NEW FIBER DELAY LINE USAGE STRATEGY IN OPTICAL BURST SWITCHING NODE

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Abstract

Optical Burst Switching (OBS) is a new paradigm for future all-optical networks. In an OBS node, a Fiber Delay Line may be used to delay a burst, effectively increasing its offset time. Traditionally, FDLs were used in contention resolution, i.e. a burst was only buffered if it would otherwise been dropped. We propose a different approach, where delay lines are used also to better arrange bursts in time. In our strategy both outgoing channels and FDL channels are assigned a price, according to their suitability for a particular burst. When a control packet arrives at a core node, all the possible ways of handling the corresponding burst are found (the outgoing channel, with or without a FDL), and the one with a lowest total price is chosen. This makes it possible to use most FDL channels for the majority of the time, reducing the probability of future contention. We present simulation results, showing how node performance depends on the size of a FDL bank, using either Last Available Unused Channel with Void Filling (LAUC-VF) and the traditional FDL usage strategy or our algorithm.

Keywords: High-speed Internet, Optical Burst Switching, Fiber Delay Lines, burst scheduling.

1 Introduction

It is widely assumed that all-optical networks will form the backbone of future Internet. Optical Burst Switching (OBS) [1, 2] is one of the most promising optical switching technologies, combining the best of both optical circuit and packet switching. In an OBS network, incoming IP traffic is first assembled into bigger entities called bursts. Bursts, being substantially bigger than IP packets are easier to switch with relatively small overhead. When a burst is ready, a control packet is sent to the core network. It is analysed in each core node, the routing decision is made, and sent to the next node. After an offset time, the actual burst is also sent, without waiting for any acknowledgement. It traverses the network entirely in the optical domain, as the path is already set according to the information contained in the control packet. When the burst reaches its destination node it is disassembled, and the resulting IP packets are sent to their respective destinations. If two bursts compete for the same channel (contention), one of the bursts would usually be lost. There are, however, several contention resolution methods. The most commonly used are: wavelength conversion, delaying one burst in a fiber delay line (FDL) and deflecting one of the other bursts. With the exception of wavelength conversion in a node with full conversion capability, any of those methods is only used when an actual contention occurs.

In this paper we present a novel strategy of using FDLs. Instead of waiting for a contention to occur and then trying to resolve it, a node is allowed to buffer a burst. This is done to better arrange bursts in an outgoing link. Effectively, this combines channel assignment and FDL usage.

To judge arrangement of bursts in a given channel we introduce the idea of channel cost. The channel is considered expensive, if allocating the new burst is likely to interfere with a future burst, for example by creating gaps. If, on the other hand, the new burst aligns itself perfectly with existing reservations, or fills an existing gap, the price of the channel will be low. In Section 2 we will propose a function that takes the state of a channel and the incoming burst as parameters, and returns a value that can be used to judge the channel's suitability for the new burst. This function will be used to design a channel allocation algorithm that offers better performance than LAUC-VF [3, 7], even when no FDLs are used. The new algorithm will be described in Section 3.

In Section 4 we present simulation results, comparing the performance of our algorithm, and LAUC-VF.

2 Cost functions

The state of a channel can be described by a set of reservations. Each reservation consists of its starting time and ending time. If we denote the starting time of the i-th reservation by S_i and its ending time by E_i then the state of the entire channel can be represented by vectors $\overline{S} = [S_1, S_2, ..., S_n]$ and $\bar{E} = [E_1, E_2, ..., E_n]$, where n is the number of reservations. The newly arriving burst is decribed by its starting and ending times, S and E, respectively.

We define the cost function as a function of the channel state, new burst and possibly other variables, that indicates the probability that the new burst will interfere with the allocation of future bursts:

$$C = f\left(\overline{S}, \bar{E}, S, E, ...\right) \tag{1}$$

The value of the cost function is called channel cost and in the general case the function will be applied to all available channels and the one with the lowest cost will be chosen. Some of existing channel allocation algorithms can be described using the idea of cost functions.

For example in case of LAUC-VF the cost function is:

$$C_{LAUC-VF} = \min\left(S - E_i\right) \tag{2}$$

for all non-negative values of $\left(S - E_i\right)$. For Minimum Ending Void (Min-EV)[4, 7]:

$$C_{Min-EV} = \min\left(S_i - E\right) \tag{3}$$

for all non-negative values of $\left(S_i - E\right)$.

