A new burst assembly technique for supporting QoS in optical burst switching networks

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This letter proposes a new burst assembly technique for supporting QoS in optical burst switching (OBS) networks. It consists of the adaptive-threshold burst assembly mechanism and QoS-based random offset-time scheme. The assembly mechanism, which is fit well to multi-class burst assembly, not only matches with IP QoS mechanism based on packet classification, and also utilizes fairly and efficiently assembly capacity. Based on token-bucket model and burst segment selective discard (BSSD), the offset-time scheme can smooth the traffic to support OBS QoS. The simulation results show that the technique can improve the performance in terms of packet loss probability (PLP).

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Because of scalability, coarse packet classification can be utilized to OBS. However, due to the burst priority limitation, we usually adopt the multi-class burst assembly technique[3], which aggregates several packet classes into a single burst priority. In the technique, there are two aspects related with the scalable QoS support, i.e., the assembly capacity allocation and the offset-time setup. And our discussions focus on them.

Currently, the discussions of the allocation of assembly capacity mostly concentrate on the fixed threshold mechanism[1,3,5], which cannot effectively utilize the assembly capacity. In this letter, we propose an adaptive-threshold mechanism, which can adjust the allocation of the assembly capacity with the input traffic variation.

In OBS networks, the offset-time setup scheme, JET (just-enough-time) based on extra-offset[6], is widely applied to support QoS. It sets the offset-time between burst control packet (BCP) and burst packet (BP) according to burst priority. However, it is not enough effective to the multi-class burst assembly because it considers only the burst priority, and neglects the assembly content of a burst, i.e., the packet classes. This results in that the QoS of high packet class cannot be guaranteed. On the other hand, it neglects the traffic shaping and smoothing. So it is possible that BCP originating from different OBS ingress nodes is nearly synchronized[2].

To alleviate the above unfavorable effects, we propose a revised scheme, i.e., QoS-based random offset-time setup scheme, which divides offset-time into the QoS-based part and the random part. The former is set by the modified JET with BSSD, while the latter is determined by token bucket model.

Our proposed burst assembly technique consists of the adaptive-threshold mechanism and the priority-based random offset-time setup scheme.

At first, we list the following notations that will be used throughout the letter: N: number of input packet classes. M: number of burst priorities. $L_k^{(\mathrm{Total\_Max})}$: maximum total length of burst of priority k. $L_k^{(\mathrm{Total\_Min})}$: minimum total length of burst of priority k. $L_{k,j}$: threshold of j-th class packet in a burst of priority k. T_k: assembling time-out of burst of priority k. S_k: a set of packet class which can map to priority k.

Because of the QoS scalability, it is more reasonable that N is usually larger than M. In multi-class burst assembly, each burst can contain several packet classes. To prevent high class from excessively preempting low class, the share of assembly capacity allocated to each class is not less than a threshold. The threshold is determined by the following constrains and operations.

C1. Which class can be aggregated into a burst priority, i.e., the mapping relationship between packet class and burst priority, is set according to literature[3]

$$\begin{cases} \text{Class } i \to \text{Priority } k,\ i \in S_k = \left[k\left\lfloor \frac{N}{M}\right\rfloor, (k+1)\left\lfloor \frac{N}{M}\right\rfloor\right) \\ \text{Class } i \to \text{Priority } M,\ i \in S_M = \left[M\left\lfloor \frac{N}{M}\right\rfloor, N\right) \end{cases}, \tag{1}$$

where $k = 0, 1, \cdots, M-1$, $\lfloor x \rfloor$ denotes maximal integer less than x.

