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Study of hybrid optical burst networks

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Abstract We propose the hybrid optical burst switching (HOBS), and investigate the HOBS-based ring topology with numerical simulation. Results indicate that the packet loss ratio in HOBS is much less than that in optical burst switching(OBS) and its performance depends on some parameters such as the packet proportion, the electronic buffer size and the processing speed in the node.

Keywords HOBS, OBS, packet proportion

1 Introduction

The rapid growth of the Internet demands higher transmission capacity and Terabit-capacity IP routers. Dense wavelength division multiplexing (D-WDM) technology can exploit the huge bandwidth in optical fibers. with D-WDM technology being used in backbone networks to meet the bandwidth requirement of IP traffic, routing/switching the traffic is a difficult problem that needs to be thought out carefully.

On one hand, optical buffer and optical processing technology have not matured and won't be in the near future. Thus, processing the packet in the optical domain can not be done yet. On the other hand, switching the high traffic in the electronic domain is difficult. Therefore it is a natural ideal to perform switching in the optical domain and processing in the electronic domain. Since the mismatch of transmission traffic and processing speed, the switching granularity must be larger than the IP packets, which leads to the concept "burst switching" [1, 2]. Therefore, OBS can be described as traffic being aggregated and assembled into bursts in the edge node, then formed into their control

packets that include the information of the bursts. Bursts and their control packets are sent in separately. Bursts pass the OBS network in the optical domain and the control packet is processed electronically to inform the core switch of the arrival time and length of the burst.

However, the performance of OBS [3, 4] does not perform very well. Firstly, the control channels cannot be used to transmit the traffic: for example, there are eight data channels and one control channel. If the channel rate of all channels is the same, the maximum link utilization is only 0.889. Secondly, it is a one-way reservation process, which means that the burst is sent without "knowing" whether it could pass the OBS network or not. So, in core switching, if only parts of the two bursts collide, the total burst will be dropped, which leads to a serious packet loss, especially in high traffic. Thirdly, a burst is usually made up of tens to thousands of IP packets. The switching and transmitting granularity is large, which leads to waste of the optical fiber bandwidth.

In fact, it could ease the electronic processing drastically to assemble the burst in the edge node. For example, consider a single link with 32 WDM channels of 10 Gb/s, each of which has a total transmission capacity of 320 Gb/s. If the average length of the burst is 50 Mbit, only 6 400 control packets need to be processed. Currently, electronic switching with a speed of several hundred gigabits per second is available. Thus, in OBS, electronic processing capacity is saved to improve network output.

In order to improve the performance of OBS, we propose a new HOBS technique. In the edge node, parts of the IP traffic are directly sent to the next hop, instead of assembling them into bursts. In core switching, every wavelength channel has two modes. The first one allows traffic to pass the switch in the optical domain. The other mode allows traffic to be stored in the core node through optical-electronic conversion. In the default mode, the IP traffic can be received in the core node through optical- electronic conversion. If a control packet (which informs the core node the time of its burst arrival and departure from the optical switching matrix) arrives, the switch changes modes to let the burst pass the switch in the optical domain.

In this paper, we call the header of the burst the control

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packet (CP), and the traffic that is not assembled into bursts is called a packet. In this paper, we only focus on describing the HOBS without FDLs and wavelength conversion. Details of the HOBS edge node can be found in Sect. 2. The core switching architecture is described in Sect. 3. In Sect. 4, we present the simulation results with circle networks.

2 The edge node architecture in HOBS

The edge node is responsible for providing access for IP traffic (IP-over-WDM) into the OBS network. The simple function block diagram of the edge node is shown in Fig. 1. In this figure, we omit the line cards and switch fabric that has the same function as common routers. We only point out the special function provided in HOBS.

