A New Optical Switching Fabric Architecture Incorporating Rapidly Switching All-Optical Variable Delay Buffers

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Abstract: This paper discusses new optical packet switch architectures utilizing all-optical variable delay buffers functioning as input and output queues in addition to circulating fixed buffers, and shows the simulation performance of the proposed architectures.

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1. Introduction

Optical packet switching (OPS) [1] brings a new vision for the future data-centric networks and bridges the gap between the electrical IP layer and the optical layer. The OPS technology allows switching of packets directly in the optical domain, overcomes the electronic switching bottleneck, and potentially provides scalability compatible with that of optical transmission capabilities. The performance and scalability of OPS networks are directly linked to the architecture and switching technologies of optical routers. The primary challenge in OPS stems from lack of all-optical random access memory. While the theoretical and experimental work for the optical-label switching router adopting fixed fiber delay lines demonstrated [2] wavelength-time-space domain contention resolution with packet loss rates below 0.1 % for relatively high load levels, even greater performance enhancement is expected for optical routers with variable all-optical buffers. Recently novel slow light effects have been demonstrated [3]. This paper first propose the design of novel single-stage and multi-stage wavelength-selective all-optical variable delay buffers by utilizing the slow-light technology. Then we present the architecture design and performance simulation results of the proposed optical switching fabric architectures exploiting such all-optical variable delay buffer technology.

2. Optical Switching Fabric Architectures with All-Optical Variable Delay Buffer

2.1 Novel Wavelength-Selective All-Optical Variable Delay Buffer Components Functioning as Input/Output Queue

The novel slow-light technologies [3] can be used to build the wavelength-selective all-optical variable delay buffer components, which only delays the optical packets in a selective wavelength channel without disturbing the packets in other wavelength channels of the same optical fiber. The single stage buffer component (Fig. 1 (a)) buffers the optical packets in a selective wavelength ?$_i$, thus it can be put at the input-side of optical switch fabric and functions as the input queue to provide flexible variable delay for the incoming optical packets arriving at the input switch port to avoid the packet contentions at the output switch port. If more than one packet arriving at the input switch ports are contending for the same output switch port, all but one are buffered in the input queue. By cascading the single stage buffer components designed to delay optical packets in different wavelength channels, the multi-stage component (Fig. 1(b)) can provide the buffering functions for a selective wavelength set {?$_i$, … , ?$_j$}, thus it can be put at the output-side of the optical switch architecture to provide more flexible variable delay for the outgoing optical packets to avoid the packet contentions at the output port/wavelength channel. If more than one packet arriving at the input switch ports are contending for the same output switch port, all the optical packets can be switched to the same output port simultaneously and then buffered in different stage of the output delay buffer.

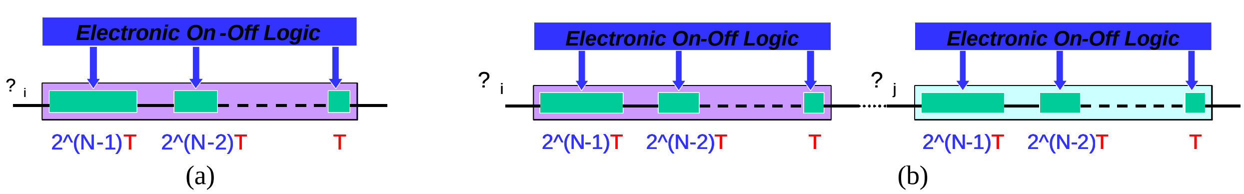
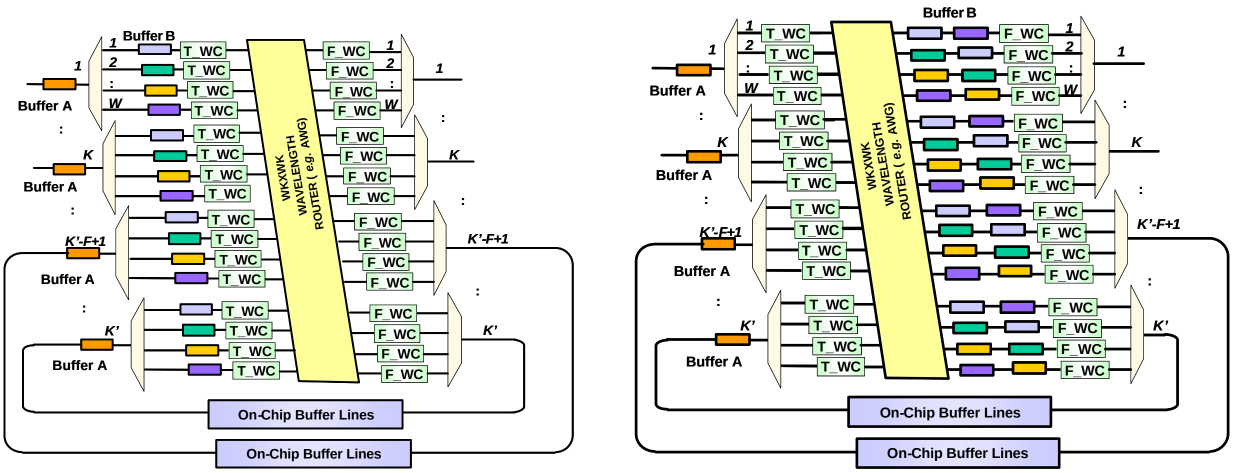


Fig. 1 (a) Single-stage all-optical input queued buffer, (b) multi-stage all-optical output queued buffer.

