OPTOELECTRONICS LETTERS Vol.10 No.1, 1 January 2014

A new composite assembly mechanism for supporting QoS in OBS networks*

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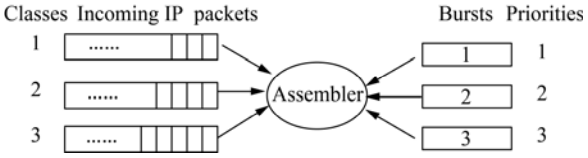
(Received 5 August 2013; Revised 23 October 2013)

To provide the differential quality of service (QoS) for different classes of packets and reduce the packet loss probability (PLP), a novel priority-based composite assembly scheme for optical burst switching (OBS) networks is proposed. The low and high packet classes are aggregated into a single burst simultaneously, and the highest-priority packets are placed in the middle, while the low-priority packets are at the tail and head of the burst. The priority is lowered gradually from the middle to the ends. Simulation results demonstrate that the proposed assembly strategy not only guarantees the integrity of the high-priority bursts, but also significantly reduces the average end-to-end delay of the bursts and the PLP of network. So it can adapt to the flexible network with QoS requirement.

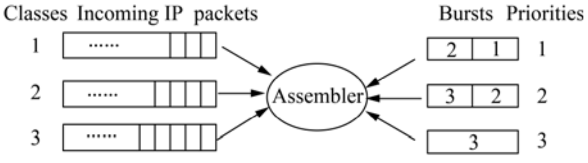
Document code: A **Article ID:** 1673-1905(2014)01-0055-4
DOI 10.1007/s11801-014-3140-9

The optical burst switching (OBS) technology, which can efficiently utilize the huge bandwidth resources provided by wavelength division multiplexing (WDM)[1], is developed under the background of the increase of internet runoff, and it is a balanced choice of optical circuit switching (OCS) and optical packet switching (OPS)[2]. One of the significant issues in OBS networks is data burst assembly[3] as it has great significance for the contention resolution[4]. Burst segmentation based on priority[5] is considered to be an effective contention resolution at present, because it can increase OBS network's resource utilization and throughput. According to this method, the corresponding assembly mechanisms at the edge node include priority-based burst's head assembly (PBHA)[6] and priority-based burst's tail assembly (PBTA)[7]. Both of them guarantee the integrity of the high-priority burst, but they don't take account of the high-class packets contained in the low-priority burst which will result in high packet loss and the deterioration of network performance in quality of service (QoS). Aiming at this point, a novel composite burst assembly scheme which incorporates PBHA with PBTA is put forward in this paper.

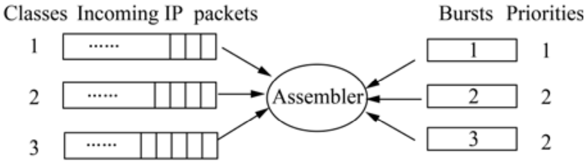
Burst assembly is the process of aggregating and assembling internet protocol (IP) packets into a burst at edge nodes in OBS networks. Because of multiple real-time demand of the information carried by IP packets, it's necessary to divide the IP packets into several classes, and then assemble them into bursts with different priorities. Compared with the single class burst assembly (SCBA) scheme, the composite class burst assembly (CCBA) scheme assembles packets of different classes into a single burst, and the IP packets form a queue according to a certain order. To provide QoS support[8], the burst assembly policies should take the number of packet classes into account as well as the number of burst priorities supported in the core. Let N and M be the number of input packet classes at the edge and burst priorities supported in the core network, respectively, where $N \geq M$. The comparison of SCBA and CCBA schemes with different M and N is shown in Fig.1, where class1 is assumed to be the highest-class packet and class3 is the lowest-class packet.



