WDM Optical Packet Switches with Bufferless and Partially Shared Buffering Wavelength Converters

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Abstract   In this paper we introduce two architectures for optical packet switches. One is a bufferless switch employing shared Tunable Wavelength Converters (TWCs), and the other is a packet switch with Partially Shared Buffering (PSB). They were proposed for solving problems of contention resolution. The bufferless optical packet switch employing shared TWCs allows a saving in terms of employed number of converters under constraints of prefixed packet loss probability. The optical packet switch with PSB, in addition to dedicating an individual prime buffer for each output, incorporates a separate buffer for all the outputs to share. A lower packet loss probability can be achieved without the need of either dramatically increasing the size of each prime output buffer or deploying a large number of wavelength converters.

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Index Terms   Optical Packet Switch, Tunable Wavelength Converters (TWCs), Partially Shared Buffering (PSB), Wavelength Division Multiplexing (WDM).

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1. Introduction

The current fast-growing Internet traffic is demanding more and more network capacity. Multiplexing has provided us an opportunity to multiply network capacity. WDM techniques have been rapidly gaining acceptance as technology is able to handle the forecast dramatic

increase of bandwidth demand in future networks. Current optical switching technologies allow us to rapidly deliver the enormous bandwidth of WDM networks. Besides the huge amounts of bandwidth, all-optical WDM networks also allow high-speed data transmission without electronic converters at intermediate nodes and transparency with respect to data format to be achieved. Therefore, the optical WDM packet switching has been extensively studied in the literature [1]-[6]. These packets are switched from input fibers to output fibers optically. One of the key problems in application of packet switching in optical domain is the handling of packet contentions that take place when two or more incoming packets are directed to the same output line. Various techniques have been examined in literature: buffering, deflection routing, wavelength conversion, and wavelength dimension.

The output buffering achieves optimal throughput performance and it has been widely applied to WDM optical packet switch architectures. In electronic routers contention is usually resolved by a store-and-forward technique, which means that the packets in contention are stored in a queue and sent out one by one. This is possible because of the available random access memory (RAM). At least with current technology, optical buffer can be only implemented through a bundle of Fiber Delay Lines, with lengths equal to a multiple of packet duration. If contention occurs, only one of the contending packets may be allowed to reach the destination, the others must be buffered for later transmission.

In deflection routing, as the name implies, contention is resolved as follows if two or more packets need to use the same output link to achieve minimum distance routing, only one will be routed along the desired link, while others are forward on paths which may lead to greater than minimum distance routing. Hence, for each source-destination pair the number of hops taken by a packet is no longer fixed. Deflection routing does not necessary exclude the use of optical buffers.

In order to reduce the buffer size, the wavelength conversion technique has been proposed. Packet contentions are handled in the wavelength: packets addressed toward the same output are converted to different wavelengths by means of Tunable Wavelength Converters (TWCs). The advantage of wavelength conversion is the ability to shift the wavelength of an optical packet so as to effectively resolve wavelength contentions. Both buffering and deflection gave their advantages and disadvantages: buffering offers better network throughput but involves more hardware and controls; deflection is easier to implement, but cannot offer ideal network performance. When combined with wavelength conversion, their disadvantages could be overcome or minimized, therefore giving the network designer more choice and flexibility.

The wavelength dimension technique uses the wavelength dimension as a logical buffer

in the WDM optical network layer. The requirements to the size of optical buffers are relaxed by introducing multiple wavelength channels to decrease the traffic load of each channel.

This paper is organized as follows. In Section 2, we introduce a bufferless WDM optical packet switch employing TWCs. In Section 3, we introduce a WDM optical packet switch with Partially Shared Buffering (PSB). In Section 4, we contrast between bufferless WDM optical packet switch employing TWCs and WDM optical packet switch with PSB. Finally, in Section 5, we give a concluding remark.

