Path Selection Strategies for OBS Networks Using Topological Network Information

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ABSTRACT
Optical Burst Switching (OBS) has been proposed as a cost-effective paradigm for supporting, with adequate flexibility, the increasingly high transmission capacity required by the forthcoming next generation of optical internet networks. However, OBS efficiency can be reduced by resource contention of bursts directed to the same transmission links, leading to burst loss. This paper presents two strategies to minimize this kind of contention on the OBS backbone using only a priori topological network information, thus reducing burst loss probability while avoiding state dissemination protocol penalties. Numerical results, obtained through simulation using a dynamic framework scenario, demonstrate that our approaches are effective in reducing the overall network burst drop probability when compared with the traditionally used shortest path routing.

Keywords: Optical Burst Switching, Routing Optimization, Path Selection Strategies.

1. INTRODUCTION
Optical Burst Switching [1] have been proposed as a switching paradigm with a number of attractive advantages over the previously proposed switching technologies for all optical transport, namely, Optical Circuit Switching (OCS) and Optical Packet Switching (OPS). By combining the merits of both while avoiding their shortcomings, OBS has attracted considerable attention from researchers as an optical architecture to support huge bandwidth demands in optical backbones using Wavelength Division Multiplexing (WDM) [2]. Among its merits, OBS presents the following advantages when compared with their more coarse-grained OCS and more fine-grained OPS counterparts: high bandwidth utilization, low setup latency, moderate switching speed requirements, medium processing complexity and good adaptivity to bursty traffic [3].

In OBS the basic transport unit is a burst containing a certain number of IP packets grouped by destination address criteria and assembled at the ingress node. Each data burst can be regarded as an optical super packet traveling from source to final destination without any optical-electrical-optical (OEO) conversion. For the burst delivery attempt, OBS uses out-of-band signaling and an offset time delay, getting as a result a separation between the control information and its correspondent burst in both space and time, a distinguishing mark of this switching paradigm that simplifies the data path implementation and improves the efficiency of the optical switching technologies. However, OBS presents low reliability since it generally uses a one-way reservation protocol where bursts are transmitted without confirming the network resources reservation along the entire burst path. Therefore bursts may contend for the same resources leading to burst drop. This is the primary cause of burst loss in OBS and it happens when the number of overlapping burst reservations at an output port of a core node exceeds the number of data wavelengths available at a specific time [3]. Figure 1 presents a simplified view of an OBS network architecture and we refer the reader to [4] for further details on the OBS technology.

Figure 1. Simplified view of an OBS network architecture.

The work reported in this paper was supported in part by the Foundation for Science and Technology (Portugal) within CEOT, U. Algarve – project POSC/EEA-CPS/59556/2004.
Burst drop has impact on OBS performance, such as bandwidth utilization and latency, since dropping naturally leads to rescheduling of lost data and to the waste of the network resources used from the source node until the dropping point. Burst dropping can be minimized by appropriately choosing the paths that bursts must follow, that is, an effective choice of paths can lead to an overall network performance improvement. In this paper we propose and analyze two path selection strategies for OBS networks. The strategies proposed here use only available topological network information, avoiding the need for link state dissemination protocols, and allow results to be obtained with useful accuracy since path selection can be adapted to network conditions. These strategies can also incorporate Quality of Service (QoS) requirements easily. Besides mathematically formulating the proposed strategies, simulation results are presented to evaluate blocking under a dynamic traffic scenario. Results show that these strategies reduce burst drops when compared with the traditionally used shortest path approach.

The paper is organized as follows. The next section presents a succinct overview of routing strategies that have been proposed for OBS networks. In Section 3 the path selection strategies are explained. In Section 4 the performance of the proposed path selection strategies are evaluated for a dynamic network traffic scenario and, finally, some concluding remarks.

2. OBS NETWORKS AND ROUTING STRATEGIES

Network resource contention leading to burst drop can be resolved using different strategies lead to an overall network performance improvement. While most of the proposals support single-path strategies in which a unique primary path is used to route bursts between each pair of nodes, there are also some studies combining multi-path strategies with final delivery schemes to overcome out-of-order delivery problems at the egress nodes[4]. Recently, relevant work on adaptive path selection strategies has been presented in [5], where the authors assume that each node maintains a short list of alternative paths for each destination and recent congestion network information is used to rank these paths. However, the strategies proposed in [5] require a link state dissemination protocol so that the overall network state information is kept updated. This means that it is difficult to define the write update interval: a large value means that the information propagated can be outdated whereas a small value can congest the bandwidth available to carry link state information and, therefore, induce some network instability. To overcome these difficulties we propose two approaches that use only available topological network information to select the paths that bursts will take toward their destination. The selected paths should be the ones that lead to the smallest burst drop. The proposed approaches avoid state dissemination while providing results with useful accuracy since path selection can be adapted to different network scenarios.

