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光突发交换网络中支持服务质量的一种新方案*

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A New Approach in Optical Burst Switching Networks with QoS Support

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Abstract: A new approach in optical burst switching (OBS) networks with QoS support is presented in this paper. In the approach, the data channels of an outgoing link at a core node are divided into multiple groups, with each group corresponding to a service class. The number of data channels in each group is mainly determined by data traffic. In general, a data burst (DB) can be sent on a data channel reserved by its burst head packet (BHP) only in its own group. Upon failing to reserve any bandwidth in its own group, the BHP tries to re-reserve even preempted bandwidth on a data channel in a lower-priority group. A lower-priority BHP can't reserve bandwidth on any data channel in a higher-priority group. In addition, the reasonable relation between the preempting DB length and the preempted DB length is also investigated in this paper.
Key words: optical burst switching (OBS); quality of service (QoS); differentiated service

摘 要： 提出了光突发交换网络支持服务质量的一种新方案.在此方案中,核心节点根据到达的数据突发的优先级别,将每一出口链路的数据信道进行分组.每一组别的数据信道数主要取决于相应优先级别的数据流量.通常情况下,属于某优先级别的数据突发会被调度在相应组别的数据信道上.在高优先级别的数据突发未能预留在其相应组别的数据信道上时,可尝试为其在低组别的数据信道上预留,甚至抢占低组别内已经被预留的信道;低优先级别的数据突发不能被预留在高组别的数据信道上.另外,也考察了抢占数据突发长度与被抢占数据突发长度之间的关系.
关键词： 光突发交换;服务质量;区分服务

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1 Introduction

Recent studies show that optical burst switching (OBS)[1,2] is a promising solution for building an all-optical wavelength-division-multiplexing (WDM) layer for the optical Internet. In OBS networks, a great deal of IP packets, with the same network egress address and some common attributes like quality of services (QoS), are grouped into a burst and forwarded through the network as a single entity. OBS uses physically separate wavelengths (or channels) to transmit DBs and their BHPs. The BHP is transmitted ahead of DB in order to configure the switches along the burst's route. The DB follows BHP after some offset time without waiting for an acknowledgment that the necessary resources have been reserved or configured. This allows optical core routers to process BHP electronically for the establishment of an end-to-end optical path, and to switch DB optically. The offset time allows BHP to be processed at each node while DB is buffered electronically at the source; thus, no fiber delay lines are necessary at the intermediate nodes to delay the burst while the header is being processed.

Over the past decade, a significant amount of work has been dedicated to the issue of providing QoS in non-WDM IP networks. This work has culminated in the proposal of the Integrated Services (Intserv)[3] and the Differentiated Services (Diffserv)[4] architectures by the IETF. Intserv achieves QoS guarantees through end-to-end resource (bandwidth) reservation for packet flows and performing per-flow scheduling in all intermediate routers or switches. Diffserv, on the other hand, defines a number of per-hop behaviors that enable providing relative QoS advantage for different classes of traffic aggregates. However, previous QoS methods proposed for IP networks are difficult to be applied in WDM networks mainly due to the fact that these approaches are based on the store-and-forward model and mandate the use of buffers for contention resolution.

There are two models for QoS: Relative QoS and absolute QoS. In the relative QoS model, the QoS of one class is defined relatively in comparison to other classes. For example, a class of high priority is guaranteed to experience lower loss probability than a class of lower priority. However, no upper bound on the loss probability is guaranteed for the high-priority class.