2. Bufferless WDM Switch with Shared TWCs

The considered optical switch architecture is shown in Figure 1. It has N input and output fibers, each fiber supports a WDM signal with M wavelengths, so an input (or output) channels is characterized by the couple (i, λ_j) wherein i $(i \in \{1, \ldots, N\})$ identifies the input/output fiber and λ_j, $(j \in \{1, \ldots, M\})$ identifies the wavelength.
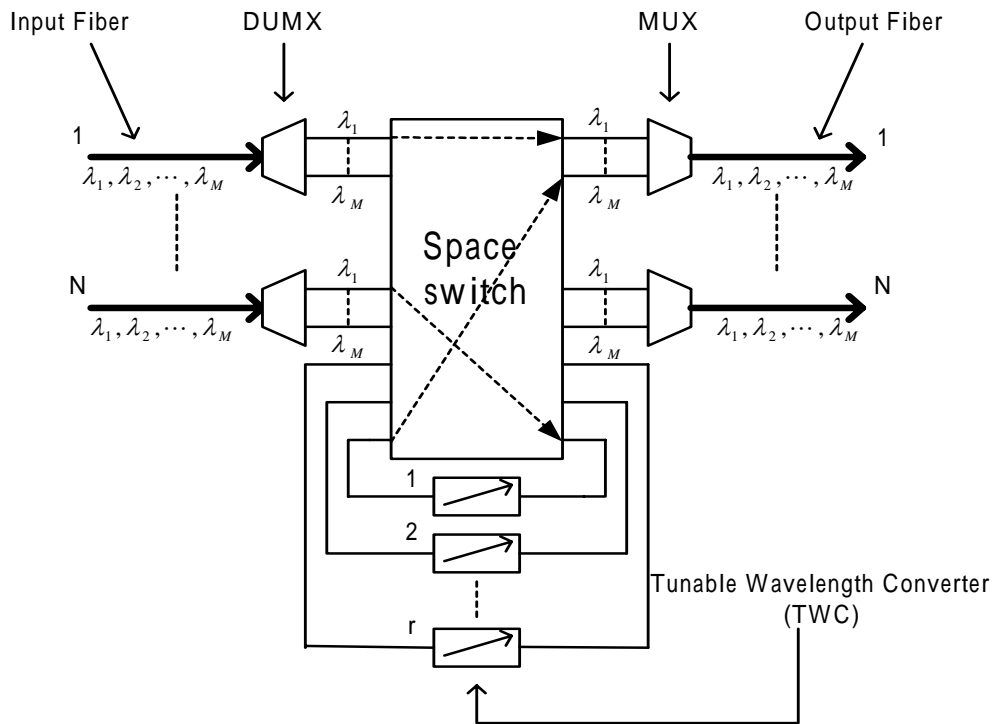

Figure 1. Structure of bufferless WDM optical switch equipped with TWCs.

The switch architecture is equipped with a number r of Tunable Wavelength Converters (TWCs) shared among the input channels. At each input line, a small portion of the optical power is tapped to the electronic controller not shown in the Figure 1. All packets have a fixed size and their arrivals on each wavelength are synchronized on a time-slot basis, and a time slot is the

time needed to transmit a signal packet. The switch control unit detects and reads packet headers and drives the space switch and the TWCs. Incoming packets on each input line are wavelength demultiplexed (DEMUX blocks in Figure 1). Electronic control logic, on the basis of the routing information contained in each packet header, handles packet contentions and decides which packets have to be wavelength shifted. Packets not requiring wavelength conversion are directly routed toward the output lines (e.g., the packet arriving at the input line 1 and wavelength λ_1 and directed to the output 1, as shown in Figure 1); on the contrary, packets requiring wavelength conversions will be directed to the pool of r TWCs and, after a proper wavelength conversion, they will reach the output line (e.g., the packet arriving at the input line N and wavelength λ_1 and directed to the output 1, as shown in Figure 1).

As a remark, it is to be noted that, the use of shared TWCs involves two main drawbacks to be dealt with: 1) the enlargement of the switching matrix of a factor equal to the number of used converters r (see Figures 1 and 2) the introduction of an additional attenuation of the optical signal caused by the twice crossing of the switching matrix.