(a) SCBA scheme (N=M=3)



(b) CCBA scheme (N=M=3)



(c) SCBA scheme (N=3, M=2)

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* This work has been supported by the Natural Science Research Foundation of Education Department of Henan Province (No.13A510163).
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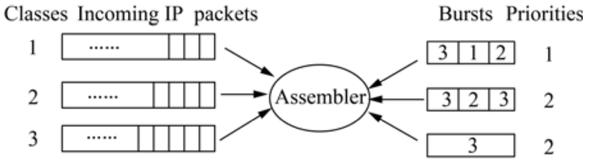

(d) CCBA scheme (N=3, M=2)

Fig.1 Comparison of different burst assembly schemes

According to the method of prioritized burst segmentation[9], when segmentation is implemented, only part of bursts which overlap with another are discarded, while the remainder of the bursts can continue to be transmitted on the output-data channel (ODC). Head segmentation (HS)[10] and tail segmentation (TS)[11] are the common dropping policies used mostly. Both of them have good effects in protecting the high-priority bursts and enhancing the network performance. However, when only HS or TS is adopted, a great deal of high-class packets contained in the low-priority burst which is dropped entirely will suffer a heavy loss. It is a better choice that HS and TS schemes are employed at the same time, so bidirectional segmentation (BS) based on priority is presented to overcome the limitation associated with HS and TS[12]. As shown in Fig.2, the burst which arrives at a node first is referred to as the original burst data packet (OBDP), and the burst which arrives later is referred to as the contending burst data packet (CBDP). $P_{\rm O}$ and $P_{\rm C}$ refer to the priorities of the OBDP and CBDP, respectively. Only one OBDP and one CBDP are considered here. If $P_{\rm O}$>$P_{\rm C}$, the head of CBDP is segmented, and then the remainder is routed on the ODC to be transmitted with OBDP. On the contrary, if $P_{\rm O}$<$P_{\rm C}$, the tail of OBDP is segmented, and then CBDP is routed on the ODC to be transmitted with the remainder of OBDP.

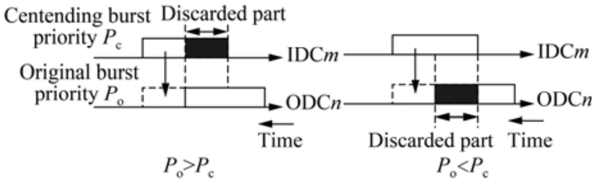

Fig.2 Priority-based bidirectional segmentation

Corresponding assembly mechanisms at the edge node are essential to ensure the valid implementation of segmentation schemes. According to HS and TS, the priority-based burst's head assembly (PBHA) in which segments with packets of different classes are arranged in ascending order from burst's head to tail and the priority-based burst's tail assembly (PBTA) in which segments are arranged in descending order are the most common policies of composite assembly mechanisms. Here, a new assembly scheme according to BS mechanism, which is called as priority-based burst bidirectional assembly (PBBA) combining PBHA and PBTA, is put forward. The highest-priority packets are arranged in the middle of the burst, and the low-priority packets are arranged at the tail and head. The priority is lowered gradually from the middle to two ends of the burst. When burst contention occurs, HS and TS are implemented simultaneously so that the high-priority bursts and the high-class packets are well protected. The internal assembly structure of PBBA is shown in Fig.3.

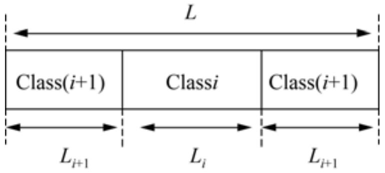

Fig.3 Internal assembly structure of PBBA

As shown in Fig.3, L is the length of the burst, L_i and L_{i+1} are the lengths of the segments with class$i$ and class(i+1) packets, and their sizes change with load to adapt to the flexible network. It's assumed that the QoS level of IP packets satisfies the relation as class1> class2>⋯>class$i$>class(i+1).

