Performance improvement for optical packet switch with shared buffers

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In this paper, an inner wavelength method is proposed to enlarge buffering capacity of shared fiber delay line buffers. In addition, an optical packet switch called extended shared buffer type optical packet switch (extended SB-OPS) is proposed to realize the inner wavelength method. In order to further improve performance of extended SB-OPS, a greedy algorithm based on inner wavelength method is introduced. The performance of extended SB-OPS is evaluated by simulation experiments.

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The exponential growth of Internet traffic is requiring more and more network capacity every day. Wavelength division multiplexing (WDM) technology is currently used to multiply network capacity. Optical packet switching (OPS) is expected to bridge the granularity gap between the WDM transport network and the IP network[1].

Contention resolution is one of the critical issues in OPS. In general, there are three ways to resolve packet contentions, i.e., optical buffering, wavelength conversion, and deflection routing[2]. Among these three contention resolutions, optical buffer, which can only consist of fiber delay lines (FDLs) with present technology, is most effective and has been extensively studied[3]. Output buffer type optical packet switch (OB-OPS) and shared buffer type optical packet switch (SB-OPS) are two usual types of optical packet switch. Compared with OB-OPS, SB-OPS can make full use of FDLs and reduce the size of switch matrix. However, performance of SB-OPS is worse than that of OB-OPS mostly because SB-OPS has less buffering capacity. In this paper, an inner wavelength method (IWM) is proposed to enlarge buffering capacity of SB-OPS. In order to further improve performance of SB-OPS, a greedy algorithm based on inner wavelength method (GA-IWM) is proposed. The performance of SB-OPS under IWM is evaluated by simulation experiments.

In an OB-OPS, every output port is equipped with a FDL-buffer, so incoming packets destined for different output fibers do not contend for FDL with each other. However, in a SB-OPS, only one FDL-buffer is shared among all output ports. Consequently, it is always possible for the case that the FDL required by an incoming packet is occupied by another previously arriving packet that is destined for another output fiber. This is called FDL contention[4]. When a FDL contention occurs, in order to avoid being dropped, the incoming packet has to try to be buffered in another longer FDL, which causes excess traffic load[5]. Therefore, the performance of SB-OPS is deteriorated. It is evident that the performance of SB-OPS can be improved through enlarging the buffering capacity of FDL-buffer. There are two ways to enlarge FDL buffering capacity, i.e., using more FDLs or using more buffering wavelengths in FDLs. However, using more FDLs will lose advantage of shared buffer (e.g., need larger size of switch matrix). So we propose an IWM to enlarge the buffering capacity of SB-OPS.

The main idea of IWM is that additional inner wavelengths can be used in the FDL-buffer to enlarge buffering capacity of SB-OPS. In a SB-OPS, the transmission wavelengths used in input/output fibers can be characterized by (λ_j, $j \in \{1, \cdots, W\}$). In the FDL-buffer of SB-OPS, in addition to these W wavelengths, m additional wavelengths are also used to buffer blocked packets. Therefore, in a SB-OPS, the buffering wavelengths can be expressed as (λ_k, $k \in \{1, \cdots, W, W+1, \cdots, W+m\}$). When an incoming packet is to be buffered in the FDL-buffer, if FDL contention occurs, i.e., the buffering wavelength in the required FDL is occupied by another packet, the incoming packet will try to be buffered on another buffering wavelength in the same FDL. In each output port, the packets buffered on the buffering wavelengths are translated into appropriate transmission wavelengths.

An example of IWM is illustrated in Fig. 1. For simplicity, only one transmission wavelength (λ_1) and two buffering wavelengths (λ_1 and λ_{w+1}) are considered. When an incoming packet carried on λ_1 and destined for output port n arrives, it has to be buffered on the FDL-buffer because the output port n is occupied by another

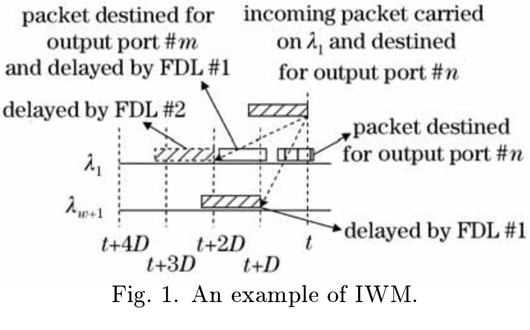

Fig. 1. An example of IWM.

packet. According to the minimum delay time, the incoming packet is buffered on FDL #1 with delay D. However, FDL contention occurs because FDL #1 is occupied by another packet destined for output port m. In this case, if there is only one buffering wavelength in the FDL-buffer, the incoming packet can be delivered to the next FDL, i.e., FDL #2, which results in additional void space and deteriorate performance of SB-OPS. For IWM, because there is another buffering wavelength (λ_{w+1}), the incoming packet can be buffered on it in FDL #1. Consequently, void space is reduced and performance of SB-OPS can be improved. In output port n, the packet buffered on λ_{w+1} is translated into wavelength λ_1 for transmission.