For example, Figure 2 shows that λ_1 on which five packets arrive, λ_2 on which three packets arrive, and other two wavelengths, λ_3 and λ_4, on which no packets arrive. In the λ_1 channel, one packet arrives the output on the λ_1, and others have two packets after conversion process which arrive the output on λ_3 and λ_4, and others will be lost. In the λ_2 channel, one packet arrives the output on the λ_2, and others will be lost.
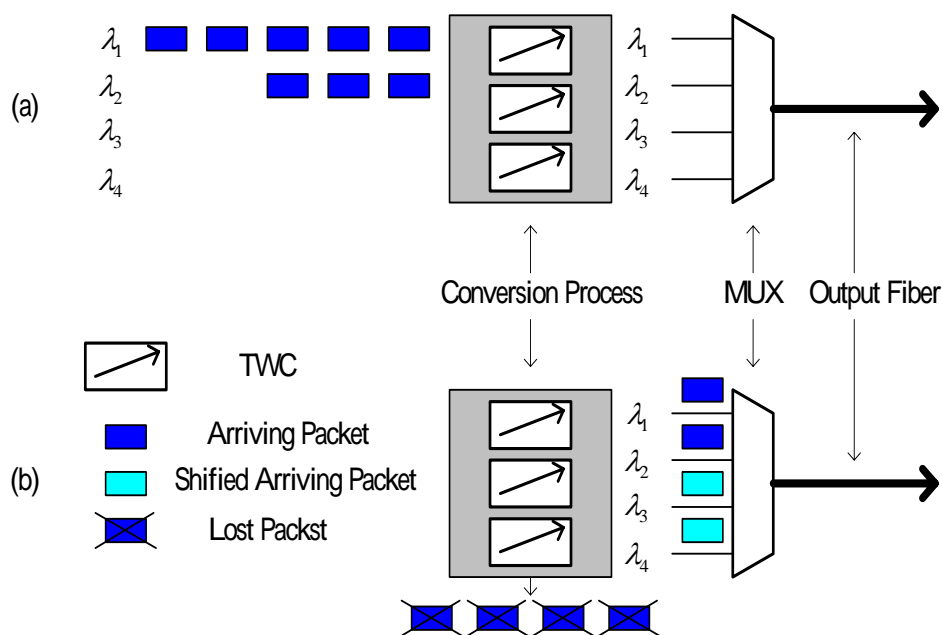

Figure 2. Wavelengths of arriving packets (a) before and (b) after conversions.

3. Partially Shared Buffering for WDM Packet Switch

The considered optical switch architecture is shown in Figure 3. Each input and output fiber consists of M different wavelengths. Each wavelength represents a unique channel. To resolve the packet contention, an optical buffer, with the capacity C, is included to each output fiber. These buffers are referred to as prime buffers. In addition, a separate group of fiber delay lines forming a common buffer, with the capacity of C', is allocated for all outputs to share. The buffer is referred to as shared buffer. All packets are of fixed size representing typical ATM traffic. Each wavelength can independently carry one packet at one time frame.
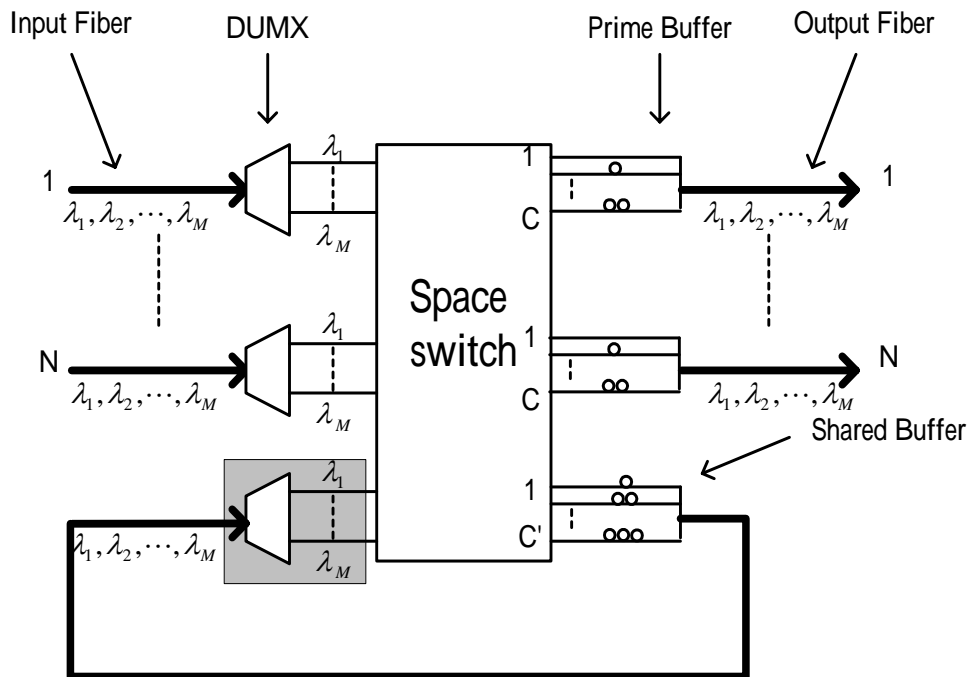

