Paradigm Shift for Commercially Viable OPS/OBS with Shared Buffer and Wavelength Converter

(Invited Paper)

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Abstract: Performance of optically transparent packet and burst switching is significantly improved by true buffers, even in a shared manner, rather than by wavelength converters in WDM OPS and OBS. A novel design rule is proposed, aiming at commercial feasibility.

Keywords: optical packet switching, optical network, shared buffer architecture, wavelength converter

1. Introduction

Development of optical packet switching (OPS) and optical burst switching (OBS) technologies targets to introduce optical networks that can deliver extreme bandwidth data transport at a substantially lower cost. All-optical switch technologies have gained strong attention to achieve such a techno-economic goal as we can eliminate costly optical-to-electrical-to-optical (OEO) conversion. The recent rapid development of electronics technologies, however, has brought new techno-economic boundaries between OEO and all-optical technologies. Consequently, we need to revisit the assumptions for all-optical technology solutions. Especially, iterations of optimization of design rules that significantly rely on wavelength converters (WC) to obtain various all-optical functions are anticipated. This presentation identifies significance of each key element in OPS switch architecture and proposes a paradigm shift in the design rule that can guarantee practical network requirements and minimize the cost.

2. Performance and cost considerations of optical switch node sub-functions

2.1 Wavelength continuity versus ideal buffering

In a WDM packet switching system, contention between optical packets occurs only when the packets destined to the same output fiber try to go through the fiber at the same wavelength at the same time. Such contention can be resolved by two approaches: wavelength conversion and buffering. Traditionally, completed wavelength continuity by WCs is considered as the key solution for contention as buffers in the optical domain is not available. However, recent fast growth of OEO technologies shows that all-optical WC may not be a dramatic cost-saver. Moreover, the impact to the switching performance of buffering if we adopt OEO buffers is even more efficient than wavelength continuity.

In order to investigate performance impact of OEO buffers and WCs, we consider two switch models: a) a switch fabric with complete wavelength continuity [1,2,3], and b) a switch fabric with partial buffering [4]. Fig. 1 shows the blocking performance comparison between the two cases. In this analysis, we consider a switch fabric consisting of arrayed waveguide routers (AWGR) sandwiched between tunable WCs and DWDM D/MUX for the wavelength continuity case [1,2,3], and a passive switch fabric without wavelength conversion but with OEO buffers for the buffered switch case [1,4]. Both cases we consider the architecture can utilize partially installed WCs and buffers with certain sharing ratio (SR) as indicated in Fig. 1. The packet blocking probability decreases more with shared OEO buffering. Only 50% SR in the OEO-buffer and switch gives a better performance than 100% SR in the WC and switch. For this example, we assume an OPS node with an 8x8 node degree and 64 DWDM channels per fiber. The performance contrast increases as the number of DWDM channels decreases. Considering available technologies for the WC and OEO buffer designs, one can estimate that

$$\text{Cost of a WC} \approx \text{Cost of an OEO buffer.}$$

In this simple but representative analysis, we may infer that OEO buffer with passive optical switch may be more cost-effective and performance-effective approach.

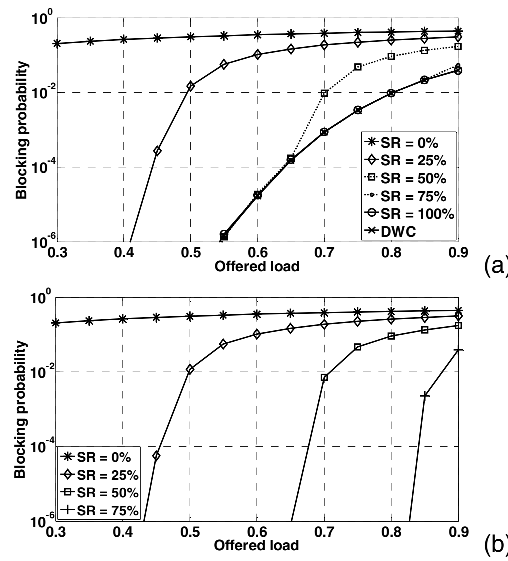
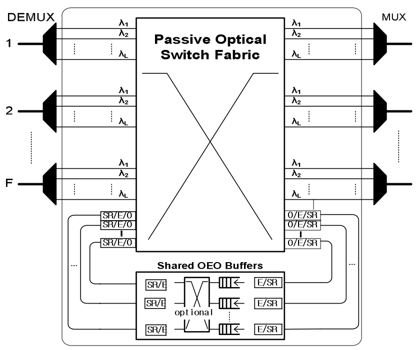


Figure 1 : Performance impact comparison between wavelength continuity (a) and buffering (b).