A SB-OPS, which can realize IWM, is shown in Fig. 2. It has N input and output fibers. Each input and output fiber consists of W different wavelength channels (λ_j, $j \in \{1, \cdots, W\}$). A FDL-buffer, which consists of a number B of FDLs, is shared by the N output ports and is used to store blocked packets. These FDLs are arranged in degenerate form[6], i.e., delays achieved by FDLs uniformly cover the entire range of buffer depth, from D to BD, with increment of one buffering unit D (also called granularity). In the FDL-buffer, $W+m$ wavelengths (λ_k, $k \in \{1, \cdots, W, W+1, \cdots, W+m\}$) can be used to buffer packets. In all input ports, each wavelength channel is equipped with one tunable wavelength converter (TWC) to shift arriving packets to appropriate wavelengths in output fibers or FDL-buffer. In each output port, a number $W+m$ of TWCs are used to convert optical packets to appropriate wavelengths for transmission.

This type of optical packet switch is called as extended SB-OPS, which is an extended case of common SB-OPS. Common SB-OPS is almost the same as extended SB-OPS except that it has no TWC in each output port and no additional inner wavelength in the FDL-buffer (i.e., the number of transmission wavelengths is the same as the number of buffering wavelengths).

In this paper, it is assumed that optical packets arrive asynchronously and have variable length. At each input fiber, incoming optical packets are wavelength demultiplexed by DMUX shown in Fig. 2. Before going into a switch matrix, each optical packet has to pass an input unit (IU), where in order to handle packet header information and configure switch matrix, the optical packet is buffered for appropriate time. On the basis of the routing information contained in each packet header, a packet scheduler (not shown in Fig. 2) decides the output port for each packet and handles packet contentions by allocating appropriate buffering wavelengths and FDLs.

In an extended SB-OPS, an incoming optical packet can be expressed as $P(i, n, \lambda_j)$, where i and n ($i,n \in \{1, \cdots, N\}$) identify the input fiber and the output fiber respectively, and λ_j ($j \in \{1, \cdots, W\}$) identifies the wavelength which carries the packet. When an incoming packet $P(i, n, \lambda_j)$ arrives, the packet is then switched to output fiber n if λ_j on output fiber n is available. However, if λ_j is occupied, packet contention occurs. In this case, through wavelength conversion, the packet will first try to be transmitted on another available transmission wavelength in the output fiber. If the packet contention cannot either be resolved by wavelength conversion, the blocked packet will try to be stored in the shared FDL-

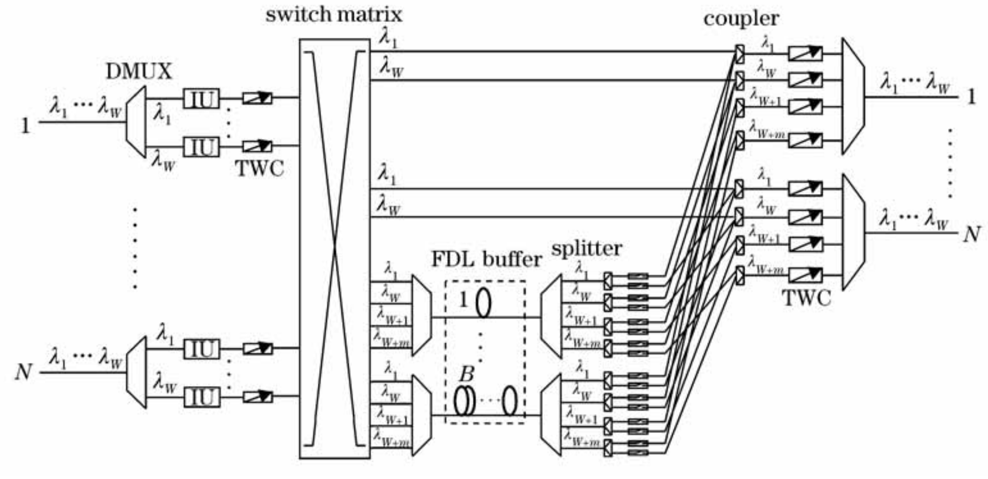

Fig. 2. Extended SB-OPS architecture.

