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Throughput improvement of deflection routed networks with an all-optical packet scrambler

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Abstract: *The throughput of deflection-routed networks are often lower than the expected because of the strong correlation between packets which can be removed by an all-optical packet scrambler.*

1. Introduction

Deflection routing is an important alternative to the use of buffers to resolve output contention in optical packet-switched networks [1, 2]. One of the shortcomings of deflection-routed networks is that, because of the strong correlation of packets in different time slots, the system performance is very sensitive to traffic distribution [3, 4]. Traditionally, the deflection routing nodes are assumed to have sufficient computational power to resolve the problem. However, this assumption is not valid in the optical packet-switched networks because only simple optical logic devices are available for ultrafast optical signal processing [2]. To improve the system performance, a straight forward way is to scramble the packets to reduce the packet correlation. In the past, scrambling was not considered in deflection-routed networks because of the additional delay incurred by scrambling, e.g., there will be a delay of at least two time slots to interchange a pair of packets. The scrambling induced delay will not be justified if each packet deflection only costs an extra delay of three or four time slots. In future optical networks, the propagation time between nodes can be much larger than the packet transmission time. The delay caused by the packet scrambling will be negligible if compared to the deflection extra delay. It will then be useful to use an all-optical packet scrambler to reduce the correlation between packets in different time slots.

2. All-optical packet scrambler

Figure 1 shows the proposed two-stage all-optical packet scrambler. The incoming packets are grouped into pairs and the packets in the pairs are reordered by the scrambler at random. The scrambler can be added to the inputs or outputs of the nodes of a deflection routed network. In Fig. 1, there are two modules SB 1 and SB 2 each of which has four switches (SW 1 to SW 4) and two sets of fiber delay lines (FDL 1 and FDL 2). Time is equally divided into time slots S_0, S_1, … each of which has a duration of one packet transmission time. We assume that each FDL in Fig. 1 has delay time of exact one slot for the storage of one packet. The switching time of all switches in Fig. 1 is assumed to be negligible. The switches SW A and SW B are in connection setting (0 – 1) at the start of time slot S_0 and change to (0 – 2) after the passing of two time slots, i.e., the start of S_2. Assume that the scrambler is installed at an output O_1 of a node N_1. During the two time slots S_0 and S_1, switches SW 1 to SW 4 of module SB 1 are all in connection setting (0 – 1). In the mean time, two time slots of bits are sent into module SB 1 from node output O_1 via switch SW A, and are completely stored in optical fiber delay lines FDL 1 and FDL 2 when time slot S_2 starts. Note that the two time slots of bits can be data bits for packets or dummy bits for idle slots. At the start of time slot S_2, the switches SW 1 to SW 4 take one of the connection settings (0 – 1) and (0 – 2) at random. If the connection setting (0 – 1) is taken, the bits in fiber delay line FDL 2 will move out via switches SW 3 and SW 4 to switch SW B during the time slot S_2. When the bits in FDL 2 moves out, those in fiber delay line FDL 1 will move into FDL 2 via switches SW 2 and will be sent out via switches SW 3 and SW 4 in the time slot S_3. If switches SW 1 to SW 4 take connection setting (0 – 2) at the start of time slot S_2, the bits in fiber delay line FDL 1 will be sent out via the switches SW 2, SW 4 and SW B. Those in fiber delay line FDL 2 will move into FDL 1 via switches SW 3 and SW 1, and will be moved out via switches SW 2, SW 4 and SW B similarly in time slot S_3. In parallel to the transmissions in module SB 1, slots of bits from node output O_1 continues to fill up the fiber delay lines in module SB 2 during time slots S_2 and S_3. The operations similar to that in module SB 1 are repeated in module SB 2 from time slots S_2 to S_5 (the switches SW A and SW B will be reset to the connection setting (0 – 1) at time slot S_4). As the time slot cycle continues, the proposed set up in Fig. 1 will provide the

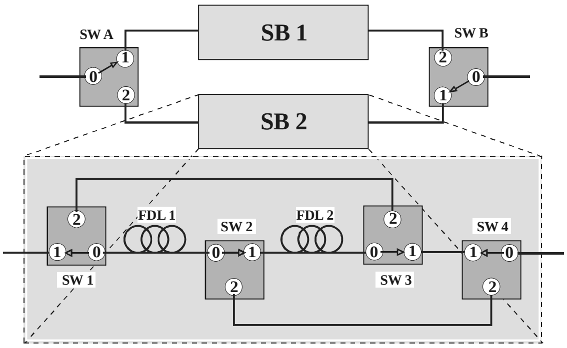

Fig. 1 A two-stage all-optical packet scrambler.

required packet scrambling function. To construct larger scramblers, we can either follow the approach in Fig. 1 or use the two-stage packet scramblers as the building blocks.

