Performance analysis of an integrated scheme in optical burst switching high-speed networks

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Received October 23, 2007

A new integrated scheme based on resource-reservation and adaptive network flow routing to alleviate contention in optical burst switching networks is proposed. The objective of the proposed scheme is to reduce the overall burst loss in the network and at the same time to avoid the packet out-of-sequence arrival problem. Simulations are carried out to assess the feasibility of the proposed scheme. Its performance is compared with that of contention resolution schemes based on conventional routing. Through extensive simulations, it is shown that the proposed scheme not only provides significantly better burst loss performance than the basic equal proportion and hop-length based traffic routing algorithms, but also is void of any packet re-orderings.

OCIS codes: 060.4250, 060.4510.

The optical burst switching (OBS) paradigm[1] has been recently gaining momentum as a solution which exploits the advantage of statistical multiplexing to make efficient use of bandwidth, reducing latency and achieving transparency in next generation all-optical networks. OBS combines the advantages of both circuit and packet switching (as shown in Table 1) and ensures efficient bandwidth and resource utilization.

In Ref. [2], the results indicate the higher efficiency of the OBS networks in utilizing the huge bandwidth of the wavelength division multiplexing (WDM) links, compared with the optical circuit switching (OCS) networks, i.e., under the identical traffic demand and network capacity, OBS networks achieve a higher throughput than OCS networks. Different OBS signaling protocols have been previously proposed[1,3], "just enough time" (JET) being the most widely recognized. The JET protocol is based on the delayed reservation (DR) paradigm[3] and offers good efficiency (resources utilization can be properly scheduled) and low latency. If, upon the arrival of the control message, no wavelengths can be reserved at the suitable time, the corresponding burst will be blocked and lost, assuming that no contention resolution (CR) mechanisms are available. In OBS networks, as shown in Fig. 1, the transmission links carry multiple WDM channels, which can be dynamically assigned to user data bursts. One channel on each link is reserved for control information. This separation of control and data simplifies the data path implementation, facilitating greater use of optical switching technologies. At the edge of the network, a setup control packet is sent on the control channel to announce an upcoming burst. The control packet is then followed by a burst of data after a short delay. At the intermediate node, the setup control packet is electronically processed, while the data channels are switched through transparently with no examination or interpretation of the data. Since data bursts are sent out without waiting for the acknowledgement replies from receivers to setup the path (one-way reservation paradigm), the burst could be blocked in an intermediate node due to resource contention, in which case, the burst has to be dropped. In order to reduce dropping probability, contention resolution is required for an OBS. In literature, some approaches have been extensively studied to resolve the burst contention problem in OBS, such as wavelength conversion, optical buffering, and space deflection[4]. However, when there is no unscheduled channel, the contention cannot be resolved by any one of these techniques, some of the bursts must be dropped. In this paper, a new integrated scheme based on resource-reservation and adaptive network flow routing to alleviate contention in OBS networks has been proposed. The objective of the proposed scheme is to reduce the overall burst loss in the network and at the same time avoid the packet out-of-sequence arrival problem.

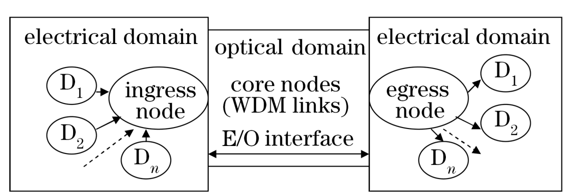

Fig. 1. An OBS network (electrical domain using aggregate traffic and optical domain using OBS).

Table 1. Comparison of Optical Switching Schemes

Optical Switching (Paradigm)	Bandwidth Utilization	Latency (Setup)	Optical Buffer	Traffic Adaptively
Circuit	Low	High	Not Required	Low
Packet/Cell	High	Low	Required	High
Burst	High	Low	Not Required	High

1671-7694/2008/040244-04

The proposed scheme is based on the JET protocol, but it introduces some mechanisms to ensure quality of service (QoS) guarantees. The ingress node checks all the different optical paths taking into account network topology and load statistical information. The resulting routing information is sent in the control packet. Then, intermediate nodes only need to check the temporal availability for the correct switching configuration to the next hop suggested by the ingress node. In other words, arriving traffic flows are assigned to multiple link-disjoint paths between each source and destination (SD) pair based on a set of flow proportions computed adaptively. Once the assignment for a new flow is made, the flow will be transmitted using the same path until its departure and will not be shifted between different paths in different time windows. Based on the measured "quality" at the end of each time window as well as the hop length factors of the paths, the set of assigned flow proportions for the paths between SD pair will be adjusted accordingly and applied to route new incoming flows in the next time window. Furthermore, the burst assembly time threshold for each path can also be varied to further enhance the burst loss performance.