Figure 3. WDM Packet Switches with Partially Shared Buffering (PSB).

When a packet carried by a wavelength λ_j, ($j \in \{1, \cdots, M\}$) arrives from an input fiber, it is demultiplexed by the DMUX with its address information in the packet header processed electrically. This address is used to route the packet from the input to the destined output. The packet will then be transmitted on the output fiber if the wavelength λ_j is available; otherwise, it will be queued at the output prime buffer for later transmission. Generally, if n packets arrive at the same wavelength and are simultaneously destined to the same output fiber, up to n fiber delay lines are need to store these packets. These buffered packets will then be transmitted out to the output fiber in the subsequent time frames.

If the prime buffers are fully occupied, a newly arriving packet will be blocked. However, with the Partially Shared Buffering (PSB), even when a prime buffer has been fully occupied, the

overflow packets can be routed to the shared buffer for temporary storage. Thus, a packet will not be completely blocked until it fails in queuing in the shared buffer. Subsequently, the packets stored in the shared buffer will recirculate back to an input port for further attempts (this recirculation may be done more than once). Therefore, from the space switch perspective, the N inputs are used to serve the recirculation packets. To solve the potential packet sequence disordering problem, we always give the recirculation packets higher priority against with other newly arriving packets, and let the end user handle sequence correction if packet sequence disordering occurs.

The PSB without wavelength conversion architecture is shown in Figure 3. The corresponding queuing model is illustrated in Figure 5(a). Each plane represents an individual wavelength channel. Since each prime buffer consists of M logical buffers, each plane therefore contains one logical buffer associated with a wavelength. Thus the rejected packets always retain the same wavelength in all their attempts to be transmitted. Let us assume a packet, carried by a wavelength $_j$, ($j \in \{1, \quad ,M\}$) arrive at an input fiber, destined to an output fiber i ($i \in \{1, \quad ,N\}$). If no packet contention occurs, the packet will be transmitted immediately, otherwise it queues in the prime buffer of the i-th output for later transmission. However, if the buffer is full, the packet will be routed to the shared at the same plane j for temporary storage, unless the shared buffer is also full.
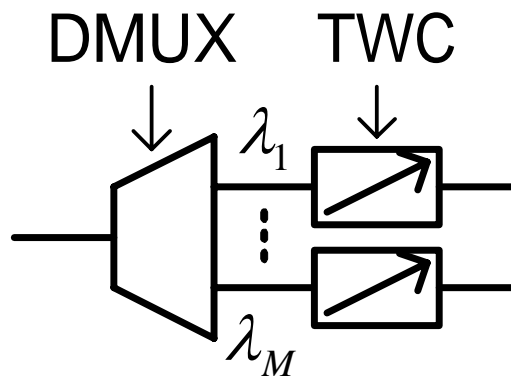

Figure 4. Wavelength conversions for recirculated packets from the shared buffer.