In general, the burst transmission delay at edge nodes is the sum of the assembly delay, the schedule delay and the offset time delay[13]. Assembly delay means the time begins with the first IP packet accessing to the assembler and ends when a burst is created. Reducing the assembly delay is an effective measure for decreasing the burst end-to-end delay of OBS networks. Fixed burst length (FBL) assembly algorithm[14] is assumed to be adopted in this paper. Using this analytical model, the average burst assembly delay $t_{\rm a}$ can be expressed by

$$t_{\rm a}=E[\tau_{D-1}+\sum_{i=1}^{D-1}(\tau_{D-1}-\tau_i)]/D=$$
$$E(\tau_{D-1})-\sum_{i=1}^{D-1}E(\tau_i)/D=$$
$$(D-1)/2\lambda\,, \qquad (1)$$

where τ_i is the average delay of the ith packet in a burst, and D is the number of IP packets arriving at the assembler when the threshold is expired. It's assumed that the arrival process of IP packets is Poisson distribution with arrival rate of λ, and μ is the mean of packet lengths which are negative exponential distribution.

The IP packets have the same QoS requirement in every assembly queue when CCBA is adopted, so it needs to wait for the following packet with a given class before the threshold is expired. On the contrary, in CCBA scheme, the packets with different classes are aggregated into a single burst directly without waiting, and each packet class is grouped into a segment with separate correlative information of its own. Moreover, the waiting time in queue of the CCBA is reduced and link utilization is higher due to the situation that in composite assembly scenario, the average packet arriving rate for a single burst is much higher than that of the single counterpart, so a burst will leave less space to be filled by useless packets. The advantage is more obvious for low traffic.

A network with three priorities is considered, and let H be the number of wavelengths used at each output port. Just-enough-time (JET) one-way resource reservation strategy is adopted[13], and IP packet loss rate of class1 can be calculated by the Erlang B formula in M/M/k/k queue as[15]

$$P_{\mathrm{B}}(\mathrm{class1}) = (\varepsilon_1^H / H!) / (\sum_{i=0}^{H} \varepsilon_1^i / i!) , \qquad (2)$$

where $\varepsilon_1=\lambda_1/\mu_1$ denotes the traffic load of packet class1.

According to M/M/∞ models[16], the first H service-side is the real service-side used to indicate the actual output wavelength channels, and the rest is virtual service-side used to record the arrival of burst in the overall system. With the addition of the principle of conservation and mathematical induction, packet loss probability (PLP) of class$i$ can be calculated as

$$P_{\mathrm{B}}(\mathrm{class}i) = \left[\sum_{i=1}^{j}\left(\frac{\lambda_i}{\lambda_j}\right)\right] \times$$

$$\left\{ \frac{\left(\sum_{i=1}^{j}\varepsilon_i\right)^H / H!}{\sum_{k=0}^{H}\left[\left(\sum_{i=1}^{j}\varepsilon_i\right)^k / k!\right]} - \frac{\sum_{i=1}^{j-1}\lambda_i}{\sum_{i=1}^{j}\lambda_i} \times \frac{\left(\sum_{i=1}^{j-1}\varepsilon_i\right)^H / H!}{\sum_{k=0}^{H}\left[\left(\sum_{i=1}^{j-1}\varepsilon_i\right)^k / k!\right]} \right\},$$

$$(i=2,3) . \qquad (3)$$

In order to evaluate the performance of different burst assembly schemes, a simulation model is developed[5]. The following assumptions are made to obtain the results. The arrival process of packets into the network is Poisson distribution with rate of λ. Burst lengths are negatively exponentially distributed with average length of μ=1 Mbyte. The network supports three packet classes, i.e., class1, class2 and class3, corresponding to high, medium and low packet classes, respectively. The ratios of individual packet classes from high to low are 50%, 30% and 20%, and the arrival ratios of them are 40, 25 and 10, respectively. The average processing time for BCP of 10 μs and the offset time of 30 μs are assumed. The optical signal transmission delay is neglected here. There are 4 wavelengths on each fiber.

Fig.4 plots the average end-to-end delay of burst versus load for both CCBA and SCBA schemes. It can be observed that both schemes lead to the longer end-to-end delay under the lower traffic load, since the average assembly time increases with the decrease of traffic load, and the longer assembly time causes the longer end-to-end delay. In addition, the average delay decreases when load increases, due to the higher arrival rate of packets which cause the threshold to be satisfied more frequently. However, we see that the value of end-to-end delay in CCBA scheme is significantly less than that in the SCBA scheme.

