Performance comparison between Optical Burst Switching and Deflection Routing

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Abstract—Optical packet-switched networks of the near future will likely use no or very small number of optical buffers. We compare the delay-throughput performance of deflection routing and optical burst switching because both do not require the use of optical buffers. Simulations show that the simple packet drop-and-retransmit contention resolution strategy of optical burst switching has a better performance than the slotted deflection routing when the network is lightly loaded.

I. INTRODUCTION

Optical networking is one of the key technologies in building future broadband communication networks. Current optical networks are based on wavelength division multiplexing (WDM) technology [1]. Point-to-point communications can reach up to hundreds gigabits per second per wavelength channel. The circuit-switching nature of WDM optical networks, however, is not suitable for the bursty multimedia traffic that are expected to be the dominant traffic in future. All-optical implementation of packet switching technology is difficult because of the lack of sophisticated optical signal processing devices and practical optical buffers [2]. In hybrid optical networks, packet switching/forwarding is carried out in the optical domain while the packet headers are converted into the electrical domain for processing. The demand on optical signal processing is reduced but the packet contention resolution problem remains.

Traditional packet-switched networks store the contending packets and schedule transmission according to the priorities of the packets. The store-and-forward strategy is not feasible in optical packet-switched networks because practical optical buffers are not yet available. To store a one microsecond only packet, which corresponds to 10 kilobits of data in a 10 Gbps channel, will require 200 meters of optical fiber. Besides being bulky, the delay for a given length of fiber is fixed. Using fiber delay lines to make optical buffers for variable size packets remains a challenge, not to mention using them to schedule the contending packets. Other packet contention resolution approaches include deflection routing [3], wavelength conversion [4], and simple drop-and-retransmit such as that used in optical burst switching (OBS) [5]. Deflection routing uses the network as buffers and has been proposed for all-optical packet-switched networks with arbitrary topology [6]. Typically, the network is assumed to be slotted and each node has the same number of input and output ports. We intentionally misroute (deflect) the contending packets to other available output ports. Transit packets always have priority over new packets to improve performance. Optical packet-switched networks in the near future however are likely to be asynchronous, use variable size packets, and have no coordination between nodes in transmission. In such networks, a transit packet may be dropped at a node by a new packet that arrives slightly earlier and takes up the last free output port. To restore the priority of transit packets over new packets, a node has to ensure that no transit packet arrives at the node during the transmission of a new packet. This can be done by installing sufficient number of optical delay lines at the input ports of the node and sophisticated algorithms for scheduling the packet transmissions. Therefore deflection routing in unslotted networks is rather complicate and may have significant performance degradation when compared to that of the slotted networks [7].

Resolving packet contention by converting the contending packets to other wavelength channels in effect uses extra transmission bandwidth to reduce packet contentions. Also, other contention resolutions are required if the number of contending packets is more than the available wavelength channels at the output port. Recently, the simple strategy of just dropping the contending packets has gained popularity through OBS [5], [8]. The lost packets may be recovered by retransmissions at upper protocol layers. Adaptive packet admission and congestion control are required to avoid possible positive feedbacks induced by the retransmission which can result in even more losses.

In this paper, we compare the delay-throughput performance of optical burst switching with deflection routing. In Section II, we discuss the simulation models. For deflection routing, we include both slotted and unslotted networks. In Section III,
we compare the performances of the two contention resolution strategies using the AT&T IP network [9] and an 8 × 8 Manhattan Street Network (MSN) [10]. Finally, we conclude in Section IV.

II. THE SIMULATION MODELS

A. Slotted Deflection Routing

We assume that the networks are slotted, the packet size is fixed, and the required packet transmission time for a packet is a slot time. We also assume that the propagation delay of all links in the networks are integral multiples of a slot time. The nodes are synchronized and send/receive packets only at the beginning of a time slot. The packet header contains all instructions for the nodes to route the packet to its destination from any location in the network. All output ports at every node of the network are prioritized in a packet. At the beginning of each time slot, a node processes the transit packets that arrive at the node. New packets are assigned output ports only if the number of transit packets is smaller than that of the output ports. If two or more packets select the same output port as their first choice, one of the packets is selected at random. Then the node processes the second choices of the transit packets that lost their respective contentions. This procedure repeats until all packets are assigned an output port. In the simulations, a packet ranks the output ports in a node according to the path lengths from the output port to the destination of the packet. Thus a packet always minimizes the path length from the current node to the destination node even if the packet is deflected. Such deflection routing approach minimizes the requirement of optical hardware and is suitable for the implementation in all-optical packet-switched networks of the near future [6]. In the simulations, the probability that a new packet arrives at a node is the offered load. We assumed that at most one new packet arrives at a node per slot time. A new packet will be blocked immediately if there is no free output port when the packet arrives at a node.

B. Unslotted Deflection Routing

We assume that the networks are asynchronous, the length of links are variable, and the packets have variable sizes. We assume that the arrival of packets to a node is a Poisson process and the transmission time of a packet is an exponentially distributed random variable with unit mean. The offered load to a node is the ratio of the average packet transmission time to the packet inter-arrival time. In unslotted deflection routing, a new packet will be blocked if i) there is no free output port when the new packet arrives at a node, or ii) a transit packet is going to arrive at the node during the transmission of the new packet and there is no free output port after admission of the new packet. The second condition ensures that transit packets have priority over new packets in the choice of output ports and it can be implemented by delaying the transit packets at the input ports the amount of time required to transmit a new packet [7]. Similar to Section II-A, we also assume that all routing informations are encoded in the packet headers.