The proposed scheme provides better QoS, as controlled loops are made by using the previously reserved resources. In contrast to JET, resources are not released just after data burst (DB) transmission but are preventively reserved. If there are no available resources at the next hop node, a loop is created by sending the burst back to the preceding node (where resources have been pre-reserved) and forwarding it again. Uncontrolled loops and the computation problems associated with rerouting are drawbacks of conventional routing mechanisms which are avoided with the proposed scheme. Due to its flow-based nature, the proposed scheme is effectively packet reordering-free. The flow routing is performed in a weighted-round-robin manner. When a new traffic flow arrives at the SD pair, a path will be selected to route the flow using the weighted-round-robin-selector[5], whose weights are given by the set of flow proportions. The basic principle is that if a path r_k's assigned flow proportion is $1/n$, then in every n selection, there must be one occurrence of path r_k. The frequency of occurrence for a specific path in the path selection sequence is proportional to its assigned flow proportion. Whenever a new traffic flow arrives, based on the path selection sequence, a path is chosen to route the flow and the path selection sequence repeats in cycles. The flow-based routing algorithm has to maintain the mapping information between the flow and its assigned path. This helps to improve the routing stability and reduce traffic fluctuations in the network[6−10]. Therefore the overall network performance can be improved. In case, when two bursts with different priorities content the same path, a distributed wavelength assignment algorithm for burst optical networks called the priority-based wavelength assignment algorithm is used to resolve the contention. The resource contention is resolved in the wavelength domain. With this algorithm, each node assigns wavelengths based on the wavelength priority information "learned" from its wavelength utilization history in a distributed manner. As the learning process progresses, nodes in the same part of the network tend to assign different wavelengths to avoid contentions, meanwhile, the same wavelengths are spatial reused in the different parts of the network. Each sender node x keeps a wavelength priority database for every destination node y. For each wavelength w, a pair of information, $P(x, y, w)$ and $N(x, y, w)$ are recorded, where $P(x, y, w)$ shows the priority function and $N(x, y, w)$ shows the number of access times to wavelength w. Priority of the wavelength is determined by the value of the priority function $P(x, y, w)$, i.e., a wavelength with the largest priority function value has the highest priority. The number of access times $N(x, y, w)$ is used to determine the modification value for updating the wavelength priority. The value of the priority function $P(x, y, w)$ determines the performance of the algorithm. The wavelength priority can be calculated with following iterative formulae. When a burst with wavelength w is successfully delivered, $P(x, y, w)$ and $N(x, y, w)$ are updated as:

$$\begin{aligned} P(x,y,w) &= \{P(x,y,w) \times N(x,y,w) + 1\} \\ &\quad /\{N(x,y,w) + 1\}, \qquad (1) \\ N(x,y,w) &= N(x,y,w) + 1. \end{aligned}$$

When a burst with wavelength w is not successfully delivered, $P(x, y, w)$ and $N(x, y, w)$ are updated as:

$$\begin{aligned} P(x,y,w) &= \{P(x,y,w) \times N(x,y,w)\} \\ &\quad /\{N(x,y,w) + 1\}, \qquad (2) \\ N(x,y,w) &= N(x,y,w) + 1. \end{aligned}$$

The modification value for updating the wavelength priority $P(x, y, w)$ decreases as $N(x, y, w)$ increases. The value $P(x, y, w)$ approaches to the successful transmission probability as $N(x, y, w)$ increases under steady state. In non-steady state, however, adaptation becomes difficult as $N(x, y, w)$ increases, since adaptation speed decreases as $N(x, y, w)$ increases. In actual case, an upper limit to $N(x, y, w)$ is necessary to maintain constant updating of $P(x, y, w)$ in order to accommodate dynamic change of burst traffic. By simulations, the burst loss performance of the proposed scheme has been investigated under different traffic conditions.

The performance of the proposed scheme has been evaluated using NS-2 simulator[11] on the NSF14-Nodes network. A bidirectional link consists of two unidirectional fibers in opposite direction. Each fiber has 4 data channels at 1-Gb/s transmission capacity. The data channel scheduling algorithm employed here is the latest available unscheduled channel with void filling (LAUC-VF). The burst loss probability, mean hop-length, wavelength utilization, and wavelength efficiency are used as the performance metrics. The burst loss probability is measured as the fraction of bursts dropped. The mean hop-length is measured as the average number of hops traversed by bursts. The average wavelength (channel) utilization is the percentage of a single wavelength that has been utilized to successfully deliver data bursts. The average wavelength efficiency is the percentage of the average offered load per wavelength that has been successfully contributed to the average wavelength utilization. It is a ratio of the average wavelength utilization over the average wavelength offered load. In other words, the average wavelength efficiency shows the successful transmission rate. The proposed scheme has been compared with two flow routing schemes: the equal proportion multi-path flow routing (EPFR) and the hop-length based multi-path flow routing (HLFR). For EPFR, traffic flows that arrive at a SD pair will be distributed evenly among the multiple paths between the SD pairs. For HLFR, flows will be routed to a path with a probability inversely proportional to the hop-length of the path. In order to get more realistic results, the long range dependent traffic model is employed. In this traffic model, traffic that arrives at each node pair in the network is the aggregation of multiple IP flows. Each IP flow is an ON/OFF process with Pareto distributed ON and OFF times. During each ON period of the Pareto-ON/OFF model, a Pareto distributed number of packets, with mean N and Pareto shape parameter β, are generated at the peak rate p packets/second. The OFF times are also Pareto distributed with mean X and γ. The following set of values are used for the Pareto-ON/OFF flows in the simulations: $N = 5$, $\beta = 1.2$, $X = 46000$ μs, $\gamma = 1.3$, $p = 600$. The packet length is set to be 100 B. The transmission rate per flow r is fixed at 30 kb/s. The wavelengths are set in between 4 and 128. The range of $P(x, y, w)$ is set to be $0 - 1$. Similarly, the limit of $N(x, y, w)$ is fixed at 10.

