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A maximum-efficiency-first multi-path route selection strategy for optical burst switching networks

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ABSTRACT

In this paper, the impact of a path selection on other existing paths in optical burst switching (OBS) networks is studied by analyzing the contention among different traffic streams and the interaction between the route selection and traffic load balance. The results show that there exists a mutual reinforcement interaction among the traffic load of a path, the path burst loss ratio and the contention ability of the path when burst loss ratio based multi-path selection strategies are adopted, which may increase the unbalance of traffic and lead to severe congestion further. A maximum-efficiency-first multi-path selection strategy, which considers the performance of the burst flows and the impact of a path selection on existing OBS paths at the same time by a combined metric of route efficiency, is proposed to maximize the utility of the burst flows and minimize the increment of lost throughput on the path. The performance of the proposed multi-path selection strategy is evaluated through simulation. The results show that the presented strategy obviously outperforms the least burst loss ratio strategy and shortest path first strategy in terms of the burst loss ratio in the practical unbalanced background traffic, especially when the network is heavily loaded.

1. Introduction

Optical burst switching (OBS) network has been proposed as a promising solution for future IP over WDM network. It cannot only alleviate the requirement on optical storage/buffer, optical switch fabric, and optical logic processing, but also reach higher flexibility and utilization of resources [1]. Bursts may be dropped at intermediate OBS nodes due to the contention among bursts arriving at the nodes simultaneously. It is one of the most important issues in OBS networks. Optical buffering and wavelength conversion can be used to alleviate burst contention in time domain and wavelength domain at OBS core nodes, respectively [2]. However, optical buffers for large data bursts with unfixed length are not currently mature, and no optical buffering is one of the main advantages of OBS compared to optical packet switching (OPS). All optical wavelength converters are also complexity and expensive now. Moreover, the burst loss ratio is still not low enough even when full optical wavelength conversion is adopted at OBS nodes [3]. Burst contention can also be resolved in the space domain. Deflection routing for OBS networks, which solves contention resolution in space domain by deflecting the contention burst to an idle sub-optimal optical link at OBS nodes, has been extensively studied in the literature [4,5]. Extra offset time, however, is required for deflection routing in OBS networks to compensate the extra processing delay for the burst control packet on the sub-optimal path. Delaying deflection data bursts using optical buffers at each core node will increase the complexity of OBS core nodes while setting the maximum offset for all possible deflection paths at ingress OBS nodes will degrade the performance of the network severely. Furthermore, deflection routing may lead to routing loops and undesirable vibration effects when only the local information is considered, and its improvement to the network performance decreases with the increase of network load since idle optical links are occupied as fiber delay lines for contention resolution [5].

Multi-path routing is another kind of methods to reduce the burst loss ratio in space domain. In the mechanisms, congestion is minimized by selecting the "optimal" path from several candidate end-to-end paths at edge nodes based on certain current network state information and strategies [6,7]. Several pure path selection strategies, which uses only a single parameter such as burst loss ratio and link utilization to determine congestion level in the network, have been proposed [7–10]. Ref. [7] shows that hybrid path selection strategies outperform pure path selection strategies since the information used by pure path selection strategies provides only a limited view of the network. Ref. [11] presented a self-learning autonomous route selection scheme which dynamically maintains priority values for all the routes to each egress node at each ingress node. In order to dynamically update the priority value

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of paths, ingress nodes have to send search packets and receive feedback packets, which will cause a higher network overhead and require the core nodes having the capability to send acknowledgments. Ref. [12] modeled the path selection as a multi-armed bandit problem and presented a single agent learning approach to select the path that minimizes the burst loss ratio at each ingress node. The single agent learning approach does not guarantee the optimal path selection for the entire network since it only considers the local *Q*-values of the selected path [13].

An edge node can take the impact of path selections into account in its path selection procedure from two ways: including the effect of the path selection made by other nodes or including the effect of the path selection made by its own on other existing paths. Ref. [13] developed a multi-agent reinforcement learning approach to minimize the burst loss ratio of the entire network by including the effect of the path selection made by all the other nodes in the network. In order to implement the cooperation among different agents, however, each agent at each ingress node has to know the existence of other agents and their actions. Therefore, fully-connected information exchanges among all agents for the path selection strategy are needed, which will cause a higher network overhead with the increase of the number of edge nodes. In this paper, we model the effect of a path selection on other existing paths and propose a maximum-efficiency-first (MEF) path selection strategy where the effect of the path selection made by an edge node on other paths is considered by the "local" edge node. In the approach, each edge node considers the performance of the burst flows to be routed and the impact of the coming path selection on existing OBS paths at same time by a combined metric of route efficiency. The candidate path with the maximum route efficiency is selected to maximize the utility of the burst flows and minimize the increment of lost throughput on the path.

