is assumed that the kth priority segmented bursts arrive to the network according to a Poisson process, and the arrival rate is $\lambda(k)$. Let $P_{i,i+1}(k)$ be the deflection probability of the kth priority burst from link $(i, i+1)$ to link (i, j). Then the network load $\rho_{i\to j}(k)$ is given by

$$\rho_{i\to j}(k)=\lambda(k)\mu_X P_{i,i+1}(k).\quad k=1,2,3,\cdots,m \tag{13}$$

The deflection probability adaptive change with the priority and network load of the segmented burst, and is regulated by the constant impact factor θ $(\theta>0)$. Let $r_{i,i+1}(k)$ be the ratio of the kth priority burst network load in link $(i, i+1)$. Let $B_{i,i+1}(k)$ be the kth priority packet loss probability in link $(i, i+1)$. $P_{i,i+1}(k)$ is then given by

$$P_{i,i+1}(k)=[1-r_{i,i+1}^{\theta/k}(k)]B_{i,i+1}(k) \tag{14}$$

According to the flow conservation principle, the constraint condition of formula (14) is given by

$$\sum_{k=1}^{m}[1-r_{i,i+1}^{\theta/k}(k)]=1 \tag{15}$$

An assumption is made that the transmission of the different priority burst is independent. Let $C_{i,j}(k)$ be the ratio of the kth priority burst network load in link (i, j) as the burst is segmented. $B_{i,j}(k)$ is then given by

$$B_{i,j}(k)=\frac{B[\sum_{a=1}^{k}(\rho_{i\to j}(a)+\rho_{i,j}),w]-\sum_{a=1}^{k-1}C_{i,j}(a)B_{i,j}(a)}{C_{i,j}(k)} \tag{16}$$

Where, $B(\rho, w)$ is the Erlang-B formula. Let $r_{i,j}(k)$ be the ratio of the kth priority burst original input network load in link (i, j). $B(\rho, w)$ and $C_{i,j}(k)$ are estimated by

$$B(\rho,w)=\frac{\rho^{w}/w!}{\sum_{h=0}^{w}\rho^{h}/h!} \tag{17}$$

$$C_{i,j}(k)=\frac{\rho_{i\to j}(k)+\rho_{i,j}r_{i,j}(k)}{\rho_{i,j}+\sum_{a=1}^{m}x_{i,j}(a)\rho_{i\to j}(a)} \tag{18}$$

Similarly, $B_{i,j}$ is given by

$$B_{i,j}=B[\rho_{i,j}+\rho_{i\to j}(k),w] \tag{19}$$

δ_k is the initial offset time between BCP and BDP. In order to obtain the minimum length of deflection path, the delay condition of the kth priority deflection burst on the deflection path should meet

$$\sum_{i,j}x_{i,j}(k)D_{i,j}\leqslant\delta_k\quad \forall\, i,j\in Y;\ k=1,2,3,\cdots,m \tag{20}$$

In this paper, the deflection probability can adaptive change with the priority and network load of the segmented burst. The dynamic control of the deflection service is achieved by regulating the constant impact factor θ. The optimum deflection path objective function can regulate the data loss cost factor γ_k and γ to choose the deflection path. A group of optimal solution (or a group of vector $\{x_{i,j}(k)\}$) will be obtained by the integer linear programming. Therefore, we can obtain the optimum deflection path of the kth priority segmented burst from the source node s to the destination node d.

3 Numerical results

In order to evaluate the performance of the proposed scheme and to verify the analytical models, a simulation model is developed. We do simulation tests and compare the performance of the Priority and Burst Segmentation-based Deflection Routing (PBSDR) algorithm, the

Priority-based Burst Segmentation (PBS) algorithm and the Tunable Parameter-based Deflection Routing (TPDR) algorithm.

In the simulation, a network with two priorities is considered. The fraction of high-priority (Class 0) bursts is 20% and the fraction of low-priority (Class 1) bursts is 80%. The high-priority bursts and the low-priority bursts arrive following a Poisson basis with rate 2, 10, respectively. An assumption is made that a network consists of 14 core nodes and 21 links. A pair of two-way fiber is set in each link and each fiber consists of one control channel and eight data channels. There is the wavelength conversion at the core node. The first-fit wavelength channel allocation algorithm is adopted in each fiber.

IP flows arrivals of the edge node are assumed to be Poisson. But bursts arrivals of the core node are uniformly distributed over all sender-receiver pairs. Burst lengths are exponentially distributed with average length of 1 Mbits. The link transmission rate is 10 Gbit/s. Packets are assumed to be 1 250 bytes. The configuration time of the switching is assumed to be 0.1 ms[11-12].

In the analytical model, the data traffic of each core node is equivalent to the Erlang load. 14 edge nodes send the data to the core network at the same time. The destination addresses randomly select 13 nodes except for the source node. The Latest Available Unused Channel (LAUC) algorithm is adopted to schedule bursts in the core node.

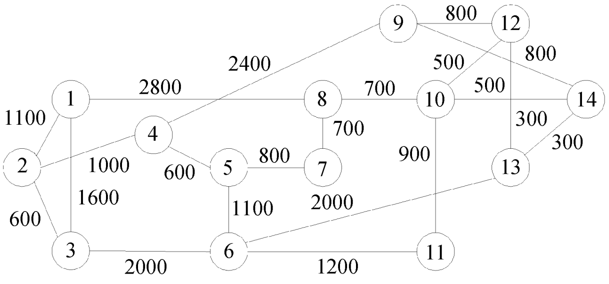


Fig. 5 Sketch map of NSFNET network topology

Fig. 6 Gives PLP versus network load for PBSDR, TPDR and PBS algorithm with $\gamma=\gamma_k=1$ and $\theta=2$. Fig. 6 shows that the high-priority packet loss probability is lower than the low-priority, which means that PBSDR algorithm provides QoS for OBS networks. The packet loss probability of PBSDR algorithm is higher than PBS algorithm when the network load is less than 0.2 ($\rho<0.2$). However, a conflict occurs between deflected bursts and bursts of other links in the deflection route of OBS networks when the network load is low, it leads to a excessive link blocking, what′s more, the packet loss probability of PBSDR algorithm is largely increased. But the packet loss probability of PBSDR algorithm is the lowest when $\rho>0.2$, it means that the performance of PBSDR algorithm is more effective than TPDR and PBS algorithm. The reason is that the burst segmentation scheme based on priority is introduced to the PBSDR algorithm before deflection routing.