Figure 2(a) shows the mean hop-length traversed by a burst with varying traffic load per node pair for various routing schemes. The mean hop-length can reflect the delay, initial offset time and control burst signaling overhead in the network in an indirect manner. From the graph, it is observed that resource-reservation and adaptive network flow routing (RR-ANFR) proposed in this paper achieves a shorter mean hop-length over EPFR and HLFR. The rationale behind is that the EPFR and HLFR treat all the paths in a fixed manner. Flows are routed through different paths based on the initial flow proportion assignment throughout the whole course.

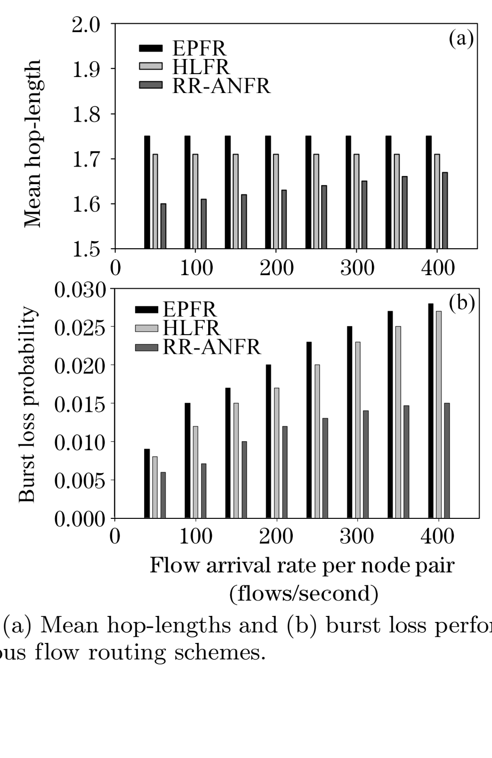

Fig. 2. (a) Mean hop-lengths and (b) burst loss performances of various flow routing schemes.

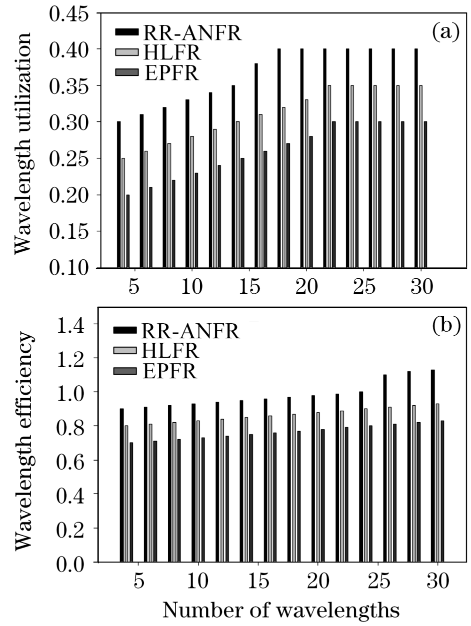

Fig. 3. Graph of (a) wavelength utilization and (b) wavelength efficiency.

Therefore, on the average, bursts traverse longer paths more often than RR-ANFR since the routing does not adapt to the varying traffic conditions in the network. It is also observed that the mean hop-length for RR-ANFR increases when the traffic load increases. The proposed scheme tends to give more flow proportions to the longer paths when traffic load increases.

Figure 2(b) shows the burst loss probability of various flow routing approaches with varying traffic load per node pair. Traffic load is expressed as the mean flow arrival rate (FAR) per node pair in the network. It is observed that RR-ANFR performs much better than EPFR and HLFR in terms of overall burst loss performance. On average, the performance of RR-ANFR is improved by up to 32% when compared to EPFR and 26% when compared to HLFR. Although both EPFR and HLFR distribute traffic flows across multiple paths, they perform worse because they fail to keep track of the varying traffic situations in the network.

Figures 3(a) and (b) show that RR-ANFR significantly improves the wavelength utilization and the wavelength efficiency as compared to EPFR and HLFR.

In conclusion, the attractiveness of the proposed approach lies in the preservation of packet ordering of individual flows while reducing the overall burst loss in the network. The proposed approach offers a significant advantage when compared to conventional routing. The previous node has already reserved the resources when it has transmitted the burst, so no new paths have to be calculated. This allows computational resources to be saved and reduces the number of signaling messages to be conveyed over the network. This simplifies OBS network control. Through simulations, it has been demonstrated that the proposed scheme can significantly reduce burst loss in the network and improve wavelength utilization and efficiency as compared with the static flow routing schemes such as EPFR and HLFR algorithms.

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