In the simulations, the maximum packet transmission time is truncated to the minimum link propagation delay in the networks. The link propagation delay is at least tens of the average packet transmission time, the probability of truncation is in general small.

C. Optical Burst Switching

The OBS networks are similar to that described in Section II-B but the communications between nodes are in form of data bursts [5]. When a packet arrives at an ingress node of an OBS network, the packet is stored in an electronic buffer until the number of packets with the same destination reaches a threshold value or the first packet in the batch exceeds the storage time limit. The node then sends out a control packet to the destination. After an offset time, a data burst containing the new packets are sent out following the path of the control packet. The control packet reserves the resources at the nodes on the path for the data burst. No acknowledgment is sent back to minimize electronic buffering and the data burst waiting time. In the original form, OBS simply drops a data burst if the latter encounters output contention at an intermediate node. Retransmission of the lost data burst is carried out by higher protocol layers. Since we are not interested in the process of grouping the arriving packets, we assume that the traffic arrival is in the form of data bursts with Poisson probability distribution. The offered load is defined similarly as that in Section II-B. We used the node structure proposed in [8] and assumed that the offset time is negligible if compared to the data burst transmission time. When a data burst is dropped at a node, a negative acknowledgment is send back to the source. After the propagation delay, the source is aware of packet loss and a retransmission will then be scheduled with a random delay. The node is assumed busy in the retransmission scheduling period and any new data burst will be blocked. The procedure is repeated until the data burst is received by the destination.

III. PERFORMANCE COMPARISONS

We compare the performance of deflection routing (both slotted and unslotted) and optical burst switching using the AT&T network topology shown in Fig. 1 and an 8 × 8 MSN [10]. The average delay-throughput curves for the two contention resolution strategies are plotted in Figs. 2 and 3. For the AT&T network, there are a total of 27 nodes and 37 links. We assumed that all links are bi-directional. The average number of output links per node is 2.8. The link propagation delays are normalized and marked next to the links. The minimum and maximum normalized propagation delays are 1 and 22 link propagation delay units, respectively. For the 8 × 8 MSN, all links have the same propagation delay of one unit. We assume that the average packet transmission time is one tenth of the minimum link propagation delay. When a new packet (or data burst in OBS) arrives
at a node, it randomly chooses a destination from the rest of the nodes in the network. We also assume that all nodes have the same offered load. In the simulations, shortest path routing is used for communications between nodes. The packet transmission delay is the difference between the time of the packet being received by the destination and that of the packet admission, irrespective of deflections or retransmissions. The throughput of a node in slotted networks is the average number of packets received per slot time. In unslotted networks, we define the throughput as the number of data bits received at a unit time normalized by the link capacity.

Figures 2 and 3 show the average delay-throughput curves for the two contention resolution strategies. Crosses, asterisks, and circles represent unslotted deflection routing, slotted deflection routing, and OBS respectively. The average delay is measured in term of unit link propagation delay. The offered loads are marked beside the curves for OBS switching for reference. From Figs. 2 and 3, both slotted deflection routing and OBS perform better than the unslotted deflection routing. If the network is lightly loaded, e.g., the offered load below 0.26 and 0.28 in Figs. 2 and 3 respectively, OBS have lower packet transmission delay than slotted deflection routing for the same throughput. Slotted deflection routing however has a higher maximum throughput than OBS. The maximum throughputs of slotted deflection routing are 0.31 and 0.155 for AT&T network and MSN respectively while that for OBS are 0.2 and 0.142 respectively.

Because of the higher average output degree of the AT&T network, the average throughputs of the AT&T network are always larger than that in the MSN in all three cases. Moreover, the $8 \times 8$ MSN is easier to get congested. Figure 4 plots the throughput versus offered load for the two contention resolution approaches on the $8 \times 8$ MSN. The notation is the same as that in Figs. 2 and 3. We note that the throughput of slotted
Fig. 4. The throughput versus offered loading for deflection routing and OBS using an $8 \times 8$ MSN. Crosses, asterisks, circles, and squares represent unslotted deflection routing, slotted deflection routing, OBS, and OBS combined with unslotted deflection routing, respectively.

and unslotted deflection routings increases monotonically up to the offered loading of 1. The throughput of OBS however decreases from 0.145 to 0.082 when the loading increases from 0.3 to 1. In Figure 4, we also plot the performance result of combining OBS with unslotted deflection routing in the curve with squares. Contending packets are deflected whenever possible, and are dropped only when there is no free output port. The combined approach improves the performance if the system is lightly loaded but lead to congestion when loading is larger than 0.18.

IV. CONCLUSION

We have compared the delay throughput performance of deflection routing (both slotted and unslotted) with optical burst switching (OBS) using simulations on a network of AT&T network topology and an $8 \times 8$ Manhattan Street Network. Although unslotted deflection routing is suitable for asynchronous variable packet length optical networks, its performance is the worst among the three. Slotted deflection routing provides better throughput performance when the system loading is high. However, the requirement of synchronization, fixed size packet, and coordination among the nodes may cause difficulties in the implementation. Basic drop-and-retransmit strategy in OBS provides fair performance in lightly loaded systems. This approach may be a suitable choice for packet contention resolution because of its minimal optical hardware requirement. The performance of OBS in light traffic range can be improved by combining it with unslotted deflection routing. Such arrangement, however, is more easier to get congested. Adaptive admission control is in general needed to prevent OBS systems from congestion.

REFERENCES