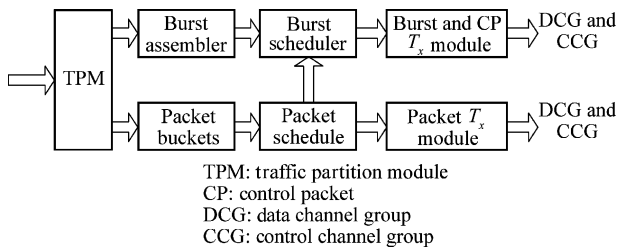


Fig. 1 Function block diagram of edge node

In HOBS, There are two architectures that can be selected. Since traffic from every channel can be converted into electronic signals, CPs can be transmitted in every channel. However, bursts transmitted in a channel usually only last several milliseconds. For example, a burst with 50 Mbits length needs 5 ms when sent in a 10 Gbit/s channel. If all channels are occupied by bursts, CPs will be dropped since there is not enough time to wait until bursts are fully sent. The loss of the control packet also means a loss of burst, which is made up of tens or hundreds of packets. So, the CP loss ratio must be very low (for example less than e^{-7}). In our scheme, all the channels are divided into DCGs and CCGs, ADCG can transmit bursts and packets, and CCGs can be used by CPs and packets.

Traffic partition module (TPM) is an important part that is never talked about in OBS. Its function is to separate the bursts and packets. On one hand, the packet proportion (the traffic sending according to packets in proportion to all traffic) needs to be thought out carefully. This proportion is influenced by some facts such as the processing speed of the edge node and core node, the traffic volume, and the buffer size in the edge node and core node. Details of the study on these influences are shown in Sect. 4. On the other hand, another important issue is how to separate the bursts and packets. In our scheme, the burst assembly mechanism is based on time and length restriction [6]. A simple method is after the burst has been assembled, the following IP traffic with the same destination and QoS is sent in a single packet

until the packet proportion is reached. Thus, the burst assembly and packet storage do not influence each other. However, separating the bursts and packets is the open topic that needs to be thought out carefully.

In HOBS, the process of the burst assembly, channel schedule and transmission are almost the same as in OBS. However, packet schedule and transmission becomes the new issue. In Fig. 1, packet buckets store the packets, and packet number and variable are controlled by TPM. A packet bucket is sorted into packets with the next hop to a core node connected to the edge node. Packet schedule is the module that searches the free time gaps in channels. The channels include all of the DCGs and CCGs. The search method may be a random selection or selection with a fixed order. If a free channel is found and the corresponding packet bucket is not empty, the packet in the header of the bucket (FIFO) can be transmitted immediately. Otherwise, it will wait until a free channel is obtained.

The relationship of burst schedule and packet schedule is the core issue. In my scheme, since bursts include many packets and utilize much memory and processing resources, packets schedule and transmission should not influence the bursts schedule and transmission. Therefore, the HOBS is the hierarchical network. The edge node schedule is not parallel processed, if a packet is being schedule, while a burst finishes assembly. Packet scheduling should finish immediately and shift to burst scheduling, which assures that no extra delay is introduced.

3 The core node architecture in HOBS

The general architecture of a core node is shown in Fig. 2. Other than the basic functions, which are the same as in OBS, packets storage and processing are also added. The optical switching matrix has extra outputs to convert packets from optical into electronic form. Packet buckets store the packets according to their next hop destination. In the default mode, optical switching matrix can transmit the datum from DCG to outputs, which can convert and store packets. When a burst arrives, the switch control unit will inform the optical switching matrix to change its mode to let the burst pass the core node in the optical domain.