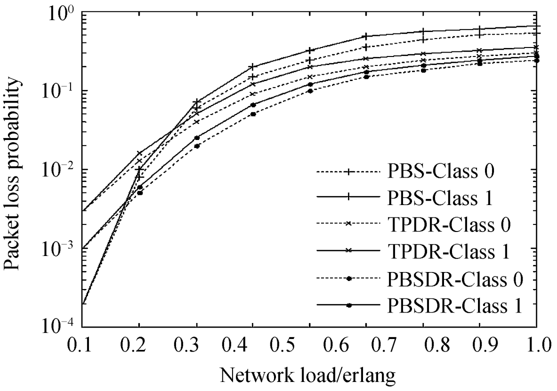


Fig. 6 The packet loss probability of *k*th priority burst versus network load

Fig. 7 plots the total PLP versus network load for PBSDR, PBS, and TPDR algorithm with $\gamma=\gamma_k=1$ and $\theta=2$. The total packet loss probability is the average value of the packet loss probability from the source node s to the destination node d. Fig. 7 shows that the total packet loss probability of PBSDR mechanism is the lowest. The total packet loss probability will increase with the increase of network load. Especially, the increased amplitude is extremely large when ρ is less than 0.4, the total packet loss probability increase rapidly while the variation amplitude is extremely gentle when ρ is more than 0.4. Therefore, this mechanism can efficiently improve the performance of networks when network load is low.

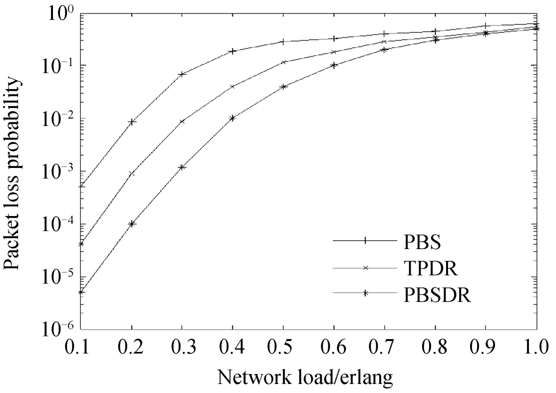


Fig. 7 The total packet loss probability versus network load

Fig. 8 shows the average end-to-end delay versus network load for PBSDR, PBS, and TPDR algorithm with $\gamma=\gamma_k=1$ and $\theta=2$. The average end-to-end delay of PBS algorithm is normalized to PBSDR and TPDR algorithm. Fig. 8 shows that the end-to-end delay of Class 0 is lower than the delay of Class 1. The end-to-end delay of PBSDR mechanism is lower than TPDR algorithm. So this mechanism can reduce the offset time deficit on QoS guarantee. In the worst cases, the PBSDR mechanism takes 0.05 ms longer than PBS algorithm which has a little influence.

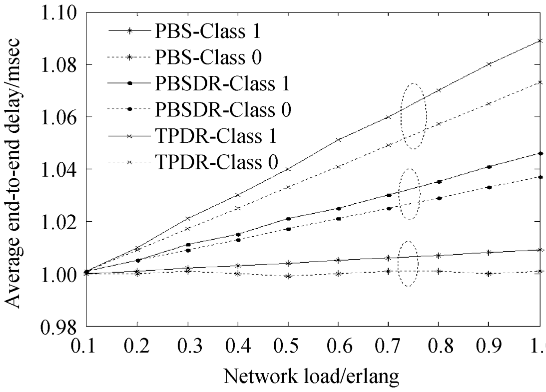


Fig. 8 The end-to-end delay versus network load with $\gamma=\gamma_k=1$ and $\theta=2$

4 Conclusion

A contention resolution technique by combining burst segmentation and deflection routing is given in this paper which provides QoS for OBS networks. The segmented burst will be deflected rather than droped or retransmitted. Then an analytical model was developed to calculate the packet loss probability and the end-to-end delay for a two-priority network. Simulation results show that high - priority bursts have significantly lower the packet loss probability and the delay than low-priority, and the scheme tend to perform better than the scheme with only burst segmentation or deflection routing.

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OBS网络中基于优先级与突发包分割的偏射路由机制

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摘　要：为了有效地降低突发包的丢失率和保证OBS网络中不同优先级业务的服务质量，提出了一种基于优先级与突发包分割的偏射路由机制．当冲突发生时，首先基于突发包的优先级进行“竞争突发包头部分割或者原突发包尾部分割”处理；无冲突部分直接在事先预留的输出数据信道上处理，冲突部分的分割突发包根据参数可调的偏射路由机制被偏射到最佳偏射路径上．仿真结果表明，该机制能够有效地降低整个网络的丢包率和端到端的延时，并且得到高优先级突发包的丢失率和延时低于低优先级突发包．由此可知，基于优先级与突发包分割的偏射路由机制能够有效地解决突发包的冲突问题，从而提高整个OBS网络的性能．

关键词：光通信；光突发交换；冲突解决；突发包分割；偏射路由；服务质量