It is difficult to estimate the probability of interfering with future bursts based on the channel state alone. We will, therefore, include other information to achieve better results. The general form of our cost function is:

$$C = f\left(\overline{S}, \bar{E}, S, E, OT_{min}, OT_{max}\right) \tag{4}$$

where $OT_{min}$and OT_{max} are the minimum and maximum offset times expected at the node, respectively.

The range of possible offset times is important, because relative weights of the starting and ending voids change as a function of the burst's offset time. For example, the size of the starting void does not matter if the burst arrived with the smallest possible offset time. No other burst will be allocated in this gap anyway.

Our cost funtion first calculates channel price according to LAUC-VF and Min-EV (Equations 2 and 3), then applies appropriate weights to those results and chooses the smaller value:

$$C = \min\left(\frac{C_{LAUC-VF}}{OT - OT_{min}}, \frac{C_{Min-EV}}{OT_{max} - OT}\right) \tag{5}$$

A simple simulation demonstrates that indeed, this approach improves node performance. Fig. 1 shows results for the following scenario: one link, 32 channels, burst length and interarrival times exponentialy distributed, offset times uniformly distributed over the range of 10 and 30 average burst lengths. Offered load changes between 10 and 100% of maximum link load.

3 Cost-based FDL usage strategy

When a reservation request arrives at a core node, and a routing decision is made, a cost is calculated for each channel in the outgoing link. This cost is calculated again, but with the assumption that the incoming burst will be delayed in a FDL. If the latter cost is lower than the former by more than a certain value (that can be treated as a FDL price), then the new burst will be buffered. Note that a FDL can be used even if it is not strictly neccessary.

Algorithm 1 Cost-based algorithm.

```
assume no FDL
for all (channels) do
    find cost
end for
channel-no-FDL:=cheapest channel
cost-no-FDL := lowest found cost
assume FDL used
for all (channels) do
    find cost
end for
channel-with-FDL:=cheapest channel
get FDL cost
cost-with-FDL := lowest found cost + FDL cost
if (cost-no-FDL < cost-with-FDL) then
    do not buffer burst
    allocate in channel-no-FDL
else
    buffer burst
    allocate in channel-with-FDL
end if
```

The FDL price can either be constant or it can change as a function of currently used FDL channels. The choice will depend on the channel cost function used.

4 Simulation results

We developed an OBS extension to the ns-2 simulator, and this tool was used to obtain the results presented in this paper. We simulated a network consisting of nine nodes: eight edge nodes and one core node. There are eight unidirectional link, connecting four edge nodes (called source nodes) to the core node, and the core node to the other four edge nodes (destination nodes). The network diagram is presented in Fig.2.

In each source node there are four burst generators, each generating traffic destined to one of the destination nodes. Both burst length and interarrival time are exponentially distributed. The offset time is uniformly distributed over different ranges. The link load changes between 10 and 100% of maximum load (note that this applies to edge nodes). The load at the core node will be slightly smaller as some bursts will be lost in the incoming links.

The core node has unlimited wavelength conversion capability, and is equipped with a FDL, shared between all outgoing links. The delay introduced by the FDL is 0.33 of a mean burst length. It is assumed that a burst can only be buffered once.

There are 32 wavelengths in all links, and the number of FDL channels varies between 1 and 60. Note that in real

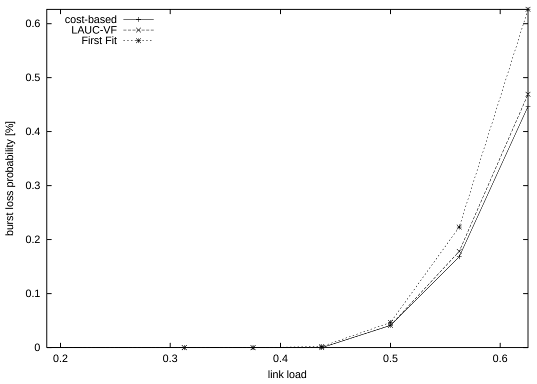

Figure 1. Performance of LAUC-VF, First Fit and the cost-based algorithm when no FDLs are used.

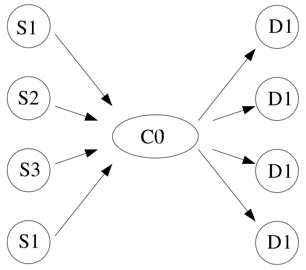

Figure 2. Network topology

networks the number of channels in a FDL will probably be equal to the number of channels in the link. Choosing an arbitrary number of FDL channels, however, will allow us to demonstrate interesting differences in functioning of alternative FDL usage strategies.