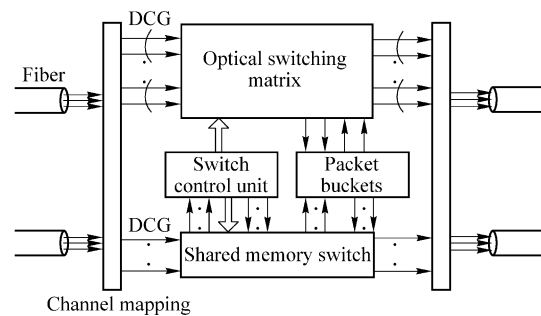


Fig. 2 General architecture of core node in HOBS

The switch control unit is the key component in the core node. Other than scheduling the burst as in OBS, packet channel searching and controlling the optical switching matrix to transmit packets are also its functions. Figure 3 shows the switch control unit processing packet. The packet forwarder is responsible for sorting packets into the packet buckets according to the next hop destination. The packet scheduler searches the channels to find the time gap for packets. The work process of the packet scheduler is shown in Fig. 4. There are two data channels (C_1 and C_2) that can transmit bursts and packets, and a control channel (C_3) that can transmit CPs and packets. In every channel, the last time to turn to the packet T_x module is recorded as T_{last} , which means that in the packet T_x module, it needs time (δ_i) to process such as sorting out the packet from the bucket, perform the L_1 and L_2 encapsulation and so on. After time δ_i , the packet can be transmitted immediately. In C_1 , between burst 1 and 2, which is a free time gap, a packet can be inserted. So, time T_{last} is close to the end of burst 1. However, in C_2 , the gap between p_3 and b_3 is too short to accommodate a packet. Thus, T_{last} is close to the end of b_2 . If the packet scheduler finds a channel with T_{last} as the current time, the channel search is finished and turns to the packet T_x module with 0 time. Otherwise, the channel with T_{last} being closest to current time is selected to transmit the packet (in Fig. 4 it is the C_1 channel to be selected). The packet scheduler searching the channels can do it randomly or follow an order. This work process of the packet scheduler will simplify the channel resource table, and reduce the collision probability between the bursts and packets.

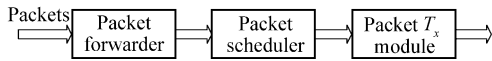


Fig. 3 Block diagram of switch control unit process packets

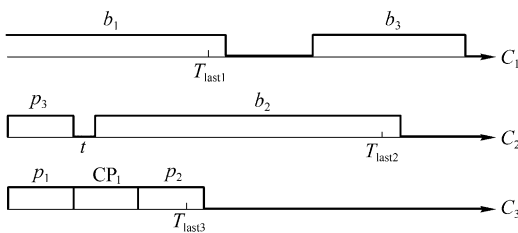


Fig. 4 Illustration channel schedule

4 Performance study

To study the performance of HOBS, we simulate HOBS with a circle network, which is shown in Fig. 5. It has five edge nodes and five core nodes. Every link has only one fiber in one direction. Every fiber has nine wavelength channels with eight data channels and one control channel.

Every channel is 1 Gbit/s rate.

In the edge node, a self-similar traffic source is designed according to Ref. [5]. There are 40 independent traffic sources. Every source generates packets when the time starts, and generates none packets when the time ends. They are all in accordance with Pareto distribution and the parameter $\sigma=1.4$ and self-similar parameter $H=(3-\alpha)/2=0.8$. The length of every packet is 1 500 byte. The assembly mechanism used is the nonperiodic time-interval burst assembly mechanism [6], which is based on time and length restriction. Here, the maximum of the burst length is 500 kbits, and the minimum is 15 kbits. The time window for the burst assembly is 20 ms. The order of channel scheduling is random and no FDLs are supported in the edge node. There are some parameters in the edge node that can influence the performance of HOBS such as the packet proportion, the packet bucket size, the CP and packets process time. Details of the analysis of these parameters are presented next.

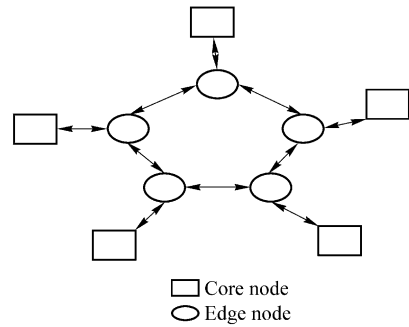


Fig. 5 Network topology

In the core node, there are no FDLs and wavelength conversion supported. The shortest path is applied to select route. Like the edge node, some parameters such as the packet bucket size, the control packet and packets processing time are used to analyze network performance. Since there is no wavelength conversion, bursts transmission must obey the wavelength continuity constraint. Channel scheduling in the core node has gaps which means that a burst can be inserted between two bursts.