2.2 Impact of wavelength continuity in buffered switch

In the previous section, we conclude that blocking probability is significantly reduced by buffered switch, rather than by the WCs. Then the next question can rise what performance measure can change if wavelength continuity is added to a buffered switch. Figure 2 shows a typical design for shared-buffered optical packet switch, which can provide wavelength continuity when fast tunable transmitters are installed in SR/E/O interfaces to the switch fabric. The performance measure by blocking probability is not enhanced by addition of wavelength continuity, as the OEO buffer can hold packets as long as it is needed. However, wavelength continuity enhances drastically the delay jitter performance, as shown in Figure 3. Wavelength continuity reduces the delay jitter standard deviation approximately by two orders of magnitudes. In this analysis, the average length of packets is considered to be 80 microseconds with a 10 Gbps payload data rate.



(SR stands for short-reach optical transmitter or receiver.)

Figure 2 : Typical node schematic of buffered switch.

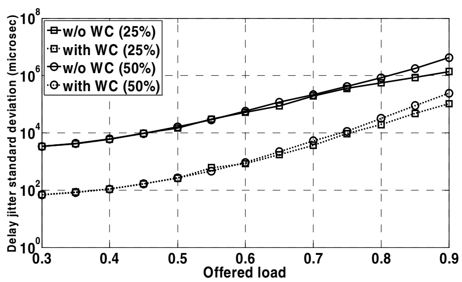


Figure 3 : Delay jitter standard deviation of packets from a buffered switch with and without wavelength continuity. (The percentile measures represent the sharing ratio of the buffers.)

Table 1: Sharing ratio requirements for an 8x8 switch node at offered load of 0.5 to guarantee packet loss probability of 10^{-6}.

Number of DWDM channels	8	16	32	64
Asynch. switch	53%	45%	38%	33%
Synch. switch	29%	20%	15%	13%

2.3 Impact of synchronous switching

It is well known that a time-slotted, namely, synchronous ALOHA network utilization is twice better than that of an asynchronous ALOHA network, meaning that contention probability is lowwer by a factor of two. The impact of synchronous packet switching in the passive optical switch fabric (Figure 2) is to reduce the contended packets, and as a consequence, the sharing ratio requirement for buffers can be reduces. Table 1 summarizes such reduction of sharing ratio requirement due to synchronous switching to guarantee a packet loss probability of 10^{-6} at offered load of 0.5. If the main cost of a node consists of OEO buffers, use of synchronous switching can reduce the node and network cost by a large fractions.

3. Conclusions for design rule and cost estimation

Summarizing discussions on blocking probability, delay jitter, sharing ratio requirement, we can conclude the following design rules:

1. The node switch fabric can functionally be a very simple but fast passive optical switch fabric.
2. OEO buffering is a more important and efficient function in resolving packet contentions than WC for switch fabric with complete wavelength continuity. OEO buffers can be efficiently shared. This is very significant observation unless cost of WC is dramatically lower than that of OEO.
3. Once OEO buffering is adopted, WC functions can be added by tunable OEOs at a marginal cost increase to reduce delay jitter.
4. Time-slotted switching can reduce the number of shared buffers, making the OPS very commercially attractive. However, savings in OEO should be balanced with time-slot tuning optics.

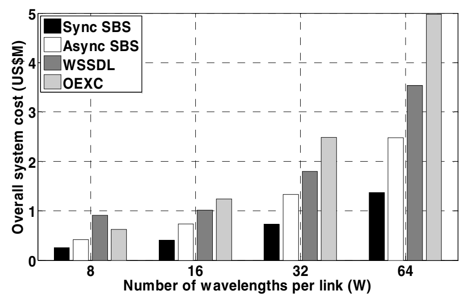


Figure 4 : Cost comparison.

Figure 4 presents cost estimation comparison among traditional electronics OEO approach (OEXC), wavelength switch fabric approach with fiber-delay-lines, asynchronous shared OEO buffer switch, and synchronous shared OEO buffer switch. Our proposed design rule has potential to achieve more than 70% cost savings over traditional node technologies, provided that a low cost fast passive switch fabric becomes commercially available.

5. Aknowledgment

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6. References

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