2.2 Proposed Optical Packet Switch Architecture with Combined Input/Output and Recirculation Queues

As in the electronic packet switching, the introduction of the above single-stage all-optical variable input-queuing buffer to the input-queued OPS architecture (IQ-OPS) lowers the packet loss rate, end-to-end delay and timing jitter.

Similarly, by taking advantage of the above multi-stage all-optical variable output-queuing buffer component, the output-queued OPS architecture (OQ-OPS) provides versatile wavelength-aware queuing, buffering, arbitrating and load-balancing functions for the optical packets from the multiple WDM channels. It also lowers the packet loss rate, end-to-end delay and jitter, without the HOL blocking effect (the buffer is wavelength selective) [4]. By further combining the recirculation buffer delay lines with IQ-OPS and OQ-OPS, the two new OPS architectures CIRQ-OPS (Fig. 2 (a)) and CORQ-OPS (Fig. 2 (b)) are expected to achieve the better performance in terms of packet loss rate, delay, jitter, etc. The proposed CIRQ-OPS and CORQ-OPS for the optical router includes tunable wavelength converters (T_WC), a N x N arrayed waveguide router (AWGR), fixed wavelength converters (F_WC), fixed optical Buffer A, and the single and multi-stage wavelength-selective all-optical delay Buffer B either at the input or output stage. Buffer A provides the time to look up the forwarding table and to make a forwarding decision. Buffer B functions as the input and output queues to provide the variable delay.



(a) (b)

Fig. 2 (a) Optical packet switch fabric with combined input queue and recirculation queue (CIRQ-OPS), (b) optical packet switch fabric with combined output queue and recirculation queue (CORQ-OPS).

3. Performance Simulation Studies of Proposed Optical Switch Architecture

The simulation studies are conducted to investigate the performance of the proposed optical packet switch architectures with input/output/circulation queues. To achieve a fair comparison, the total size of the input and the output queue buffers are at the same value.

3.1 Simulation Configuration

Three classes of simulations are conducted. The simulation configurations for each class are listed in Table 1.

Table 1. Simulation Configurations

Type	Port	Channel/Port	Switch Size	Fiber Delay Lines	Input Traffic	Packet Length Distribution
Class-I	4 x 4	10	40 x 40	1	Self-Similar	Fixed: 500 Bytes
Class-II	4 x 4	10	40 x 40	1	Self-Similar	Variable: 40~1500 Bytes
Class-III	8 x 8	10	80 x 80	1 and 2	Self-Similar	Variable: 40~1500 Bytes

3.2 Simulation Results Analysis

3.2.1 Effects of Queueing Schemes on the Proposed Switch Fabric Performance

Fig. 3 (a), (b), (c) show that in each simulation CIRQ-OPS always achieves lower packet loss rates but higher delays and jitters than CORQ-OPS. This is a fundamental queuing characteristics of input vs. output buffers in general.

3.2.2 Effects of Packet Length Distributions on the Proposed Switch Fabric Performance

Comparing the simulation results of Class-I (Fig. 3 (a)) and Class-II (Fig. 3. (b)), the self-similar traffic input with variable packet length distribution leads to a higher packet loss rate, delay, and jitter than the traffic input of fixed length packets. This is because variable size packet switching has higher contention probabilities for a given traffic.

3.2.3 Effects of the Number of Switch Ports on the Proposed Switch Fabric Performance

Comparing the simulation results of Class-II (Fig. 3 (b)) and Class-III (Fig. 3. (c)), when the number of the switch ports doubles, the packet loss rate increase slightly for the same number of wavelength channels per port. This is due to the fact that wavelength domain contention resolution is more effective than the space domain counterpart.

3.2.4 Effects of the Number of Fiber Delay lines on the Proposed Switch Fabric Performance

Based on the simulation results of Class-III, when the number of fiber delay lines doubles, the packet loss rate drops greatly while the delay and jitter increase slightly. This is because the additional buffering possibility through the fiber delay line provides additional room for contention resolution at the expense of additional delay variation.