The channel utilization of OBS is shown in Fig. 6, the traffic is normalized traffic computed by $\rho =$

$$\sum_{i=1}^N \frac{\overline{ON}_i}{\overline{ON}_i + \overline{OFF}_i} / B_{\text{channel}}, \quad \overline{ON}_i \text{ is the average ON time of the No. } i$$

source. \overline{OFF}_i is the average OFF time of the No. i source, B_{channel} is the channel bandwidth. By adjusting the ON/OFF proportion, different traffic is produced. In Fig. 7, the link utilization increase with the traffic is heavier. However, even when the normalized traffic is up to 0.9, the link utilization is only more than 0.4, which means that half of the traffic is lost since there are no channel resources. In the low and mid traffic, the utilization of the link between the core nodes is lower than that of the link between the

core node and the edge node, which means that the outgoing collision in the core node is the important fact or in reducing utilization. In high traffic, collision in the edge node is also serious; the utilization of the link between core nodes can equal and exceed the link between the core and edge node.

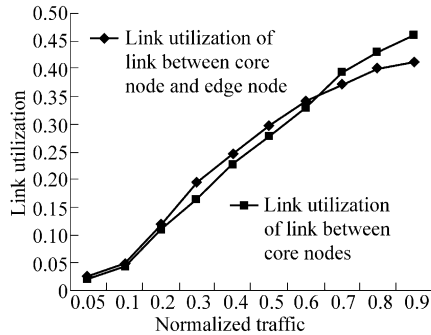


Fig. 6 Link utilization in OBS

In HOBS, the packet proportion is an important parameter. High proportion of packets will reduce the number of bursts and reduce the probability of collision between bursts. At the same time, there are enough packets to fill the free time gaps between bursts. However, high proportion packets will enhance the burden on the hardware. For example, it demands higher processing speed and larger buffer size.

In Figs. 7 and 8, we present the network packet loss ratio and burst loss ratio of HOBS and OBS. The time of processing a control packet is 20 μ s and that of processing a packet is 1 μ s. In Fig. 8, burst loss ratio is declining while the packet proportion is increasing. It is reasonable that in TPM, the burst assembly is not influenced by packets. Its length is varied only by the traffic volume during the assembly. So when the burst proportion is less, the burst number is less. Therefore the bursts collision is alleviated.

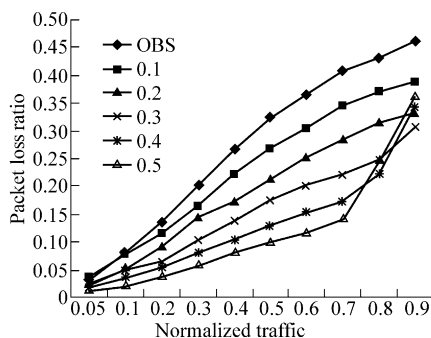


Fig. 7 Packet lost ratio with different PP

Packet loss ratio is shown in Fig. 7, even with only 0.1 proportion of packets, the loss ratio is evidently reduced. In low traffic, the higher proportion of packets has lower packet loss ratio, which means that transmission with packets in low traffic can get better performance. However,

in high traffic, too many packets don't improve performance. On the contrary, it enhances the loss ratio. For example, when the packet proportion is 0.3 and traffic volume is heaviest, the packet loss ratio is 0.3. However, when the packet proportion is 0.4 and 0.5, the packet loss ratio is about 0.35. This is because of the restriction of the processing speed and buffer volume. Too many packets will be dropped and make the loss ratio high. Thus, some adaptive mechanism should be considered to address changes in the traffic. This is the next step of our research.

The packet loss ratio of more rapid processing rates is shown in Fig. 9 with burst processing being 2 μ s and packet processing being 100 ns. Compared with Figs. 7 and 9, OBS packet loss is almost the same. It means that if CP loss ratio is low enough, a higher process rate doesn't improve the performance of networks evidently. However, in HOBS, processing rate is the key parameter. In a high packet proportion (0.4 and 0.5), the packet lost is higher (about 0.35) in low processing speed. But in rapid processing speed, packet loss ratio is much less (0.22 and 0.17 corresponding to 0.4 and 0.5 packet proportion).