C2. The threshold of each class follows the inequalities

$$\begin{cases} \mathrm{Min}(L_{k,i}) \geq L_{k,j} & i \in S_k,\ j \notin S_k \\ L_{k,i} \geq L_{k,j} & i < j,\ i,j \in S_k \\ \mathrm{Min}(L_{k,i}) \geq \mathrm{Max}(L_{k,j}) & i \in S_m,\ i \in S_n,\ m < n \end{cases}. \tag{2}$$

C3. The threshold sum of all classes in priority i should meet total length constrain

$$L_i^{(\mathrm{Total\_Min})} \leq \sum_{j=0}^{N-1} L_{i,j} \leq L_i^{(\mathrm{Total\_Max})}. \tag{3}$$

Along with the input traffic variation, the corresponding adjustment is operated according to the following cases.

Case1: The threshold is unchanged. When the traffic load of each class does not vary, each packet class is aggregated based on the predetermined thresholds.

Case2: The threshold of higher class is extended. When the traffic load of a class decreases, its old threshold exceeds its actual need. Then the surplus capacities are reallocated to the high class which assembly capacity is insufficient.

Case3: The threshold of lower class is extended. When the traffic load of a class increases, it can borrow some surplus capacity from higher class if capacity of lower class is just necessary, and not abundant.

The adaptive-threshold mechanism builds the mapping relationship, determines the initial threshold, and adjusts the threshold as the above processes. All packet classes can utilize burst assembly capacity fairly and efficiently.

In burst assembly, the offset-time setup is one of key issues to impact the efficiency of QoS support in OBS networks. We have taken advantages of JET scheme and token-bucket mechanism, and proposed a new scheme, i.e., the QoS-based random offset-time setup scheme, which divides offset-time into the QoS-based part and the random part, and then determines them by respective mechanisms. The scheme is illustrated as follows.

As shown in Fig. 1, if $t_{s,l} \leq t_{s,h} \leq t_{s,l} + L_l$, or $t_{s,h} \leq t_{s,l} \leq t_{s,h} + L_h$, then conflicts between bursts would occur. At this time, the segments or the entire burst of low priority are always discarded at first in the literatures [3], [4] and [6] because the QoS offset-time is calculated based on the priority, and larger offset-time is assigned to higher burst priority. The discard rate of high priority reduces at the expense of blocking low priority. Obviously, from the improvement of global performance, it is not a wiser choice. However, if we selectively discard some burst segments containing lower packet class, as illustrated by the shadow parts in Fig. 1, the QoS coherence from IP to OBS can be guaranteed to the utmost. We call the discard mechanism as BSSD. Hence, it is reasonable for the calculation of QoS offset-time to take both the burst priority and its containing packet classes into consideration.

The setup of QoS offset based on BSSD is shown in Fig. 1. For simplicity, we assume that $N = 2$ and $M = 2$, and consider the two following situations respectively: $t_{s,h} \leq t_{s,l} \leq t_{s,h} + L_h$, i.e., the higher priority burst is served first; and $t_{s,l} \leq t_{s,h} \leq t_{s,l} + L_l$, i.e., the lower priority burst is served first. According to BSSD, it is feasible and simple for the QoS offset-time setup to discard burst segment containing low packet. In other word, when offset$_h$ has been known, we can determine offset$_l$ by the overlapping reducing between segments containing high classes, as illustrated by the following inequality.

$$\begin{cases} \text{offset}_l \geq \text{offset}_h + t_{a,h} + L_{h,\text{high}} - t_{a,l}, \\ \qquad t_{s,h} \leq t_{s,l} \leq t_{s,h} + L_h \\ \text{offset}_l \leq \text{offset}_h + t_{a,h} - L_{l,\text{high}} - t_{a,l}, \\ \qquad t_{s,l} \leq t_{s,h} \leq t_{s,l} + L_l \end{cases}, \tag{4}$$

where offset$_h$, $t_{a,h}$, $L_{h,\text{high}}$, L_h denote offset-time, arrival time, and the segment length, the burst length of high priority respectively. offset$_l$, $t_{a,l}$, $L_{l,\text{high}}$, L_l denote their counterparts of low priority.