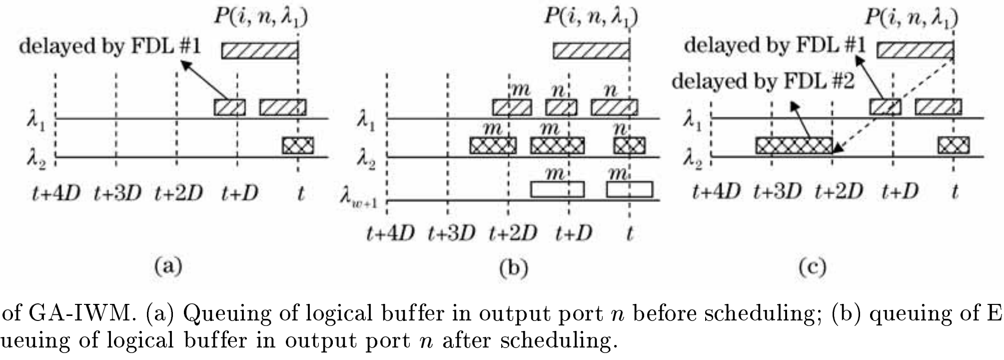

Fig. 3. Example of GA-IWM. (a) Queuing of logical buffer in output port n before scheduling; (b) queuing of EDL-buffer before scheduling; (c) queuing of logical buffer in output port n after scheduling.

buffer. How to choose appropriate FDLs and buffering wavelengths for these blocked packets affects the performance of extended SB-OPS greatly. Consequently, in the following, a GA-IWM is proposed to make full use of FDL-buffer.

In an extended SB-OPS with N output ports, the physical FDL-buffer can be seen as a combination of N logical buffers (each output port has a logical buffer). In the physical FDL-buffer, there are $W + m$ wavelength queues, however, in each logical buffer there are W logical wavelength queues. When incoming packet $P(i,\ n,\ \lambda_j)$ has to be buffered in the FDL-buffer, the logical buffer of destination output port n is searched. According to minimum delay requirement, $P(i,\ n,\ \lambda_j)$ chooses the shortest logical wavelength queue (e.g., FDL #k and wavelength λ_k are required). In this case, if FDL contention occurs, i.e., λ_k in the required FDL (FDL #k) is occupied by other packet, $P(i,\ n,\ \lambda_j)$ will try to be buffered on other available buffering wavelengths in the same FDL. If all buffering wavelengths in the required FDL are occupied, the next FDL will be searched until the last one with maximum delay. In the destination output fiber (output fiber n), $P(i,\ n,\ \lambda_j)$ is translated into appropriate wavelength (i.e., λ_k) for transmission.

An example of GA-IWM is illustrated in Fig. 3. For simplicity while keeping generality, only two output ports (i.e., output port m and output port n) are considered. In addition, we assume that there are two transmission wavelengths (λ_1 and λ_2) in input/output fibers and three buffering wavelengths (λ_1, λ_2, and λ_{w+1}) in FDL-buffer. As shown in Fig. 3(a), when an incoming packet $P(i,\ n,\ \lambda_1)$ arrives, because transmission wavelengths (λ_1 and λ_2) in output port n are all occupied by other packets, $P(i,\ n,\ \lambda_1)$ has to be buffered. According to minimum delay time requirement, FDL #1 and transmission wavelength λ_2 are required. However, as shown in Fig. 3(b) FDL contention occurs, i.e., all buffering wavelengths (λ_1, λ_2, and λ_{w+1}) in FDL #1 are occupied by other packets. In this case, the next FDL, i.e., FDL #2, is searched. If there is an available buffering wavelength in FDL #2, $P(i,\ n,\ \lambda_1)$ is delivered to the available buffering wavelength in FDL #2. Otherwise, the next FDL is searched again until the one with maximum delay. As shown in Fig. 3(b), buffering wavelength λ_{w+1} in FDL #2 is available, thus $P(i,\ n,\ \lambda_1)$ is buffered on it. In output port n, $P(i,\ n,\ \lambda_1)$ is translated into wavelength λ_2 for transmission. The queuing of logical buffer in output port n after scheduling is illustrated in Fig. 3(c).