3. DESCRIPTION OF THE PROPOSED STRATEGIES

This section discusses the path selection strategies proposed in this paper. The overall objective of the proposed strategies is to minimize the overall burst blocking probability by appropriately selecting the path over which a burst must travel. To reach this overall objective two strategies are followed: minimize the Maximum Congested Link (MCL) and minimize the Maximum End-to-End Congested (MEC) path. For both strategies, input information includes a set of paths for each pair of nodes. Each strategy must select one path for every pair of nodes, from the given set, so that its objective is achieved. That is, for the overall network, \( N(N-1) \) paths must be calculated and allocated for burst delivery. MCL and MEC will be compared under a dynamic scenario for an OBS network using the shortest path approach.

In the following discussing let \( G(N,L) \) be a network graph, where \( N \) is the set of nodes and \( L \) is the set of links, and let us define a path over which a burst must travel, \( v \), as a connected series of directed links, written as \( v : s(v) \rightarrow d(v) \), from source node \( s(v) \) to destination node \( d(v) \). The set of paths that can be used by a burst from \( s \) to \( v \) is defined as \( V_{s,v} = \{v : s(v) \rightarrow d(v) | s = s(v), d = d(v)\} \) and the set including all \( V_{s,v} \) is defined as \( V' \). We also define \( p^v_l = 1 \) if link \( l \in L \) is included in \( v \), \( p^v_l = 0 \) otherwise, and \( q^v_{ld} = 1 \) if the two paths \( v \) and \( v' \) share at least one link. A demand matrix \( T \) can also be considered, where \( t_{s,d} \) represents a relative load from source node \( s \) to destination node \( d \). We note that the following formulations are independent of the details of the demand model, which may include the total or average number of demands, over a period of time, or some integer value that reflects the local demand weight over the total network demand.

3.1 Strategy I: Minimize MCL

This strategy is based on the idea that the more a certain link is included in the chosen paths for source-destination pairs, the highest the blocking probability will be. Therefore, paths for source-destination pairs
should be selected with the objective of minimizing the blocking probability of the link with highest expected contention value, denoted by \( \zeta_{\text{MAX}} \). This is achieved by the following ILP optimization problem:

\[
\text{Minimize} \quad \zeta_{\text{MAX}} \tag{1}
\]

Subject to

\[
\sum_{v \in V} \sigma^v = 1, \forall s, d \in \mathcal{N} \tag{2}
\]

\[
\sum_{s, d} \sum_{v \in V_{s, d}} \sigma^v \times p^v_i \times t_{s, d} \leq \zeta_{\text{MAX}}, \forall l \in L \tag{3}
\]

\[
\sigma^v \in \{0,1\} ; \text{ non-negative integer: } \zeta_{\text{MAX}} \tag{4}
\]

where \( \sigma^v \) is a binary variable that indicates if \( v \) is used to carry bursts from node \( s(v) \) to node \( d(v) \).

Constraint 2 states that one path must be found for each pair of nodes. Each path is selected from the corresponding set \( V_{s, d} \) of available paths. Constraint 3 states that the expected congestion at a link must not exceed \( \zeta_{\text{MAX}} \).

### 3.2 Strategy II: Minimize MEC

This strategy is based on the idea that blocking may occur at any link traversed by a burst along the path. Therefore, paths for source-destination pairs should be selected so that demands have the smallest probability of contending with other demands at every link from source to destination, minimizing the end-to-end blocking. This is achieved by the following ILP optimization problem, where \( \phi_{\text{MAX}} \) denotes the contending value of the path having the highest number of contents.

\[
\text{Minimize} \quad \phi_{\text{MAX}} \tag{5}
\]