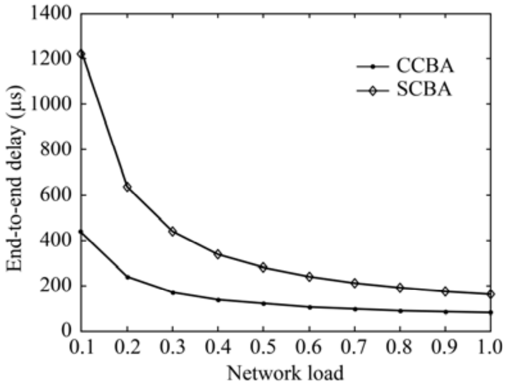

Fig.4 Average end-to-end delay versus network load for CCBA and SCBA schemes

Fig.5 illustrates the PLPs for services with different classes in PBBA mechanism. We can see that PLP is proportional to the network load, and decreases with the QoS level of class from the lowest to the highest under the same load. As shown in Fig.5, with a relatively low network load, the average PLP for packet class2 is nearly 10 times higher than that of class1, and nearly 3 times lower than that of class3. Moreover, with the increase of network load, the growth rate of PLP becomes low.

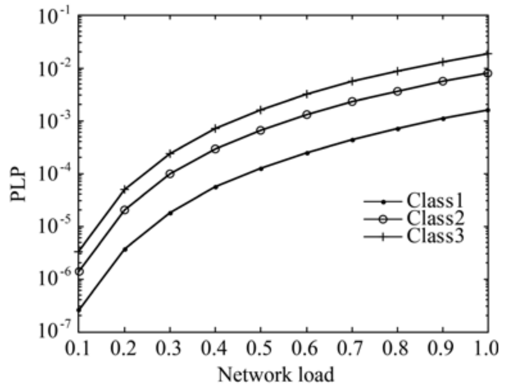

Fig.5 PLP versus network load for services with different classes in PBBA scheme

Fig.6 gives the simulation results of the total PLP versus network load for PBHA, PBTA and PBBA mechanisms. Obviously, the total PLP of PBBA scheme is the lowest, which is about 10 times lower than those of the other two methods. At low load, since the network is lightly loaded, the PLP is also low. As the offered load gets higher, the number of contending bursts increases, and the PLP increases. Especially, the increased amplitude is extremely large when the load is less than 0.3, and the total PLP increases rapidly while the variation amplitude is extremely gentle when the load is more than 0.3. Therefore, the proposed assembly mechanism can particularly improve the performance of networks when the load is low.

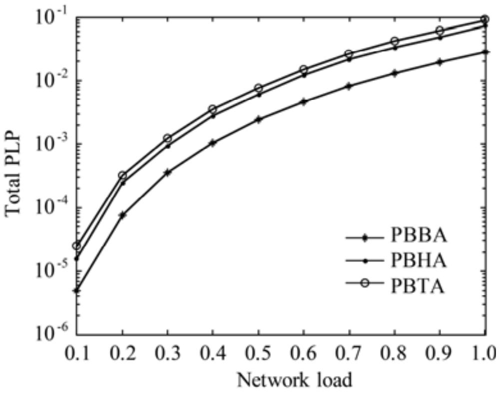

Fig.6 Total PLP versus network load for PBHA, PBTA and PBBA mechanisms

A novel assembly mechanism, which combines packets of different classes into the same burst, is put forward to provide QoS for OBS networks. The packets with the relatively high level of QoS requirement are assembled in the middle, while those with low level are at the tail and head of the burst. As a single burst is aggregated, according to the packet classes, several relatively independent segments which have their own assembly information are generated. Then a simulation model is developed to calculate the end-to-end delay and the PLP. Simulation results show that the given composite assembly scheme causes low end-to-end delay compared with the single-class assembly method, and also causes low PLP compared with the other two composite assembly methods, so it can effectively improve the loss performance and support QoS.

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