Up to now, several solutions have been proposed to support relative QoS in OBS networks. Yoo first studied offset-time-based QoS scheme[5], whose basic idea is that an extra offset-time is required for high priority class besides the basic offset-time to obtain high probability of bandwidth reservation. However, the use of an extra offset time, which isolates a high priority class from lower priority classes, does increase the end-to-end delay. Studies show that well isolation degree of adjacent classes of service can be achieved while their difference of offset-time is at least 3L, where L denotes the duration of a DB. Vokkarane proposed segmentation-based QoS approach[6]. When a contention occurs, the DB is broken into multiple segments, and only the overlapped segment with the lower priority will be dropped. It is very difficult to guarantee QoS of each class. Chen studied a proportional QoS scheme[7]. The loss rate of each class is maintained in a predefined proportion according to the priority. An arrival packet will be dropped if its predefined loss rate is violated regardless of whether there is an idle channel. The intentional dropping gives more and longer free periods of wavelengths in the output link to admit high priority bursts. This approach, however, always causes excessive dropping. By introducing preemptive technology, Loi, Cankaya, Yang, etc. studied the proportional QoS issue[8−10], respectively. In their approaches, intentional dropping is avoided, and the preemptive technology is introduced to guarantee performance of high priority classes. However, their approaches only support relative QoS guarantees in terms of packet loss rate or reserved bandwidth, and each core node needs to trace the actual proportion for each class dynamically.

The absolute QoS model provides a worst-case QoS guarantee to applications. This kind of hard guarantee is essential to support applications with delay and bandwidth constraints, such as multimedia and mission-critical applications. Moreover, from the ISP's point of view, the absolute QoS model is preferred in order to ensure that each user receives an expected level of performance. Efficient admission control and resource provisioning mechanisms are needed to support the absolute QoS model.

Several schemes have been proposed for providing absolute loss to the guaranteed traffic[11,12], namely, early dropping and wavelength grouping. The integration of these two schemes significantly reduces the loss experienced by the non-guaranteed traffic, while also guaranteeing the loss of the guaranteed traffic. However, it only provides absolute loss at a per-hop level. By introducing path clustering technique, Zhang proposed a scheme to implement absolute QoS differentiation schemes over an entire network[13,14], so as to ensure that the maximum loss requirement on each hop along every path satisfies the end-to-end loss requirement.

Based on our early work[15], we present a new approach in OBS networks with QoS support. Contrasting to the existing QoS schemes, the approach can support quality of service in terms of packet loss rate, reserved bandwidth and delay, and can achieve well absolute end-to-end QoS guarantees rather than relative QoS guarantees. To achieve the goal, the core routers don't need to trace the actual performance of each class dynamically. In addition, due to the fact that the preemption may cause a large amount of lost packets and waste bandwidth, it is necessary to determine the reasonable relation between the preempting DB length and the preempted DB length, which is also studied in this paper.

The rest of the paper is organized as follows. Section 2 describes the basic ideas of the proposed approach. Section 3 details the functional model of the core node, and Section 4 gives the functions of ingress. The relation between the preempting DB length and the preempted DB length is analyzed in Section 5. Section 6 presents performance evaluations. Section 7 concludes the paper.

2 Basic Ideas

In the proposed approach, the data channels of an outgoing link at a core node are divided into multiple groups, with each group corresponding to a service class. The number of data channels in each group is mainly determined by data traffic. For a DB, in general, its BHP can reserve bandwidth on a data channel only in its corresponding group. Upon failing to reserve any bandwidth in its own group, the BHP tries to re-reserve even preempted bandwidth on a data channel in a lower-priority class. A low priority DB can't be granted reservation on any data channel in a higher-priority group. At ingress, a DB consists of IP packets with the same network egress address and the same service class, with its BHP marked with the service characteristics.

The following service classes are considered in this paper: best effort service, service of bandwidth guarantee, service of IP packet loss rate guarantee and service of delay guarantee. The best effort service is the lowest class of service. For this service, network tries its best to delivery DBs without any QoS guarantees. The service of bandwidth guarantee commits customer the lowest bandwidth, and its priority is higher than that of the best effort service. The service of IP packet loss rate guarantee commits customer the highest packet loss rate, and its priority is higher than that of the service of bandwidth guarantee. The service of delay guarantee supports low delay and low delay jitter, and belongs to the highest class of service.

3 Functional Model of the Core Node

To realize the above-mentioned ideas, the following modules are appended at the core node: meter, data channel group controller and policy controller, as shown in Fig.1.