The channel allocation algorithm uses the cost function presented in Section 2. To assign a price to a FDL channel, linear pricing startegy is used - the price is a linear function of the percentage of free FDL channels:

$$C = C_b \cdot (P_{total} - P_{used})$$

where C_b- base cost, P_{used}- percentage of used FDL channels.

When the traffic is high, the average size of gaps will be small. This, in turn, will decrease the average price. Adjusting the FDL price as number of free channels changes, is meant to offset this effect.

In our simulations we use the number of used channels instead of percentage of used channels. This is equivalent to introducing an additional, constant coefficient, and does not affect the generality of our results.

Performance of a cost-based algorithm strongly depends on the choice of FDL price. In this paper, when simulation results for a cost-based algorithm are presented, they have always been obtained using the optimal price.

Fig. 3 shows the burst loss probability for two different FDL usage strategies, for the link load of 0.7, and a varying number of FDL channels. When LAUC-VF is used and a FDL is only utilized when contention occurs, there is no improvement in performance when the number of FDL channels exceeds 10. When, on the other hand, a cost-based approach is used, performance improves further, and levels off for a much larger number of channels. To explain this effect we periodically sampled the number of FDL channels in use throughout the simulation. Collected data can be presented as an FDL usage histogram. Fig. 4 shows such histograms for both LAUC-VF and the cost-based algorithm. It is apparent that LAUC-VF tends to use only a few channels and for most of the time uses no FDL channels at all. The cost-based algorithm, on the other hand, tries to utilize all available FDL channels.

The performance of our algorithm depends on the chance that a suitable gap can be found for the new burst. A large number of gaps will only be created if bursts arrive with different offset times, and if the difference between minimum and maximum offset times is relatively big. This leads to a conclusion that if the offset time range is decreased, then the performance of the cost-based algorithm will approach the preformance of other algorithms. Fig. 5 and 6 show that indeed, this is the case when the offset time range becomes comparable with the mean burst length.

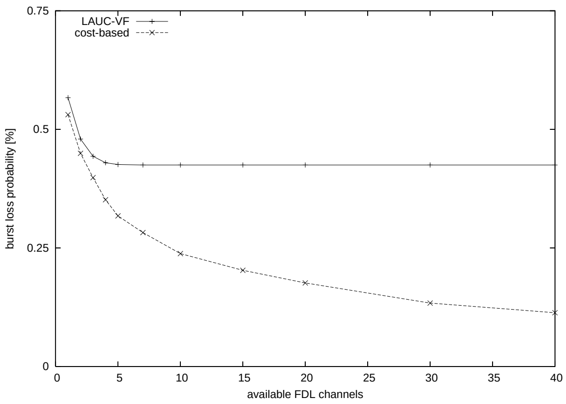

Figure 3. Performance of LAUC-VF and cost-based algorithm as a function of available FDL channels, offset time range 4 - 14 mean burst lengths.

5 Analysis of results

The results presented in the previous section show that the cost-based FDL usage strategy is never worse than the traditional one, and in some circumstances outperforms it significantly. We also found that our algorithm performs better when the range of possible offset times is relatively wide. Those results can be explained as follows.

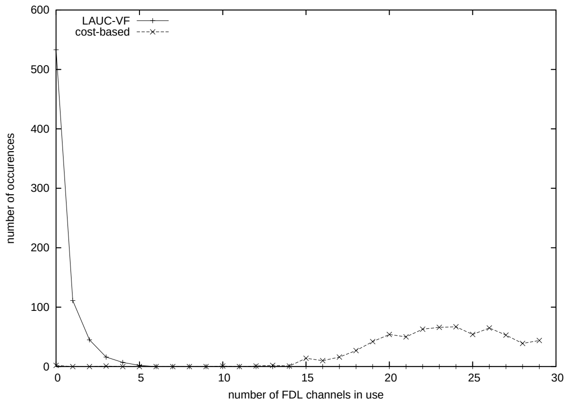

Figure 4. FDL use histograms for LAUC-VF and cost-based algorithm. link load = 0.7, 30 FDL channels, offset time range 4 - 14 mean burst lengths..