The dashed block of Figure 3 is replaced by the new block shown in Figure 4. Each demultiplexed wavelength in the dashed block is connected to a wavelength converter before joining the space switch. Thanks to the input tunable wavelength converters, the recirculation packets can be carried by any other wavelengths in its destination output fiber. The queuing model illustrated in Figure 5(b). The recirculation packets can be buffered across wavelength planes due to wavelength conversion.
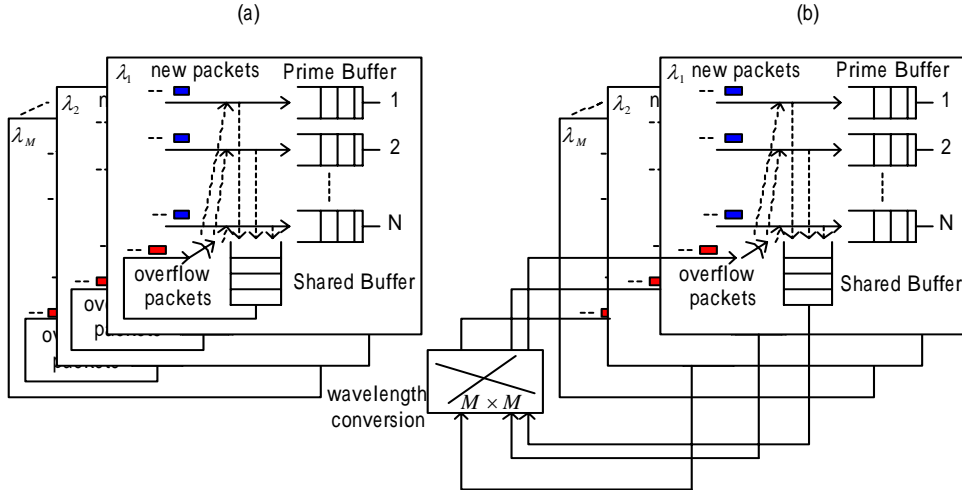
Figure 5. (a) Queueing model without TWCs; and (b) PSB model with TWCs.

4. Comparisons of Bufferless and Shared Buffer Schemes

A wavelength converter is needed to shift the wavelength of an optical packet. The switch architecture must be designed in a cost-effective way such that only a minimum number of wavelength converters are need. In addition, TWCs are active devices that create noise. A switch control algorithm is required to reduce unnecessary TWCs.

The architecture for a bufferless optical packet switch making use of the wavelength dimension for contention resolution of packets directed to the output line. The optical switch architecture is provided with wavelength converters shared among the output lines. An analytical model, allowing the dimensioning of the number of wavelengths converters according to a required performance, has been presented. The results of the analytical model fit very accurately with simulation ones. The model has been applied to carry out a sensitivity analysis of the required number of converters as a function of the main system parameters and traffic values. The proposed architecture allows us to save in terms of employed number of converters with respect to the other architectures proposed in literature.

The drawback of the delay-line buffer is that it is spacious and inconvenient. For example, more than 200m fiber is needed to delay an optical packet for 1μ s. Also, the delayed optical packet cannot be randomly retrieved. However, at present, there is no better device to buffer optical packets than the fiber delay line.

The other architecture for an optical packet switch is with Partially Shared Buffering. The architecture allocates a buffer to be shared by all outputs, in addition to the statistical nature of packet arrivals, more efficient use is made of the shared buffer resources. Therefore, a lower

packet loss probability can be achieved without the need of either employing wavelength converters. It only requires a very simple control algorithm, and needs fewer recirculation loops (less than 2). Simulation studies demonstrate the effectiveness of the PSB. The PSB with a limited number of wavelength converters that simulation studies have demonstrated that, with a fewer number of wavelength converters equipped in front of packet recirculation input, both the switch throughput and mean packet delay can be further improved.

5. Conclusions

The article introduces two architectures, one is bufferless optical WDM switch employing shared Tunable Wavelength Converters and the other is optical WDM switch with Partially Shared Buffering. The optical WDM switch employing shared Tunable Wavelength Converters discusses how to reduce packet loss probability and the number of wavelength converters. As an example, it has 16 input and output fibers, each fiber supports a WDM signal with 16 wavelengths, and the total load offered to each input line is equal to 0.8; the architecture equips only 10 converters instead of 256 that is the number of converters used in the main architecture proposed in the literature in which one converter is dedicated to each input wavelength channel.

The optical WDM switch with PSB combines the advantages of the low packet loss probability and optimal throughput delay performance. If a small number of converters are added to the recirculation delay line, the performance can be improved further. Simulation study demonstrates that the PSB can achieve a higher throughput without the need of either dramatically increasing the size of each prime output buffer or heavily employing wavelength converters.

In the future, we will propose a new architecture in accordance with the two architectures that have been proposed in other literature [7], [8]. We will utilize their advantages to propose a new architecture and join a new control algorithm for the packet optical switch. We then analyze the condition about packet loss and try to look for the best condition.

Acknowledgements

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