A burst segmentation-deflection routing contention resolution mechanism in OBS networks*

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One of the key problems to hinder the realization of optical burst switching (OBS) technology in the core networks is the losses due to the contention among the bursts at the core nodes. Burst segmentation is an effective contention resolution technique used to reduce the number of packets lost due to the burst losses. In our work, a burst segmentation-deflection routing contention resolution mechanism in OBS networks is proposed. When the contention occurs, the bursts are segmented according to the lowest packet loss probability of networks firstly, and then the segmented burst is deflected on the optimum routing. An analytical model is proposed to evaluate the contention resolution mechanism. Simulation results show that high-priority bursts have significantly lower packet loss probability and transmission delay than the low-priority. And the performance of the burst lengths, in which the number of segments per burst distributes geometrically, is more effective than that of the deterministically distributed burst lengths.

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One of the significant issues in optical burst switching (OBS) networks is the contention resolution[1]. Existing contention resolution techniques include optical buffering[2,3], wavelength conversion[4,5], burst segmentation[6] and deflection routing[7,8]. Burst segmentation can significantly reduce the amount of lost data due to contention events. Deflection routing is the effective contention resolution method without extra hardware support, and can be rather effective under light or medium traffic load[7].

A contention resolution mechanism incorporating burst segmentation with deflection routing is proposed in this paper for providing quality of service (QoS) support in OBS network by adopting contention resolution mechanism. In the contention resolution mechanism, priorities are included as a field in the burst control packet (BCP). The priority field is used for segmenting and deflecting bursts preferentially when the contention is resolved in the core node of OBS networks.

One original burst data packet (OBDP) and one contending burst data packet (CBDP) are considered in this paper as shown in Fig.l. Let i, j, $(i+1)$ and h be core nodes. s and d denote the source node and the destination node. Po and Pc refer to the priorities of the OBDP and CBDP, respectively.

In order to simplify the analytical model, we assume that the link i-$(i+1)$ is the reserved route, which has the optimal free fiber link resource, and link i-j-$(i+1)$ (link 1) and link i-h-$(i+1)$ (link 2) are the alternative deflection routes, which have secondary optimal free fiber link resource. The shadow part of the burst is the segmented and deflected part.

In this approach of Po<Pc, the tail of OBDP is segmented. OBDP is divided into OBDP’ and OBDP”. The unaffected parts CBDP and OBDP’ are transmitted on the reserved link i-$(i+1)$ directly, as shown in Fig.1(a). The overlap part OBDP” is deflected. At the same time, the control system produces the corresponding BCP for every burst data packet (BDP). The information of BDP should be consequential changed according to the original BCP and the proceeding situation. The OBDP” is transmitted to the destination node on the optimum deflection link.

For the case of Po>Pc, the head of CBDP is segmented. CBDP is divided into CBDP’ and CBDP’’. The unaffected parts CBDP’ and OBDP are routed on the reserved link i-$(i+1)$ directly, as shown in Fig.1(b). The overlap part CBDP” is deflected on the optimal route by deflection routing mechanism. The optimum deflection path is determined in terms of placket loss probability (PLP) and the deflection

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path length. PLP of the kth priority burst and the overall bursts and the length of the deflection path are the minimum in the optimal deflection route. Similarly, the corresponding BCP is produced by the control system for every BDP when the head of CBDP is segmented. The information of BDP should be changed according to the original BCP and the proceeding situation.

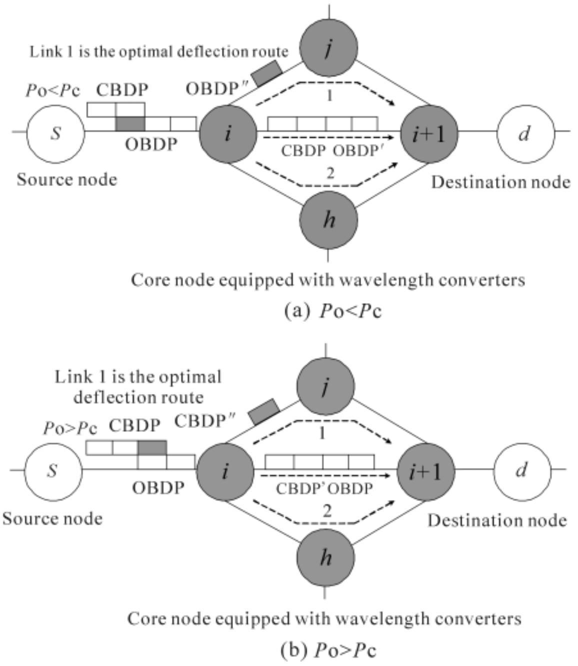

Fig.1 Schematic diagram of the contention resolution mechanism

It is assumed that all bursts have the same offset time. The segmented burst is scheduled on the optimum deflection link (i, j). While the unaffected bursts are transmitted to the destination node on the reserved link (i, i+1). Just-enough-time (JET) one-way resource reservation mechanism[9] is adopted in this paper, and the bursts arrive at the network according to a Poisson process. The average amount of the segmented burst is analyzed firstly when bursts are segmented.