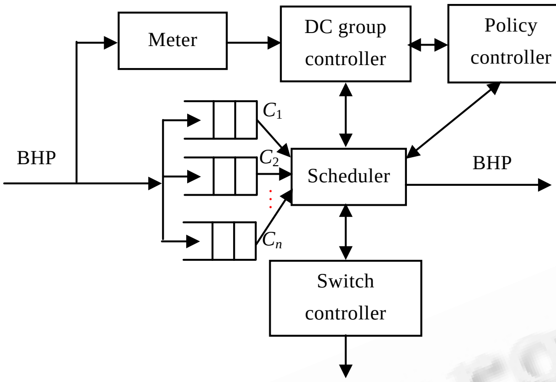


Fig.1 Functional model of the core node

3.1 Meter

The meter performs metering of BHP traffic of each class. Since each DB has a corresponding BHP, the traffic of BHPs also reflects that of DBs.

3.2 Data channel (DC) group controller

Based on the traffic of each class and the rule for data channel grouping, the DC group controller performs distribution of data channels to determine the number of data channels in each group.

3.3 Policy controller

Based on the traffic of each class, the policy controller determines the rule for data channel grouping and the rule for BHP scheduling. The policy controller also determines the rule for bandwidth reservation based on the information about the reserved bandwidth in each class.

3.3.1 The rule for data channel grouping

The rule for data channel grouping is determined by the service characteristics and the traffic of each class. In general, only the traffic is considered, in which case, the number of data channels in each group is proportional to the traffic of the corresponding class. The rule may not be strictly obeyed under the consideration of both the service characteristics and the traffic of each class. In this case, the basic rule must be obeyed that the data channels to be distributed must increase with the traffic amount in each class.

3.3.2 The rule for BHP scheduling

The rule for BHP scheduling is also determined by the service characteristics and the traffic of each class. For example, the FIFO (first-in-first out) algorithm can be used to schedule BHPs with the same service characteristics, and the WRR (weighted-round-robin) algorithm or other scheduling algorithms for supporting differentiated services can be used to schedule BHPs with different service characteristics. For the WRR algorithm, the weight can also be updated adaptively by the traffic amount in each class.

3.3.3 The rule for bandwidth reservation

In general, BHP makes a reservation on a data channel only in its own group for transmitting the followed DB, and it is not allowed for a BHP to reserve bandwidth on a data channel in a higher-priority group. Upon failing to reserve bandwidth initially in its own group, does the BHP try to re-reserve? Does it perform preemption when the re-reservation fails? Which group will be selected for the preemption? Therefore, the rule for bandwidth reservation will address all these issues.

3.4 Scheduler

The scheduler is responsible for scheduling BHP and reserving bandwidth based on their respective rules. Preemption is performed at the cost of few lost packets and little wasted bandwidth.

3.5 Switch controller

The switch controller configures the optical switching matrix based on information from the scheduler.

4 Functions of Ingress

At ingress, IP packets are classified and metered in terms of its service characteristics. IP packets in-profile or out-profile are queued into separate queues, and then are assembled as DB in-profile or out-profile, respectively. The corresponding BHP is marked with the service characteristics. In this way, as long as core nodes guarantee the reservation for DBs in-profile, the corresponding service is achieved.

5 The Relation between the Preempting DB Length and the Preempted DB Length

In the approach, the higher-priority DB may preempt bandwidth having been reserved for the lower-priority DB, thereby causing large amount of IP packets of the preempted DB to be lost and the bandwidth on the preempted data channel to be wasted.

5.1 Ignoring the influence of void

For one preemption case, the lost IP packets of the preempted DBs and the wasted bandwidth on the preempted data channel are analyzed under the presumption that the preempted data channel is fully utilized when the preemption occurs. The assumption allows us to ignore the void between adjacent preempted DBs. To facilitate formulizing the relation, symbols and variables are defined as follows.