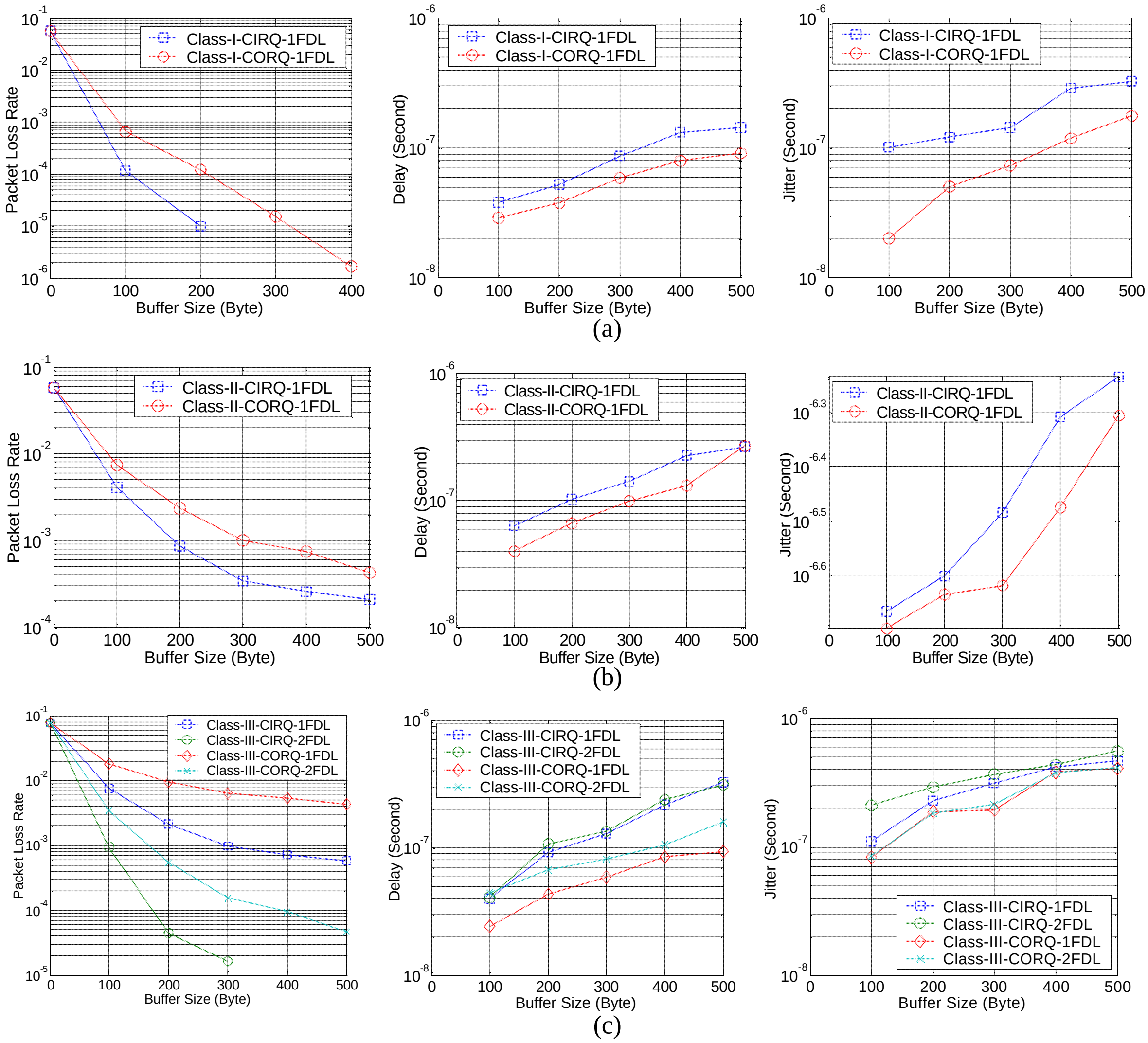


Fig. 3 (a) Class-I: PLR, delay, and jitter, (b) Class-II: PLR, delay, and jitter, (c) Class-III: PLR, delay, and jitter

4. Conclusion

This paper proposes the novel optical packet switch architectures incorporating wavelength-selective all-optical variable buffer components and the recirculation buffer delay line loops, and conducts comprehensive simulation performance analysis. For the same buffer size, input optical buffering is found to be more effective than output queuing in reducing the packet loss rate while increasing the jitter.

5. References

[1]. Shun Yao, *et al*, "All-optical Packet-switching for Metropolitan Area Networks: Opportunities and Challanges," IEEE Communications Magazine, vol.39, no.3, IEEE, p.142-8 , 2001.

[2]. S. J. B. Yoo, *et al*, "Optical-Label Switching based Packet Routing System with Contention Resolution Capabilities in Wavelength, Time, and Space Domains," Technical Digest, IEEE/OSA Optical Fiber Communication Conference, paper #WO2, Anaheim, California, 2002.

[3]. A. V. Turukhin, *et al*, "Observation of Ultraslow and Stored Light in a Solid", Physical Review Letters, vol. 88, no. 2, 2002.

[4]. M. G. Hlunchyj *et al*, "Queueing in high-performance packet switch," IEEE J. Select. Areas Commun., vol. 6, no. 9, pp. 1587-1597, Dec. 1988.

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