Burst-gap cycle model is adopted in the wavelength data channel, as shown in Fig.2. A two-state (burst and gap) Markov system is proposed[10].

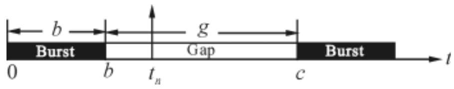

Fig.2 Structure of a burst-gap cycle

Each burst is divided into n segments with length of $1/\sigma$. 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 the probability density of $f_b=1/\alpha$, where α means the transition rate of the burst states. g is the length of the gap between bursts. An assumption is made that it is exponentially distributed with mean $1/\beta$, where β is the transition rate of the gap states. The expected value of the sum of the durations of a burst and a gap c is $1/\alpha+1/\beta$. Let t_n be the failure notification time, at which the switch is notified by its downstream neighbor, where a link failure has occurred. The failure notification time t_n is uniformly distributed over the interval [0, c]. When the tail of OBDP or the head of CBDP is segmented, the expected amount of the segmented burst conditioned on values for n and g is obtained through theoretical analysis as

$$\mu_{X|n,g} = \frac{b(b-1/\sigma)}{2(g+b)} , \tag{1}$$

where X means the amount of the segmented burst. Therefore, the theory proves that the expected amount of the segmented burst conditioned on values for n and g of the two burst segmentation mechanisms is consistent.

The joint probability density of n and g, which are independent, can be described as

$$f_{n,g}(n,g) = P_r(n)\cdot f_g(g) . \tag{2}$$

The expected amount of the segmented burst μ_X, is estimated by

$$\mu_X = \int_0^\infty f_g(g)\left(\sum_{n=1}^{\infty} P_r(n)\cdot \mu_{X|n,g}\right)\mathrm{d}g . \tag{3}$$

It is assumed that the burst length is determined. Two approaches are given as following, which consider the distribution of the number of segments per burst.

In the first approach the number of segments per burst n is deterministic with value σ/a, where σ/a is an integer. Since g is exponentially distributed with mean $1/\beta$, Eq.(3) becomes

$$\mu_X = \int_0^\infty \beta\,\mathrm{e}^{-\beta g}\,\frac{1}{g+n/\sigma}\,\frac{n(n-1)}{2\sigma^2}\,\mathrm{d}g = \int_0^\infty \frac{\beta\,\mathrm{e}^{-\beta g}(1-\alpha/\sigma)}{2\alpha^2(g+1/\alpha)}\,\mathrm{d}g = \frac{\beta\mathrm{e}^{\beta/\alpha}}{2\alpha^2}(1-\alpha/\sigma)\Gamma(0,\beta/\alpha) , \tag{4}$$

where $\Gamma(a,x) = \int_x^\infty u^{a-1}\,\mathrm{e}^{-u}\,\mathrm{d}u$ is the incomplete gamma function.

It is assumed that the average burst length $b=1/\alpha$ remains fixed. The segment length $1/\sigma$ decreases ($\sigma \to \infty$). $\mu_{X|n,g}$ and μ_X are estimated by

$$\lim_{\sigma\to\infty}\mu_{X|n,g} = b^2/2(g+b) , \tag{5}$$

$$\lim_{\sigma\to\infty}\mu_X = \frac{\beta\,\mathrm{e}^{\beta/\alpha}}{2\alpha^2}\Gamma(0,\beta/\alpha) . \tag{6}$$

The number of segments per burst n is geometrically distributed in the second approach, with probability mass function

$$P_r(n)=P_r(b=n/\sigma)=(1-p)p^{n-1},\quad n=1,2,\cdots \tag{7}$$

Applying Eq.(3) yields

$$\mu_X=\frac{\beta(1-p)}{2\sigma^2}\sum_{n=1}^{\infty}n(n-1)p^{n-1}\,\mathrm{e}^{\beta n/\sigma}\,\Gamma(0,\beta n/\sigma)\ , \tag{8}$$

where $p=1-\alpha/\sigma$.

The expected amount of the segmented burst is obtained by Eq.(4) and Eq.(8) in different circumstances.

