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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.

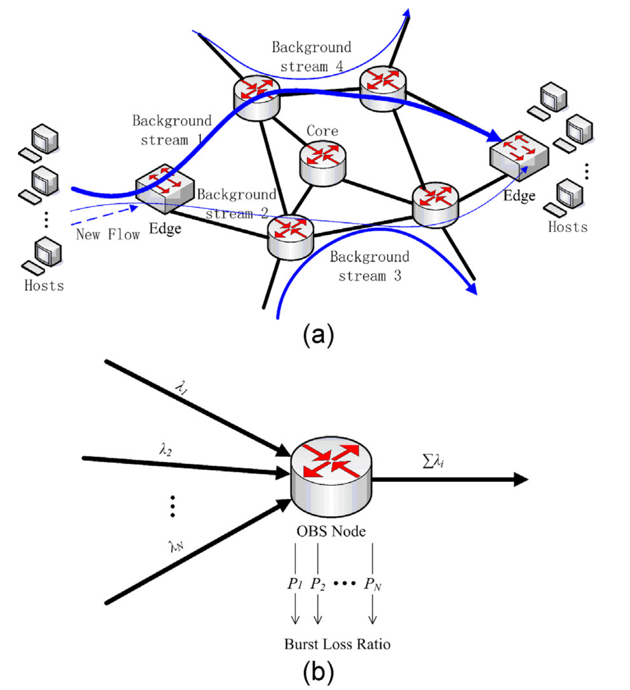

Fig. 1. (a) Different flows pass through the same link; (b) an example of route selection for the new flow.

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].

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

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

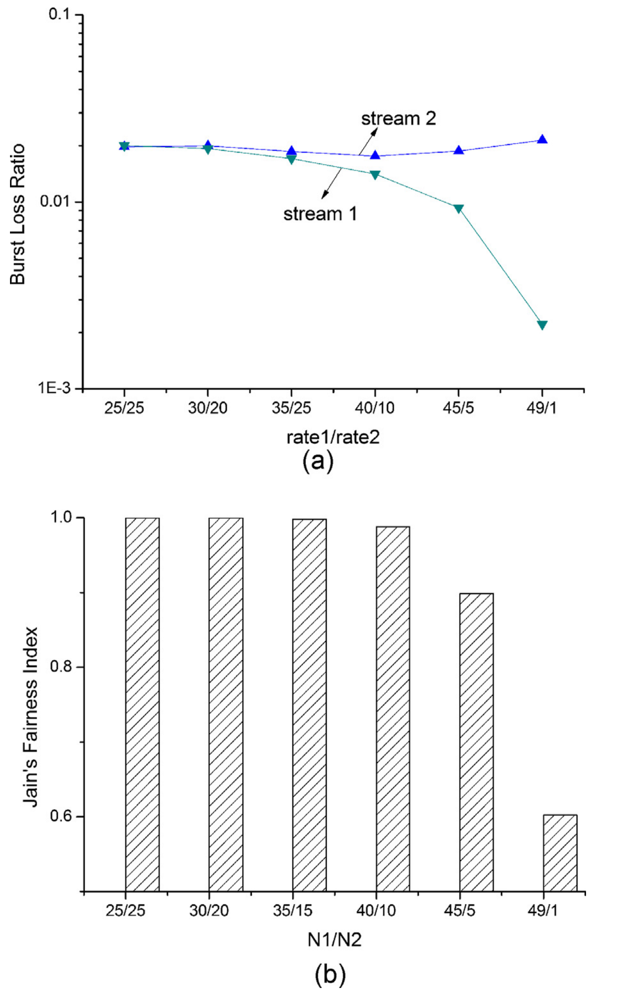

Fig. 2. Burst loss ratios (a) and Fairness index (b) as a function of the rates of streams.

figure, we can see that the burst loss ratio of stream 1 decreases and the burst loss ratio of stream 2 increases with the increase of arrival rate ratio of stream 1 to stream 2. The fairness of the two streams is also shown in Fig. 2(b). We can see that the fairness of the two streams is degraded with the increase of the arrival rate ratio of the two streams.

2.2. Interaction between path selection and traffic load

Consider the multi-path route selection in the OBS network, in order to avoid the out of order of data, it is best that the traffic from a common flow takes a common OBS path between the ingress and egress pair. When a new flow arrives at an OBS edge node, the OBS edge node will select the "optimal" path from the corresponding path list according to a certain metric, which can reflect the congestion degree of paths. The proposed metrics include end-to-end path burst loss ratio based [8,11], link utilization based and their varieties [7]. The end-to-end path burst loss ratio based strategies are relatively simpler, and the core OBS nodes can be kept simple and low cost since the strategies only involve information collection and transmission at OBS edge nodes.