Subject to

\[
\sum_{v \in V_{s, d}} \sigma^v = 1, \forall s, d \in \mathcal{N} \tag{6}
\]

\[
\eta^{v, v'} \geq (\sigma^v + \sigma^{v'} - 1) \times q^{v, v'}, \forall v \in V, \forall v' \in V \setminus V_{s(v), d(v)} \tag{7}
\]

\[
t_{s, d} + \sum_{v \in V_{s, d}} \sum_{v' \in V_{s(v), d(v)}} \eta^{v, v'} \times t_{s, d} \leq \phi_{\text{MAX}}, \forall s, d \in \mathcal{N} \tag{8}
\]

\[
\sigma^v, \eta^{v, v'} \in \{0,1\} ; \text{ non-negative integer: } \phi_{\text{MAX}} \tag{9}
\]

where \( \sigma^v \) is a binary variable that indicates if \( v \) is used to carry bursts from node \( s(v) \) to node \( d(v) \), and \( \eta^{v, v'} \) is a binary variable that indicates if \( v \) and \( v' \) have both been selected to carry bursts and share at least one link. Similarly to the previous strategy, constraint 6 states that one path must be found for each pair of nodes. Constraint 7 forces \( \eta^{v, v'} \) to be 1 if \( v \) and \( v' \) share a link and have both been selected to carry bursts. Otherwise, and due to the minimizing nature of the objective function, \( \eta^{v, v'} \) will be 0. Constraint 8 states that the contending value of a source-destination pair must not exceed \( \phi_{\text{MAX}} \).

### 3.3 Calculation of the Set of Input Paths

The previously proposed path selection strategies must have as input a set of paths for each pair of nodes. In this study we propose the use of the \( K \) shortest paths with less links in common. That is, if several paths exist with an equal number of hops then the more distinct ones are chosen. Note that this task is independent of the path selection strategies since different paths can be supplied to the strategies, either resulting from detailed network performance observations or from any other criteria adopted by network administrators.

### 3.4 Other Benefits of Proposed Approach

Besides avoiding the link state dissemination problem the proposed approaches have the following advantages: since candidate paths are previously calculated and given as input for the path selection strategies, the solutions of the ILPs can be promptly solved; a single shortest path can be assigned to pairs of nodes that require a high quality connection while a set of alternative paths can be assigned to pairs of nodes requiring less quality, that is, lower quality connections are allowed to use paths that take more hops than the shortest path; traffic demands can be removed from the ILPs leading to a solution based on the number of hops of paths; the models can be
easily extended to include two different sets of paths for each pair of nodes, one for priority traffic and another for non-priority traffic.

4. NETWORK SIMULATION AND PERFORMANCE RESULTS

In this section we evaluate, by simulation, the performance improvements of the two proposed methodologies. The OBS network under study uses the European COST 239 topology with a dual layer architecture like the one represented in Fig. 1, having \( W = 16 \) wavelengths per link and 10 Gbit/s of transmission capacity per channel. The adopted traffic assumes a Poisson pattern with a threshold-based assembly method, generating bursts with 100KB forwarded under the JET[1] signaling scheme with processing time of 10 µs per core node. Simulations were done for different traffic loads assuming full wavelength conversion. If burst scheduling fails the burst is simply dropped and no further contention resolution method is adopted. The model employs source routing, in that a complete routing decision is taken at the ingress edge node. Like the approach adopted on [5], the path over which the burst must travel is carried on the CPH that precedes the transmission of the burst. Here, the adopted path is the result of one of the path selection strategies previously discussed.

This evaluation was performed using C++ in combination with the discrete event simulation system OMNeT++. Simulations were done for \( K = 2, K = 3 \) and \( K = 4 \), where \( K \) is the number of shortest paths, per pair of nodes, being provided to the path selection strategies. The results are shown in the plots of Fig. 2 where the proposed strategies, MCL and MEC, are compared with the traditionally used shortest path approach. From such plots it is possible to conclude that both strategies reduce the number of bursts being dropped outperforming on the best cases the results achieved with the shortest path in 94.9% and 89.6%, respectively. The plots also show that while for MCL the drop probability slightly decreases with the increase of \( K \), indicating that the algorithm benefited from the alternative paths given as input, with MEC the opposite happens showing that the longer paths adopted can be a disadvantage resulting in less gain.

![Figure 2. Evaluation of the proposed strategies vs. shortest path.](image)

5. CONCLUSIONS

In this paper two new path selection strategies for OBS networks using only topological network information are proposed and evaluated. The objective of both strategies is to minimize the burst loss due to resource contention of bursts aimed at the same output link. It is demonstrated that it is possible to achieve an initial stage of improved performance, measured in terms of burst loss reduction, without incurring into link state dissemination protocol penalties. It should be noted that other contention avoidance strategies, including dynamic contention resolution schemes, can also be additionally applied to this methodology.

REFERENCES