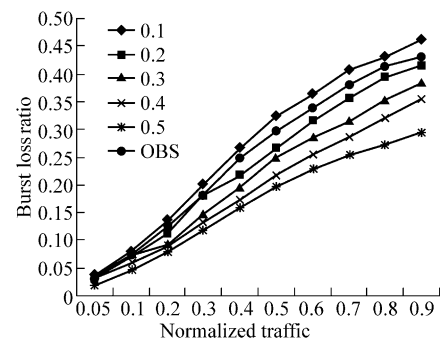


Fig. 8 Burst lost ratio with different PP

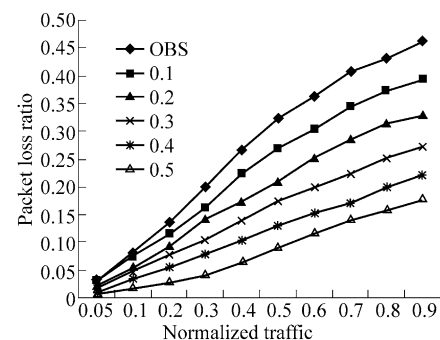


Fig. 9 Packet lost ratio with different PP

Figure 10 shows the packet number in the packet bucket in different traffic settings. In the edge and core nodes, the buffer volume can accommodate 500 packets (packet length is 1 500 bytes, so the bucket size is 6 Mbits). It shows that the edge node bucket has a much longer packet queue in high traffic. Since in our topology the link from the edge node to

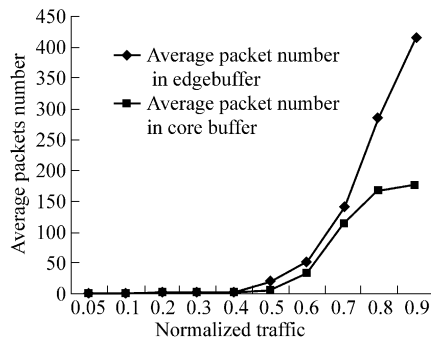


Fig. 10 Compare with average packets number

the core node has the heaviest burden, the bucket has to be longer, or more fiber is required to alleviate the burden.

Figure 11 shows the packet delay time with the heaviest traffic in HOBS networks. High processing rate is 100 ns when processing a packet and low processing rate is 1 μ s. Packet delay time in this paper doesn't include the transmit time in the optical fiber. In this circle network, the packet delay time (about 80 μ s) is much less than the burst delay time (assembly time is 20 ms and offset time is about tens of μ s). With the high speed rate, the delay time is shorter. With increasing the packet proportion, the time delay increases lightly.

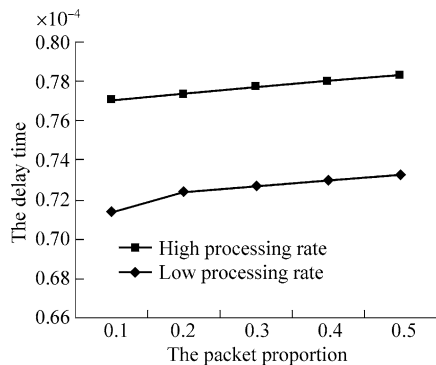


Fig. 11 The delay time in different processing rate and packet proportion

5 Conclusions

HOBS can utilize electronic storage and processing to improve the OBS performance. In this paper, we talk about the HOBS architecture in details and present the simulation result with a circle network topology.

In our results, we show that packet loss is dependent on some parameters such as processing speed, proportion of packets and bursts and buffer size. A higher processing rate can reduce the loss ratio drastically. In low traffic, it seems that a higher packet proportion can get the lower loss ratio. However, in high traffic, packet loss ratio is not always lower with the higher proportion. So an adaptive mechanism of separate proportion packets and bursts should be thought out carefully in future research. By simulation, we show that the packet delay time is much less than the burst delay time, and with higher processing speed and packet proportion, the delay time of packets can be shorter.

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