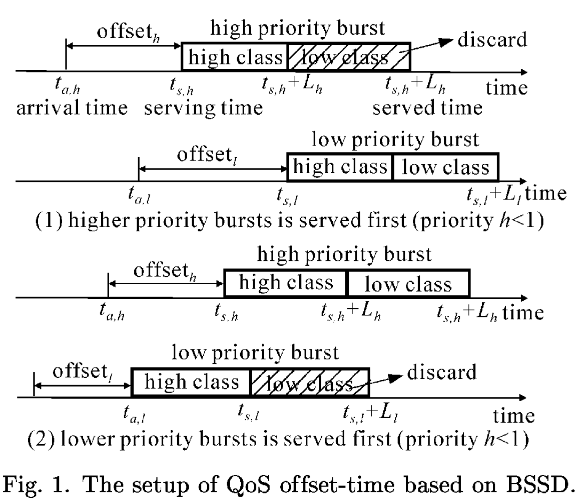

Fig. 1. The setup of QoS offset-time based on BSSD.

To alleviate the synchronization effect, random offset-time part is determined by a shaping mechanism based on token bucket model[2]. In the model, token is generated by a random process, such as Poisson process with λ_{token}, which is close to the rate of burst assembly. Combined with the QoS-based offset-time, the burst is shaped as follows. A burst can be generated if and only if its BP has lagged behind its BCP Offset$_{\text{QoS}}$, and holds a token. In other word, BCP and BP have the offset time relation Offset$_{\text{QoS}}$ + Offset$_{\text{random}}$. To satisfy the time relation, the shaping mechanism must intentionally discard some tokens when token's arrival time overlaps the transmission time of previous data burst, or data burst has been ready, as illustrated in Fig. 2. In addition, it is required that the bucket can contain only one token in order to mitigate the effect of tokens accumulation and decrease the reaction time. After the above processes, the total offset between BPs and BCPs are determined in the similar manner as shown in Fig. 2. Therefore, in the long term, burst is smoothly injected into OBS network, and also the QoS requirement of each packet class is effectively guaranteed by the resource reservation

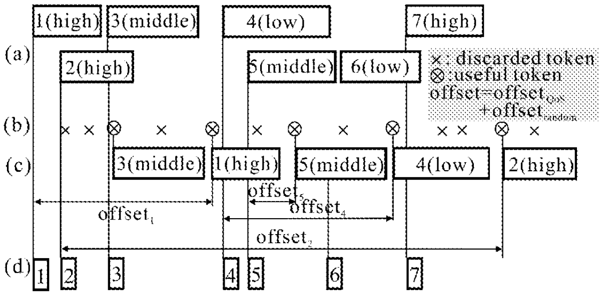

Fig. 2. The off-time relation illustration of our proposed scheme. (a) BPs before shaping; (b) Randomized tokens; (c) BPs after shaping; (d) BCPs.

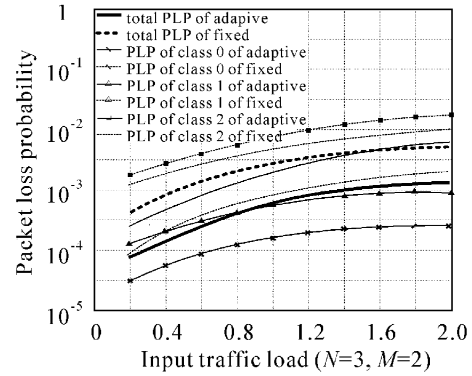

Fig. 3. Comparison between adaptive and fixed threshold.

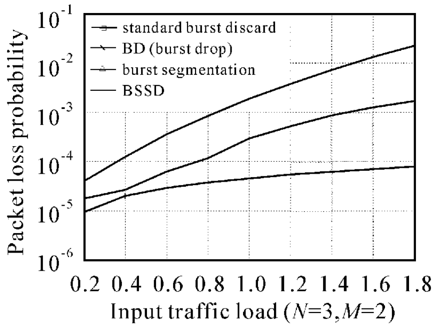

Fig. 4. Comparison between BSSD and other mechanisms.