DB_H: the preempting DB

DB_L: the preempted DB

BHP_H: BHP corresponding to DB_H

BHP_L: BHP corresponding to DB_L

K_H: the number of IP packets in one DB_H

K_L: the number of IP packets in one DB_L

L_H: the duration of DB_H

L_L: the duration of DB_L

L_{IP}: the duration of one IP packet

r: the value of L_H/L_L

$B_{①}$, $B_{②}$: the sum of wasted bandwidth

$N_{①}$, $N_{②}$: the sum of lost IP packets

$p_{①}$, $p_{②}$: the probability of preemption

B: the average of wasted bandwidth

N: the average of lost IP packets

where the subscripts ① and ② represent two kinds of preemptions, respectively.

For $(k-1)L_L \le L_H < kL_L (k=1,2,3,\ldots)$, Table 1 illustrates the values of the related parameters for two kinds of preemptions.

Table 1 Values of the related variables for two preemption cases

k times of DB_L are preempted	k+1 times of DB_L are preempted
$B_{①}=kL_L-L_H$	$B_{②}=kL_L-L_H+L_L=(k+1)L_L-L_H$
$N_{①}=kK_L$	$N_{②}=(k+1)K_L$
$p_{①}=(kL_L-L_H)/L_L$	$p_{②}=1-p_{①}=1-(kL_L-L_H)/L_L$
$B=B_{①}p_{①}+B_{②}p_{②}=K_L L_{IP}=K_H/r\cdot L_{IP}$	
$N=N_{①}p_{①}+N_{②}p_{②}=(r+1)K_L=(1+1/r)K_H$	

Obviously, parameter r plays an important role in computing the wasted bandwidth and the lost IP packets. Given the consistent length of DB_L, B is consistent and is independent of r, whereas N is approximately proportional to the value of r. Given the consistent length of DB_H, the larger the r is, the less B and N are. In this case, however, the length of DB_L will be decreased, which will lead to high overhead due to the increase of the number of BHP_L. So, it is necessary to choose a reasonable r in terms of the wasted bandwidth, the lost IP packets and system overhead.

Due to the fact that the system overhead is mainly rooted in dealing with BHPs, parameter, H, is introduced to represent the overhead and its value is proportional to the number of BHPs, that is.

$$H=1/K_H+R_T/K_L=(R_T r+1)/rK_L=(R_T r+1)/K_H \quad (1)$$

where R_T denotes the ratio of data traffic between two classes.

For the sake of description, all variables are appended subscript "0" while r=1.

$$H_0=(1+R_T)/K_{H0}=(1+R_T)/K_{L0} \quad (2)$$

In purpose of comparison, we can find the relative difference of the wasted bandwidth, B_E, and the relative difference of the lost packets, N_E, as given by,