3. Performance evaluation

Figure 2 shows the throughput performance of using the proposed packet scrambler on a 10×10 deflection-routed Manhattan Street Network (MSN) that supports multicast services [4, 5]. For an $r \times c$ MSN, there are r rows and c columns of nodes. We label the nodes from left to right, and top to bottom. The node in the upper left corner is labeled 1, and that in lower right corner is labeled N, i.e., $N = r \times c$. In the simulations of Fig. 2, we use the same multicast tree as that in [4], Fig 3 : $\{(1 \rightarrow 2 \rightarrow 3 \rightarrow 4 \rightarrow 5 \rightarrow 6 \rightarrow 7 \rightarrow 17 \rightarrow 27), (1 \rightarrow 11), (3 \rightarrow 13), (5 \rightarrow 15)\}$. Node 1 is the root node of the tree that generates new multicast packets. The multicast packets are then sent along the tree to the multicast destination nodes. At the branch nodes 1, 3, and 5, the multicast packets are duplicated and forwarded to the downstream nodes.

In the simulations, the node-to-node propagation time is 100 slot times. We assume that a node has at most one new arrival packet per time slot but can receive two packets simultaneously. Apart from the multicast traffic, there is also background unicast traffic. The probability that a new packet arrives at a node is the offered load. The unicast load offered to each node is set to 0.1. We also assume that a node sends unicast packets uniformly to each node in the network except itself. When a multicast packet fails an output contention, it is deflected and will have to return to the same deflection node to continue the multicast, i.e., the back-to-the-deflection-node (BDN) scheme in [4]. The deflection of a unicast packet, however, has no such limitation. As the result shown in [4], the correlation between packets in different time slots will be strong if the BDN routing is used. Consequently, the BDN routing scheme is not recommended even though it is comparatively easier for the all-optical implementation because of the worst throughput performance [4].

In Fig. 2, the solid curve is the throughput performance of the multicast packet routing without the proposed packet scrambler, i.e., the BDN routing scheme. The curves with circles and squares are those with the proposed 2-stage and 4-stage packet scramblers. From Fig. 2, we observe that there is significant improvement if the proposed packet scramblers are used. The throughput of the packet routing without scrambler has the maximum value 0.22 at loading of 0.4 and drops to 0.17 at loading of 0.9. In contrast, the throughput of the packet routing with 2-stage scrambler has the maximum value 0.32 at loading of 0.7 and drops slightly to 0.31 at loading of 0.9. The proposed packet scrambler not only increases the network throughput but also improves the system stability. We also find that there is very little advantage in using 4-stage instead of 2-stage scramblers. Thus large scramblers are not necessary in most cases.

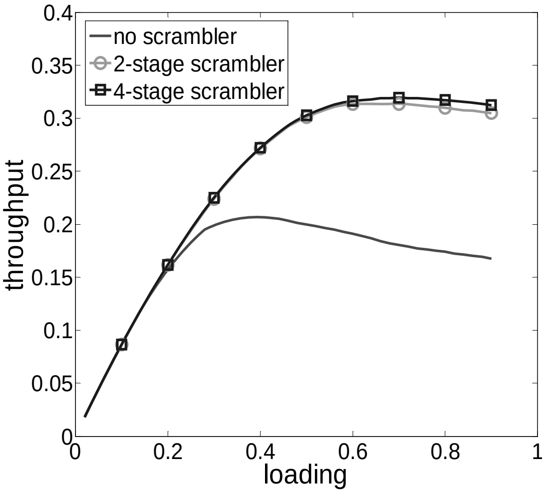

Fig. 2 The throughput performance curves of the proposed packet scrambler on a 10×10 deflection-routed Manhattan Street Network (MSN) that supports multicast services.

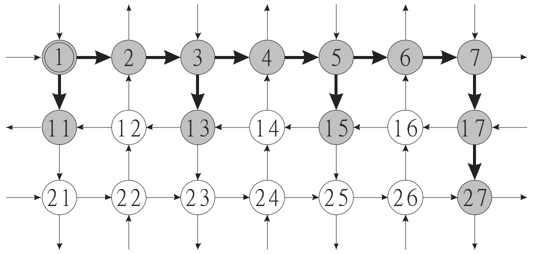

Fig. 3 A 10×10 MSN multicast tree: Node 1 is the root of the tree. Nodes 1, 3, and 5 are the branch nodes [4].

4. Conclusion

In this paper, we propose an all-optical packet scrambler to reduce the correlation between packets in different time slots in deflection-routed networks such that the system throughput performance is improved. We propose a design of the two-stage packet scrambler. We can also use the two-stage packet scramblers to build larger scramblers such as 4-stage and 8-stage. From simulation results, we observe that the two-stage packet scramblers are sufficient for most of the situations.

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