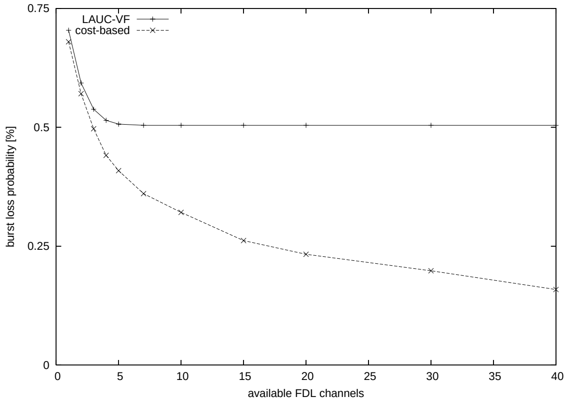

Figure 5. Performance of LAUC-VF and cost-based algorithm as a function of available FDL channels, offset time range 4 - 10 mean burst lengths.

If an FDL is only used when a contention occurs then relatively few FDL channels are needed. If the number of FDL channels is increased, this will not result in improved performance, as those additional channels will rarely or never be used. This is illustrated in Fig. 4. It can be seen that, in this particular simulation, the traditional FDL usage strategy never used more than five channels, and often used none at all. This approach is not optimal for several reasons. First, it is not guaranteed that using an FDL will resolve a contention. It also makes the contention - resolveable or not - more likely to happen.

The cost-based strategy can be viewed as a way of matching the size of a FDL bank to the needs of a node. If the bank is oversized, then, by setting a low FDL price it can be allowed to use a FDL for even small improvements in burst alignment. A good price will also ensure that a few FDL channels will usually be available for contention resolution. Fig. 4 shows that our algorithm tends to use most of the available FDL channels.

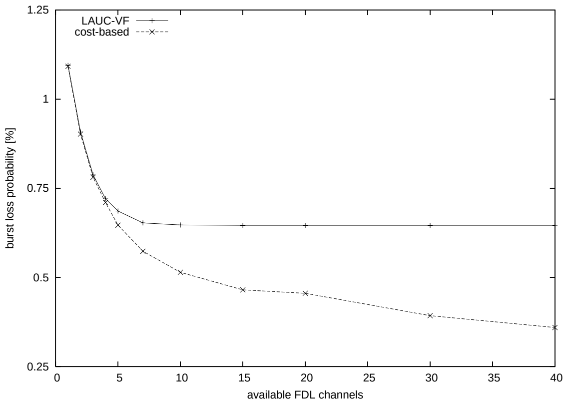

Figure 6. Performance of LAUC-VF and cost-based algorithm as a function of available FDL channels, offset time range 4 - 6 mean burst lengths.

The cost-based strategy depends on two probabilities:

- probability of finding a channel, where the new burst can be aligned with another burst after being buffered in an FDL,
- probability that the channel, where the new burst would be originally allocated can be later used by another burst.

Let's assume that all bursts arrive with an identical offset time. Then, using a FDL will offer no benefit if a given burst can be allocated either with or without buffering. This is because its original channel would be effectively wasted, as any other burst would have to arrive with smaller offset time in order to use it.

Additionally, if the FDL length is comparable with or greater than the mean burst length then it will be difficult to align delayed bursts with any other ones, as there will be very few reservations so far away in the future.

The influence of the aforementioned effects decreases as the range of possible offset times increases. It becomes more likely to find a better channel for a burst that arrives with a relatively small offset time, because there will be many reservations made in the future. If, on the other hand, the new burst arrives with a big offset time and is buffered, then the gap where it would originally be allocated is likely to be utilized by bursts with smaller offset times. This explains the improved performance of our algorithm when the range of possible offset times is significantly greater than the mean burst length.

6 Conclusions

We presented a novel cost-based strategy of using delay lines in an OBS node. Instead of being used exclusively in contention resolution, they are utilized to better arrange bursts in outgoing channels. We proposed a channel cost function that can be used to judge suitability of a given channel for the new burst.

We presented simulation results showing that the new strategy is capable of utilizing FDL banks more efficiently than existing algorithms, especially as the size of a bank grows.

We showed that the new approach works well when the offset times are distributed in a uniform fashion over a wide range. Further work is needed to determine the performance of our algorithm in more realistic scenarios, especially for other offset time distributions.

This strategy could be further improved. The first way would be to use a better cost function, possibly one utilizing more information about the incoming traffic. Another possible idea is to treat the FDL loop as a channel and apply the cost function to it as well. This would ensure that bursts in the optical buffer are arranged in an efficient way.

The approach described in this paper could be applied to groups of bursts, extending the idea presented in [5]. It can be reasonably expected that if information about more than one burst is available, then utilizing both outgoing channels and FDLs in a more efficient way will be possible.

Finally, it is possible to incorporate ideas presented in [6] by manipulating the FDL price, depending on the amount of network resources that have been already used by a particular burst. Then, the probability of a burst being dropped close to its destination will decrease.

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