$$B_E=(B-B_0)/B_0 \quad (3)$$

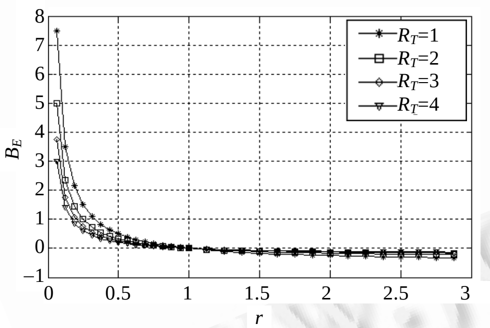
$$N_E=(N-N_0)/N_0 \quad (4)$$

Inserting the expressions for B and N, we finally have

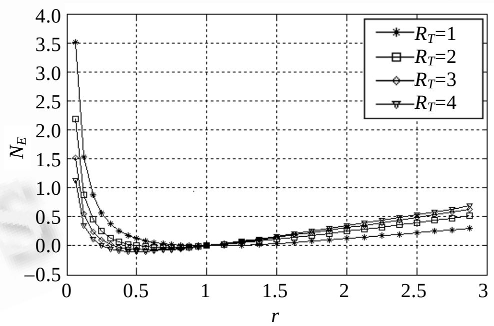
$$B_E=(1-r)/[(R_T+1)r] \quad (5)$$

$$N_E=[R_T r^2-(R_T+1)r+1]/[2(R_T+1)r] \quad (6)$$

Figure 2 shows the numerical results of B_E and N_E against r. From the results, we can observe: (1) B_E monotonously decreases with r. The curve is comparatively flat while $r>1/R_T$, and the low limit is $-1/(1+R_T)$. (2) N_E does not vary monotonously with r. The curve is considerably steep and N_E is above zero while $r<1/R_T$. N_E is negative while $1/R_T<r<1$. N_E increases approximately linearly with r while $r>1$. Therefore, the reasonable value of r is close to 1, i.e., the length of the preempting DB and that of the corresponding preempted DB are approximately equal.



(a) The curves of B_E



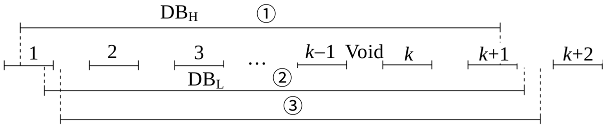
(b) The curves of N_E

Fig.2 Curves of B_E and N_E to r with different R_T

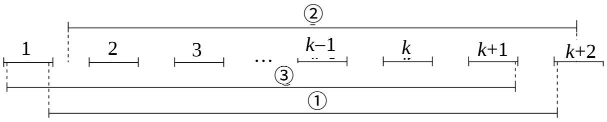
5.2 With the influence of void

Let L_V denote the duration of each void, and $L_V<L_L$. Other variables have the same meanings as in Section 5.1. Figure 3 illustrates the possible preemption cases while $L_L>L_V$, and accordingly, Table 2 lists the values of the related variables for these cases.

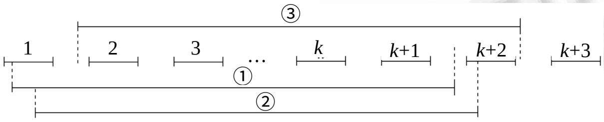
The following the similar analysis narrated in Section 5.1, we can obtain the numerical results of B_E and N_E, as shown in Fig.4, where $r_V=L_V/L_L$ and R_T=4. We can observe the similar relationship of B_E and N_E to r.



(a) $kL_L+kL_V\le L_H\le kL_L+(k+1)L_V$



(b) $kL_L+(k+1)L_V\le L_H\le (k+1)L_L+kL_V$

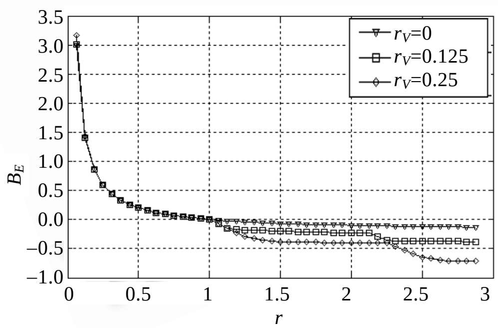


(c) $(k+1)L_L+kL_V\le L_H\le (k+1)L_L+(k+1)L_V$

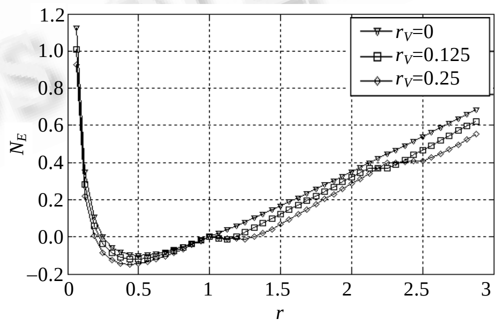
Fig.3 Possible preemption cases while $L_L>L_V$

Table 2 Values of the related variables for possible preemption cases (k=0,1,2,3,…)