The rest of the paper is organized as follows. Section 2 discusses the multi-path selection problems in OBS network by considering the interaction among traffic load, burst loss ratio and path selection. In Section 3, a multi-path selection strategy that seeks the route path with the maximum defined route efficiency is proposed. Section 4 shows the simulation results of the proposed strategy and compares it with least burst loss ratio strategy and shortest-path-first strategy. Section 5 is the conclusion.

2. Multi-path selection problems in OBS networks

An OBS network consists of edge nodes, core nodes and WDM links. At ingress edge node, the data from hosts and/or sub-networks is assembled to bursts according to certain assembly scheme. The bursts are transmitted to corresponding egress edge nodes through the OBS network according to the OBS protocols, and disassembled to original data at egress edge nodes which are sent to the destination hosts or sub-networks [14].

Fig. 1 shows the diagram of an OBS network adopting multi-path route strategy. The paths of bursts are determined end-to-end at the corresponding ingress edge node by selecting the "optimal" one from a list of paths to the egress node according to certain selection strategy. The selected path information is carried in burst control packets that go ahead of the corresponding data bursts to setup the optical path for the date bursts.

Generally speaking, an "ideal" path selection should consider the existing traffic of the network to improve the network performance. For multi-path route, the traffic over each end-to-end path can be characterized as an end-to-end stream which is the aggregate of all burst flows over a common OBS path between an ingress–egress node pair. At OBS nodes, the burst loss ratio of all flows in a stream is same, and there are only contentions among streams on the link because of the streamline effect [14]. In this section, we will analyze the contention features among streams and its interaction with multi-path selections. We assume that each OBS node in the network has a full wavelength conversion capability and no FDL buffer for contention resolution of data bursts.

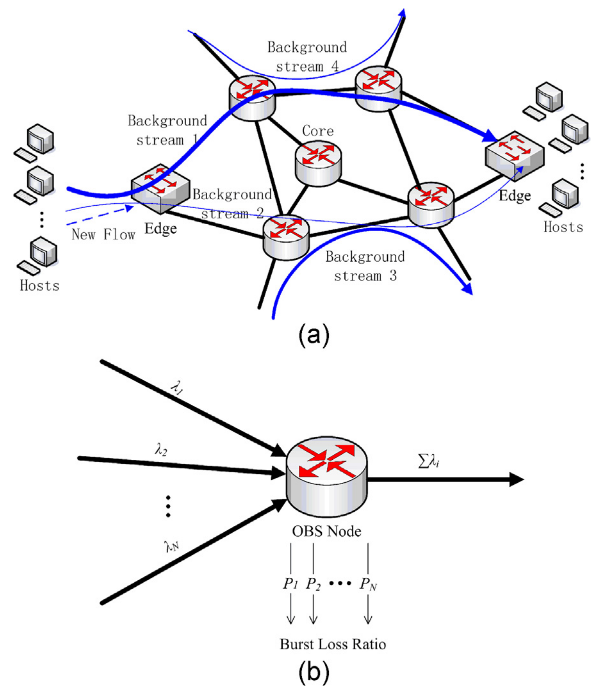

Fig. 1. (a) Different flows pass through the same link; (b) an example of route selection for the new flow.

2.1. Contentions among different traffic streams

At an OBS node with *N* input streams, each of which is an aggregate of all burst flows inputting in a common input link and destined for a common output link, as shown in Fig. 1(b), the burst loss ratio of stream *i* can be expressed as follows according to Ref. [15].

$$\begin{cases} P_i = \dfrac{p_{\mathrm{all}} - p_i}{1 - p_i} \\ p_{\mathrm{all}} = \dfrac{\rho^W/W!}{\sum_{n=0}^{W}\rho^n/n!} \\ p_i = \dfrac{{\rho_i}^W/W!}{\sum_{n=0}^{W}{\rho_i}^n/n!} \\ \rho = \displaystyle\sum_{i=1}^{N}\rho_i, \quad \rho_i = \dfrac{\lambda_i}{\mu} \end{cases} \tag{1}$$

where, λ_i is the burst arrival rate of stream *i*, which is determined by the number of flows and the arrival rate of each flow in the stream; μ is the service rate for bursts at the OBS core node; *W* is the number of data channels; *N* is the number of the streams. According to Eq. (1), the traffic stream with a larger burst arrival rate tends to experience a relatively lower burst loss ratio, which means traffic flows with different arrival rates in OBS network are unfairness in terms of burst loss ratio.

Fig. 2(a) shows the relationships between the burst loss ratio of streams and their arrival rate ratio at an OBS core node by simulation. In the simulations, the core OBS node in Fig. 1(b) is connected to two ingress edge nodes and one egress edge node through WDM links, respectively. Each WDM link has 8 wavelengths with the rate of 10 Gb/s. 50 flows with the rate of 50 Mb/s are generated and assigned to two streams as different ratio of the number of flows, which is equal to the arrival rate ratio of the two streams. From the