Let $G=(Y, Z)$ denote OBS network node structure, Y and Z be the node sets and the link sets, respectively. It is assumed that the segmented burst is the kth priority burst. 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 the following conditions[11]: PLP of the kth priority burst and the overall bursts in the deflection path are the minimum, and 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; γ_k is the data loss cost factor of the kth priority PLP; γ is the data loss cost factor of the total PLP; 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); $\tilde{n}_{i\to j}(k)$ is the network load of the kth priority burst in link (i,j) as a result of deflection routing; $\tilde{n}_{i,j}$ is the original input network load in link (i,j); $B_{i,j}(k)$ is the kth priority PLP after the kth priority segmented burst is deflected in link (i,j); $B_{i,j}$ is the total PLP after the kth priority segmented burst is deflected in link (i,j); and $D_{i,j}$ is the transmission and processing delay from the node i to the node j.

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

Minimize: Min $\{H\}$[11].

$$H=\sum_{i,j}[x_{i,j}(k)\rho_{i\to j}(k)(D_{i,j}+B_{i,j}^{\gamma_k}(k))+ x_{i,j}(k)\rho_{i,j}(D_{i,j}+B_{i,j}^{\gamma})]\ . \tag{9}$$

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

$$x_{i,j}(k)=\begin{cases}1,\mathrm{link}(i,j)\in\mathrm{link}(s,d)\\0,\mathrm{otherwise}\end{cases},\forall i,j,s,d\in Y\ . \tag{10}$$

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

$$\sum_{j\in Y}x_{i,j}(k)-\sum_{i\in Y}x_{i,j}(k)=\begin{cases}1,i\in s\\-1,i\in d\\0,\mathrm{otherwise}\end{cases},$$

$$\forall i,j,s,d\in Y,k=1,2,3,\cdots,m. \tag{11}$$

It is assumed that the kth priority segmented bursts arrive at 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 $\tilde{n}_{i\to j}(k)$ is given by

$$\rho_{i\to j}(k)=\lambda(k)\mu_X P_{i,i+1}(k),k=1,2,3,\cdots,m\ . \tag{12}$$

The deflection probability changes adaptively 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 PLP in link (i, i+1). $P_{i,i+1}(k)$ is then given by

$$P_{i,i+1}(k)=[1-r_{i,i+1}^{\theta/k}(k)]B_{i,i+1}(k)\ . \tag{13}$$

According to the flow conservation principle, the constraint condition of Eq.(13) is given by

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

It is assumed that the transmissions of different priority bursts are 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

$$B_{i,j}(k)=\frac{B[\sum_{a=1}^{k}(\rho_{i\to j}(a)+\rho_{i,j}),w]-\sum_{a=1}^{k-1}C_{i,j}(a)B_{i,j}(a)}{C_{i,j}(k)}\ , \tag{15}$$

where B ($\tilde{n}$, 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 ($\tilde{n}$, w) and $C_{i,j}(k)$ are estimated by

$$B(\rho,w)=\frac{\rho^w/w!}{\sum_{h=0}^{w}\rho^h/h!}\ , \tag{16}$$

$$C_{i,j}(k)=\frac{\rho_{i\to j}(k)+\rho_{i,j}r_{i,j}(k)}{\rho_{i,j}+\sum_{a=1}^{m}x_{i,j}(a)\rho_{i\to j}(a)}\ . \tag{17}$$

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

$$B_{i,j}=B[\rho_{i,j}+\rho_{i\to j}(k),w]\ . \tag{18}$$

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

$$\sum_{i,j} x_{i,j}(k) D_{i,j} \le \delta_k,\ \ \forall i,j \in Y,\ \ k = 1,2,3,\cdots,m \ . \qquad (19)$$

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 factors 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.

A network with two priorities is considered. We use the model to compute PLP and the average end-to-end transmission delay when the burst length is deterministic and the number of segments per burst is either deterministically or geometrically distributed corresponding to Eq.(4) and Eq.(8), respectively. The high-priority bursts and the low-priority bursts arrive following a Poisson basis with rates 2 and 10, respectively. The fraction of high-priority (class 0) bursts is 20%, and the fraction of low-priority (class 1) bursts is 80%. It is assumed 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. The first-fit wavelength allocation algorithm is adopted in each fiber.

Internet protocol (IP) flows arrivals of the edge node are assumed to be Poisson. Burst lengths are deterministically distributed with average length of 1 Mbits. The link transmission rate is 10 Gbit/s. Packets are assumed to be 1250 bytes. The configuration time of the switching is assumed to be 0.1 ms[12,13]. But bursts arrivals of the core node are distributed uniformly over all sender-receiver pairs.