	$KL_L+kL_V\le L_H\le kL_L+(k+1)L_V$	$kL_L+(k+1)L_V\le L_H\le (k+1)L_L+kL_V$	$(k+1)L_L+kL_V\le L_H\le (k+1)L_L+(k+1)L_V$
$B_①$	$(k+1)L_L-L_H$	$(k+2)L_L-L_H$	$(k+1)L_L-L_H$
$B_②$	$(k+1)L_L-L_H$	$(k+1)L_L-L_H$	$(k+2)L_L-L_H$
$B_③$	kL_L-L_H	$(k+1)L_L-L_H$	$(k+1)L_L-L_H$
$N_①$	$(k+1)K_L$	$(k+2)K_L$	$(k+1)K_L$
$N_②$	$(k+1)K_L$	$(k+1)K_L$	$(k+2)K_L$
$N_③$	kK_L	$(k+1)K_L$	$(k+1)K_L$
$p_①$	$[(k+1)L_L+kL_V-L_H]/[(k+1)L_L+(k+1)L_V-L_H]$	$[L_H-kL_L-(k+1)L_V]/L_L$	$[(k+1)L_L+(k+1)L_V-L_H]/(L_H-kL_L-kL_V)$
$p_②$	$(L_H-kL_L-kL_V)/[(k+1)L_L+(k+1)L_V-L_H]$	L_V/L_L	$[L_H-kL_L-(k+1)L_V]/(L_H-kL_L-kL_V)$
$p_③$	$[kL_L+(k+1)L_V-L_H]/[(k+1)L_L+(k+1)L_V-L_H]$	$[(k+1)L_L+kL_V-L_H]/L_L$	$[L_H-(k+1)L_L-kL_V]/(L_H-kL_L-kL_V)$
B	$B_①p_①+B_②p_②+B_③p_③$		
N	$N_①p_①+N_②p_②+N_③p_③$		



(a) The curves of B_E



(b) The curves of N_E

Fig.4 Curves of B_E and N_E to r with different r_V

6 Performance Evaluations

In our simulations, the algorithm for data channel scheduling is LAUC-VF (latest available unscheduled channel with void filling), and the assembly algorithm is MBLMAP (min-burst-length-max-assembly-period). All ingresses use the ON/OFF source model. Three service classes are considered: service of IP packet loss rate guarantee (class 1), service of bandwidth guarantee (class 2) and best effort service (class 3). The related rules are as follows.

(1) The rule for data channel grouping: the number of data channels in each group is proportional to the traffic of the corresponding class.

(2) The rule for BHP scheduling: since there is no congestion on control channel, the FIFO algorithm is used to schedule BHPs.

(3) The rule of bandwidth reservation: re-reservation is performed for DB out-profile, and preemption is only performed for DB in-profile.

Simulation topology is shown in Fig.5, where the WDM links from ingress $E1$, $E2$ and $E3$ to core node $N1$ have 6, 8 and 8 data channels, respectively, and the bottleneck WDM link has 10 data channels. The bandwidth of each data channel is 2.5Gbps. Class 1, class 2 and class 3 are supported at ingress $E1$, $E2$ and $E3$, respectively. The ratio of source traffic at ingress $E1$, $E2$ and $E3$ is 1:2:2.

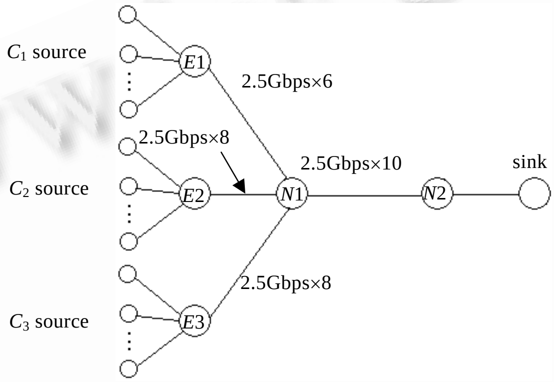


Fig.5 Simulation topology

Figure 6 shows the IP packet loss rate for three classes at node $N1$. As the offered load increases, the loss rate increases. The loss rate for class 3 is bigger than that for class 2 and class 1. The loss rate for class 1 is the smallest and less than 1E−3 even if the load reaches 1.0.