The performance of extended SB-OPS under GA-IWM is evaluated by simulation experiments. It is assumed that on each wavelength channel the packet duration and the idle duration between packets are exponentially distributed with mean lengths L_1 and L_2 respectively. The traffic load per wavelength channel is denoted by the link utilization $\rho_\mathrm{w} = L_1/(L_1 + L_2)$, which can be adjusted by changing the ratio of L_1 and L_2. Without loss of generality, the granularity of FDL (i.e., D) is normalized to the mean packet length L_1. In addition, the switch dimension N is assumed to be 16, and the number of transmission wavelengths W is assumed to be 4.

In Fig. 4, packet loss rate (PLR) of extended SB-OPS versus the traffic load in each wavelength channels is shown. In this set of simulation experiments, granularity D is chosen to be 0.3. In addition, the number of inner buffering wavelength (denoted by W_b) is set to be 4, 8, and 12. The buffer depth B is chosen to be 8 and 16 respectively in Figs. 4(a) and (b). For comparison, the performance of common SB-OPS is also evaluated in the same simulation conditions. The scheduling algorithm adopted by common SB-OPS is MINL algorithm[5], i.e., the blocked packet chooses the wavelength with shortest queue length. When the traffic load is high (e.g., ρ_w is equal to 0.8), extended SB-OPS will achieve better performance than common SB-OPS. Moreover, more inner buffering wavelengths can achieve lower PLR. However, under the condition of low traffic load (e.g., ρ_w is equal to 0.2), the performance of extended SB-OPS is almost the same as common SB-OPS. This is because when the traffic load is high, FDL contentions often occur. In this case, the additional inner buffering wavelengths can be used to reduce FDL contentions. However, under the condition of low traffic load there

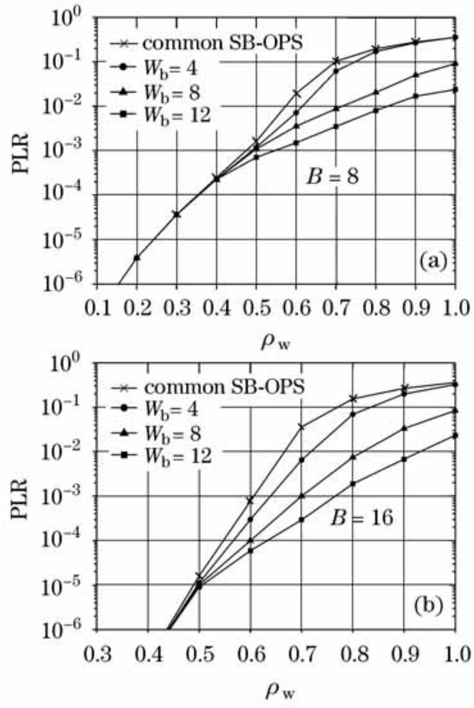

Fig. 4. PLR of extended SB-OPS versus traffic load ρ_w.

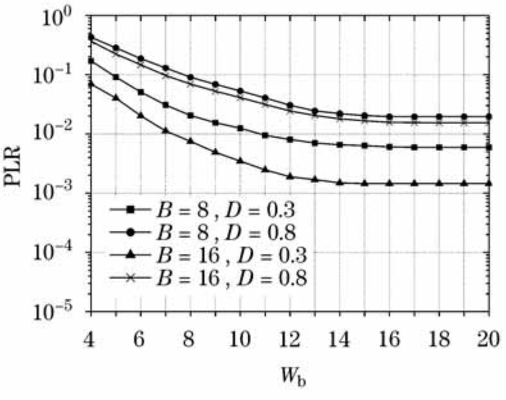

Fig. 5. PLR of extended SB-OPS versus number of inner buffering wavelength W_b.

are not many FDL contentions, therefore the additional inner buffering wavelengths are almost not used. Consequently, when the traffic load is low there is not need to use additional inner wavelength.

PLR of extended SB-OPS versus the number of inner buffering wavelengths W_{b} is illustrated in Fig. 5. In this set of simulation experiments, ρ_{w} is set to be 0.8. In each simulation case, with the increase of W_{b}, PLR of extended, SB-OPS decreases. However, when W_{b} becomes large enough PLR saturates. It is also found that with same buffer length B, different value of D also achieve different PLR. Therefore, in order to get better performance, the influence of D should be considered.

In this paper, an inner wavelength method is proposed to improve performance of optical packet switch with shared FDL-buffers. In addition, an optical packet switch called extended SB-OPS is proposed to realize the inner wavelength method. In order to further improve the performance of extended SB-OPS, a greedy algorithm based on inner wavelength method is introduced. Through simulation experiments, it is found that when traffic load is high, the inner wavelength method can effectively improve the performance of SB-OPS.

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