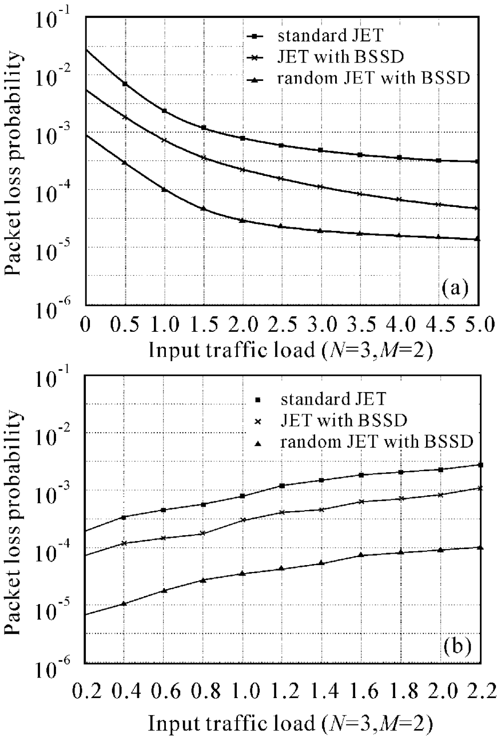

Fig. 5. The performance improvement of our proposed scheme. (a) The required offset-time comparison; (b) The carrying capacity comparison.

based on offset-time.

Here, we present some numerical results to evaluate the effectiveness of our proposed technique in terms of PLP. The packets' arrivals are generated by the Monte Carlo method. For simplicity, assume that IP packet and burst are fixed in length, and each burst segment is exponentially distributed with an average length, normalized to the burst length. The burst assembly process can model as N the multiplexing of data streams into M data streams ($N \geq M$).

At first, let's evaluate the advantage of adaptive-threshold in multi-class burst (MCB) assembly. We assume that the assembled bursts can be transmitted to its destinations without any loss, and so we can concentrate on only the PLP due to burst assembly. Fig. 3 plots the relation of PLP vs. traffic load under fixed and adaptive threshold respectively when $N = 3$ and $M = 2$. In general, PLP of high packet class is lower than that of low packet class. We observe that PLP of adaptive-threshold is also lower than that of fixed-threshold, regardless of the total PLP or the individual PLP. Moreover, the PLP of low class in adaptive-threshold is even less than that of high class in fixed threshold when traffic load is light. The results show that adaptive-threshold greatly outperforms fixed-threshold. The advantage of adaptive-threshold profits from the fair and efficient utilization of assembly capacity.

OBS usually adopts the burst discard mechanisms when contention occurs, i.e., conventional burst discard[6], burst segmentation[3], and burst drop[4]. Here, we will compare our proposed BSSD with them. As shown in Fig. 4, burst drop and burst segmentation are better than conventional burst discard, and the BSSD is the best. The results can be explained by the fact which BSSD considers not only the burst's priority and also each segment' class constituting the burst.

Now let's evaluate the benefits from the QoS-based random offset-time setup scheme. The evaluation is made from two aspects, i.e., total offset-time, which is normalized to the BCP processing time, and carrying capacity in terms of sustainable traffic load.

At first, Fig. 5(a) shows that their necessary offset-times for the same PLP are different. The required offset of our proposed scheme is the shortest, and then JET with BSSD and standard JET in turn. It shows that our proposed scheme can efficiently reduce the burst's transmission delay and improve the reserved resource utilization. Under the same input traffic load, our proposed scheme's PLP is the smallest, as shown in Fig. 5(b). It means that the proposed scheme can support more traffic. The reason is that it takes the traffic shaping and QoS support into consideration at the same time.

In conclusion, our proposed burst assembly technique, which consists of the adaptive-threshold assembly mechanism and QoS-based random offset-time scheme, has answered two problems related with QoS support in OBS network. Hence, it can effectively improve the coherence of QoS guarantee from IP to OBS network. By the comparisons with other mechanisms, the above numeric simulations have validated its practical effects in terms of PLP.

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