According to the results in Section 2, when end-to-end path burst loss ratio based strategies are adopted, the path with a higher rate stream will have a high possibility to be selected for a new arrival flow since the path tends to have a lower burst loss ratio, which can be represented by the burst loss ratio of existing streams over the path. Moreover, the rate of the stream on the selected path will increase with the assigning of new flows, which will further enhance the contention ability of the corresponding stream or the priority of the path in terms of the stream burst loss ratio. For example, in Fig. 1(a), the traffic rate of stream 1 is much larger than that of stream 4 while the traffic rate of stream 3 is larger than that of stream 2. Edge node 1 will have a higher priority to select the path with stream 1 for new arrival flows according to the burst loss ratio strategies. Then the traffic rate of stream 1 will increase for the input of the new flow, and its burst loss ratio will lower further. Therefore, there exists a mutual reinforcement interaction among the traffic arrival rate of a path, the path burst loss ratio and the contention ability of the path (the higher the traffic arrival rate is, the lower the burst loss ratio is, the higher the selection priority of the path is, and the higher the traffic arrival rate is) when burst loss ratio based path selection strategies are adopted.

In most practical scenarios, the traffic rate of end-to-end streams is unbalanced at a moment since different type of application, the number of hosts/sub-networks connected to edge nodes, and so on. The load unbalance of the network will become higher and higher because of the mutual reinforcement effect between the traffic arrival rate and the path burst loss ratio when path burst loss ratio based strategies are adopted. In this case, although the new flow is assigned to a path with a lower burst loss ratio, the burst loss ratio of the overall network may increase obviously since other streams bypassing the links on the heavily-loaded path are blocked severely. The unfairness among different burst flows will also become more and more serious.

3. Maximum-efficiency-first route selection strategy

In order to take into account the impact of the interaction among path selections on the overall performance of OBS network, a maximum-efficiency-first route selection strategy, which considers the performance of the burst flows and the impact of the route selections on existing OBS paths at the same time, is proposed here. In the proposed strategy, the performance of burst flows is characterized by the utility, which is related to the burst loss ratio of an end-to-end stream. According to Ref. [16], the utility of a new burst flow viewed from the host side can be expressed as follows when adopting the logarithmic utility function.

$$U = \log\left(1 + \frac{P_{\max} - P}{P_{\max}}\right) \tag{2}$$

where, $P_{\max}$ is the intolerable end-to-end burst loss ratio of the new flow; P is the end-to-end burst loss ratio of the new flow, which can be obtained as $P = 1 - \prod_{i=1}^{n}(1 - P_i)$, P_i is the burst loss ratio on link i.

The impact of a route selection on existing OBS flows by-passing a link on the selected path can be characterized by the increment of lost throughput on the link after assigning a new burst flow to it. Consider an end-to-end OBS path consisting of n links, the impact of the route selection on all existing OBS flows bypassing the links on the selected path, named as cost of route selection, C, can be expressed as,

$$C = \sum_{i=1}^{n}(\mathrm{Loss}_i(\mathrm{After}) - \mathrm{Loss}_i(\mathrm{Before})) \tag{3}$$

where, $\mathrm{Loss}_i(\mathrm{After})$ and $\mathrm{Loss}_i(\mathrm{Before})$ is the lost throughput when bursts passing from link i to link $i+1$ after and before the new flow is assigned, respectively. It can be expressed as:

$$\begin{aligned}\mathrm{Loss}_i(\mathrm{Before}) &= B(\lambda_{\mathrm{be}})P(\lambda_{\mathrm{be}})\\ \mathrm{Loss}_i(\mathrm{After}) &= B(\lambda_{\mathrm{new}})P(\lambda_{\mathrm{new}})\end{aligned} \tag{4}$$

where, B is the average length of bursts; λ_{be} is the burst arrival rate of traffic destined link i before the new flow is assigned; λ_{new} is

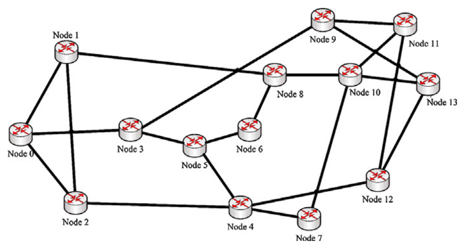

Fig. 3. Simulated OBS network.

the burst arrival rate of traffic destined link i after the new flow is assigned; $P(\lambda_{be})$ and $P(\lambda_{new})$ is the overall burst loss ratio on link i with arrival rate λ_{be} and λ_{new}, respectively.