The link utilization of the bottleneck WDM link is shown in Fig.7. The link utilization is just slightly lower than the offered load due to the very low packet loss rate while the load is less than 0.8. Even if the load is 1.0, the link utilization is still high.

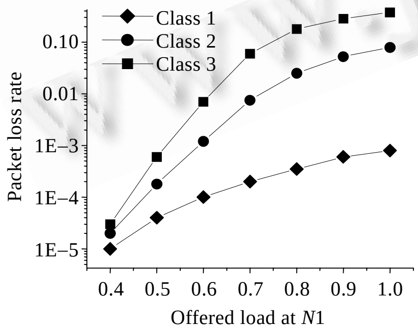


Fig.6 Packet loss rate for three classes at node $N1$

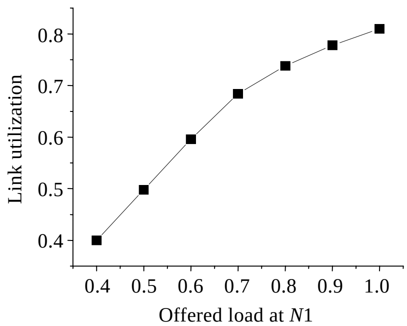


Fig.7 Link utilization of the bottleneck WDM link

Figure 8 shows the committed packet loss rate and the actual packet loss rate for class 1 at node $N1$. The actual packet loss rate is always lower than the committed packet loss rate. So the service of loss rate guarantee is well achieved. Figure 9 shows the committed bandwidth and the actual reserved bandwidth for class 2. The actual reserved bandwidth is always higher than the committed bandwidth. So the service of bandwidth guarantee is well achieved.

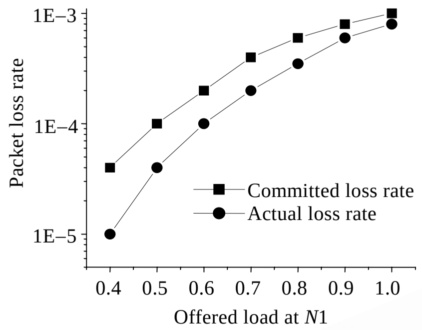


Fig.8 Committed packet loss rate and actual packet loss rate for class 1

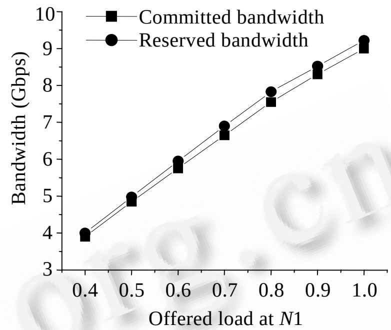


Fig.9 Committed bandwidth and reserved bandwidth for class 2

7 Conclusions

QoS support is an important issue in OBS networks. There are two models for QoS: relative QoS and absolute QoS. In the relative QoS model, the performance of each class is not defined quantitatively in absolute terms. Instead, the QoS of one class is defined relatively in comparison to other classes. The absolute QoS model provides a bound for loss probability of the guaranteed traffic. This kind of hard guarantee is essential to support applications with delay and bandwidth constraints, such as multimedia and mission-critical applications.

In this paper, we present a new approach in OBS networks with QoS support, which integrates preemptive technique and data channel grouping. Contrasting to the existing QoS schemes, the approach can support differentiated services in terms of packet loss rate, reserved bandwidth and delay, and can achieve well absolute end-to-end QoS guarantees rather than relative QoS guarantees. To achieve the goal, core routers don't need to trace the actual performance of each class dynamically. Based on the analysis, the length of preempting DB and that of preempted DB are approximately equal.

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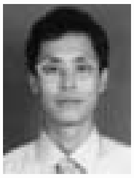

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