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

Fig.3 gives PLP of kth priority burst versus network load for priority-based burst segmentation-deflection routing (PBSDR), priority-based burst segmentation (PBS) and tunable parameter-based deflection routing (TPDR) algorithms with $\gamma=\gamma_k=1$ and $\theta=2$. Fig.3 shows that the PLP of high-priority bursts is lower than that of low-priority bursts, which means that PBSDR mechanism provides QoS for OBS networks. And PLP of the geometrically distributed burst lengths, which means the number of segments per burst, is lower than PLP of the deterministically distributed burst lengths, and that is to say the performance of the geometrically distributed burst length is better than that of the deterministically distributed. The PLP of PBSDR mechanism is higher than PBS algorithm when the network load is less than 0.15 (ρ<0.15). But the PLPL of PBSDR algorithm is the lowest when ρ>0.15, which means that the performance of PBSDR mechanism is more effective than TPDR and PBS algorithms. The reason is that the burst segmentation mechanism based on priority is introduced to the PBSDR mechanism before deflection routing.

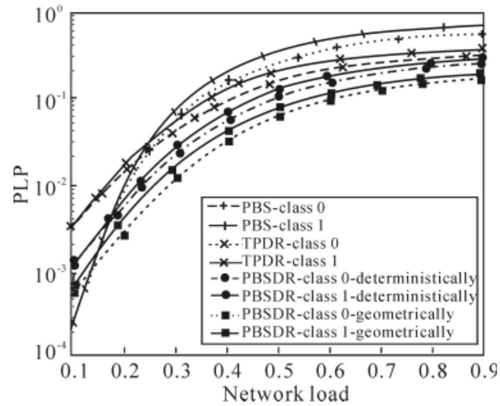

Fig.3 PLP of kth priority burst versus network load

Fig.4 plots the total PLP versus network load for PBSDR, PBS and TPDR algorithms with $\gamma=\gamma_k=1$ and $\theta=2$. The total PLP is the average value of the PLP from the source node s to the destination node d. Fig.4 shows that the total PLP of PBSDR mechanism is the lowest, and the total PLP of the geometrically distributed burst lengths is lower than the deterministically distributed. The total PLP increases with the increase of network load. Especially, the increased amplitude is extremely large when ρ is less than 0.4, and the total PLP increases rapidly while the variation amplitude is extremely gentle when ρ is more than 0.4. Therefore, this mechanism can improve the performance of networks efficiently when network load is low.

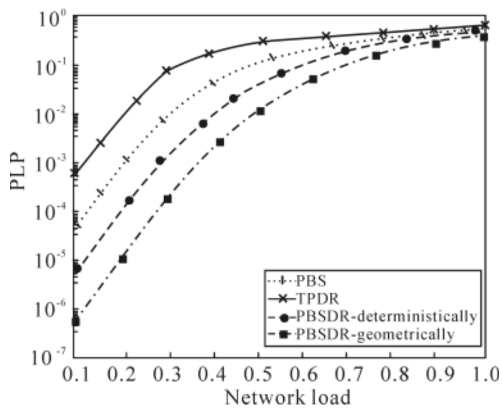

Fig.4 Total PLP versus network load

Fig.5 shows the average end-to-end transmission delay verus network load for PBSDR, PBS and TPDR algorithms with $\gamma=\gamma_k=1$ and $\theta=2$. The average end-to-end transmission delay of PBS algorithm is normalized to PBSDR and TPDR algorithms. Here the number of segments per burst is the geometrically distributed. Fig.5 shows that the end-to-end transmission delay of class 0 is lower than that of class 1. The end-to-end transmission delay of PBSDR mechanism is lower than that of 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.

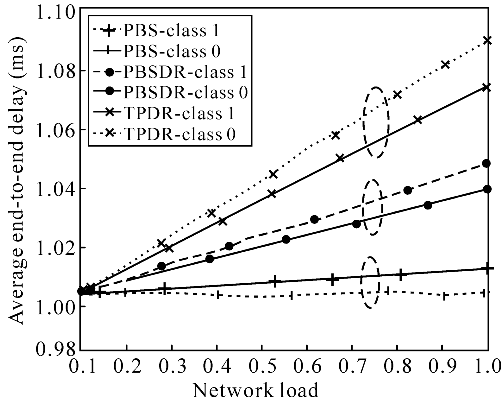

Fig.5 End-to-end transmission delay versus network load

A contention resolution mechanism, which provides QoS for OBS networks by combining burst segmentation and deflection routing, is given in this paper. The segmented burst is deflected rather than droped or retransmitted. Then an analytical mathematical model is developed to calculate PLP and the end-to-end transmission delay for a two-priority network. Simulation results show that high-priority bursts have significantly lower PLP and transmission delay than low-priority bursts, and the mechanism tends to perform better than the mechanism with only burst segmentation or deflection routing. The performance of the geometrically distributed burst lengths is more effective than that of the deterministically distributed burst lengths.

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