A combined metric, called route efficiency, is defined as the ratio of the utility to the cost of corresponding route selection.

$$\mathrm{Eff} = \frac{U}{C} = \frac{\log(1 + (P_{\max} - P)/P_{\max})}{\sum_{i=1}^{n}(\mathrm{Loss}_i(\mathrm{After}) - \mathrm{Loss}_i(\mathrm{Before}))} \quad (5)$$

In order to consider the performance of the burst flows and the impact of the route selections on existing OBS paths at the same time, the maximum-efficiency-first route selection strategy will always select the candidate path with the maximum route efficiency, which can increase the utility of the new flow at a reasonable cost of route selection.

4. Simulation results

The proposed path selection strategy is evaluated by simulation on the NSF network [17], shown in Fig. 3. We assume that each WDM link connecting two OBS nodes has one control channel and eight data channels. The bandwidth of each channel is 10 Gbps. There are no wavelength conversion and optical buffering in each OBS node.

Fig. 4 shows the overall network burst loss ratio and the path burst loss ratio from node 0 to node 13 (the burst loss ratio of all flows from node 0 to node 13) as the function of the number of flows in the network under different path selection strategies when the background traffic is uniform. In the simulation, end-to-end flows with arrival rate of 400 Mbps are generated randomly. 80% of the total generated flows are uniformly imposed on the network as the background traffic. The rest 20% flows are assigned between nodes (0, 13) as new arrival traffics which are routed at node 0 based on least burst loss ratio (LBLR) strategy, maximum-efficiency-first (MEF) strategy and traditional shortest-path-first

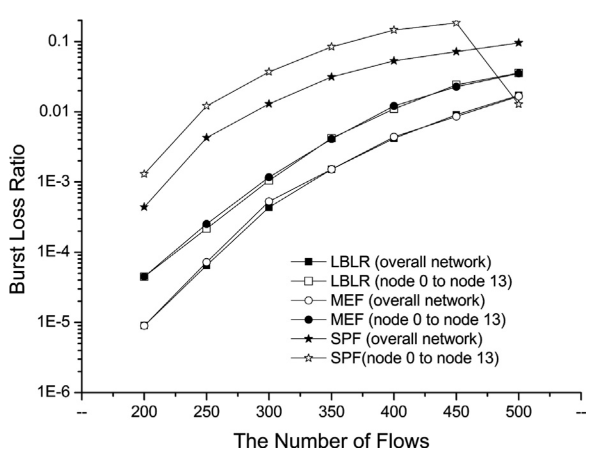

Fig. 4. The overall network burst loss ratio and the path burst loss ratio as a function of the number of flows in the network under different route selection strategies when the background traffic is uniform.

(SPF) strategy, respectively. From the figure, one can find that LBLR and MEF have very close performance under uniform traffic background. The burst loss ratio of the overall network under the two strategies is always lower than that on the paths from node 0 to node 13. It is reasonable since the load of the paths between nodes (0, 13) is higher after new flow is assigned. We can also find that both LBLR and MEF perform much better than SPF in terms of the burst loss ratio before the number of the new arrival flows is more than 100. This is because both LBLR and MEF can distribute new burst flows to multi-paths while SPF only selects the shortest path between node 0 and node 13. The path burst loss ratio between nodes (0, 13) under SPF decreases dramatically while the number of the new flows reaches 100. The main reason is that the bursts on the shortest path selected by SPF are serialized when the total rate of streams along the path is large enough [15].

The performance of LBLR and MEF are compared further in non-uniform background traffic. In the simulation, 200 end-to-end flows with arrival rate of 400 Mbps are generated as background traffic. In order to generate non-uniform background traffic, some of the generated background flows are designated to a fixed end-to-end path. The rest of them are uniformly imposed to the whole network. The load balance degree, which is defined as the maximum percentage of the total traffic flows that go through the same path according to Ref. [18], is equal to the ratio of the number of the flows on the fixed path to the total number of background flows. Obviously, the larger the load balance degree is, the less balance of the background traffic is. 50 new flows with arrival rate of 400 Mbps are generated and transmitted from node 0 to node 13 using different path selection strategies.

Fig. 5(a) shows the overall network burst loss ratio and the path burst loss ratio from node 0 to node 13 as a function of the load balance degree while adopting different path selection strategies. From Fig. 5(a), we can observe that the overall network burst loss ratio and the path burst loss ratio from node 0 to node 13 under LBLR increase more rapidly than those under EMF as the load balance degree increases before the load balance degree reaches a certain value (0.21 in the figure). The reason is that under LBLR, the new flows are more likely to be assigned to the path which has more background flows and tends to experience relatively lower burst loss ratio. It will lead to the traffic even more unbalanced in the network and eventually result in higher burst loss ratio. After the certain load balance degree (0.21 in the figure), the path burst loss ratio from node 0 to node 13 under LBLR decreases rapidly while the overall network burst loss ratio under LBLR keeps in the high level. It is because that the bursts on the path with higher load under LBLR are serialized when the arrival rate of the stream on the path becomes large enough, which decreases the burst loss ratio on the path on the one hand and severely blocks the bursts of other streams bypassing the same link on the other hand. Therefore, the overall network burst loss ratio under this case does not decrease with the decrease of the path burst loss ratio from node 0 to node 13. On the other hand, from the figure, we can see that both the overall network bust loss ratio and the path bust loss ratio under MEF always is kept at a relatively lower level and increases slowly with the increase of the load balance degree. The results shows that MEF can effectively alleviate the impact of the interaction between the path selection and the path traffic load under practical unbalance background traffic by taking the lost throughput on the path into account.

The relationship between the burst loss ratio and the arrival rate of each flow are also shown in Fig. 5(b) when the load balance degree is fixed (0.225 in the figure). From the figure, we can find that the difference of the burst loss ratio between MEF and LBLR increases with the increase of the arrival rate of each flow. That means MEF is more effective in heavily loaded network. For the same reason, we can find again that when the arrival rate of the

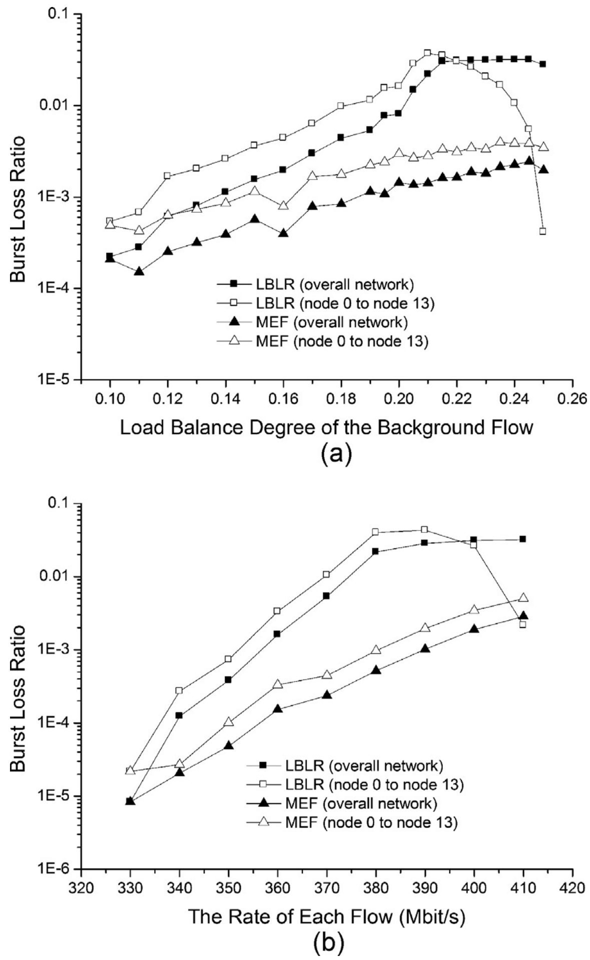

Fig. 5. The overall network burst loss ratio and the path burst loss ratio as a function of load balance degree (a), and the arrival rate of each flow when the load balance degree is 0.225 (b).

stream is large enough, LBLR also makes the path burst loss ratio from node 0 to node 13 lower by penalizing other flows, which degrades the fairness performance of OBS network.

5. Conclusion

In the paper, the multi-path selection strategy for OBS network is studied by considering the impact of a path selection on other existing paths in optical burst switching (OBS) networks. The contention among different traffic streams is analyzed. The result shows that a stream with a higher arrival rate will have a lower burst loss ratio. A mutual reinforcement interaction between the traffic load of a path and the contention ability of the path will appear accordingly as burst loss ratio based multi-path selection strategies are adopted. We proposed a maximum efficiency first multi-path route selection strategy, which can increase the utility of new flows at reasonable cost by using a combined metric of route efficiency to take the utility of each burst flow and the increment of lost throughput on the assigned OBS path into account at the same time. Simulation results show that the proposed maximum efficiency first multi-path route selection strategy can obviously reduce the burst loss ratio compared with the least burst loss ratio strategy and shortest path first strategy as the background traffic becomes more unbalanced, especially when the network is heavily loaded.

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