Delay Line Configurations in Optical Burst Switching with JET Protocol

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Abstract

Optical burst switching networks have received a lot of attention in the research community in the recent years. The JET protocol, first proposed by Qiao and Yoo in 1997 in [6, 5], is used for resource allocation in these networks. Up to the present, the JET protocol has been studied in networks that use wavelength conversion [7, 1]. In this paper the JET protocol is discussed in optical networks, where wavelength conversion is not possible, and thus the used wavelength channel is fixed at the edge router. To compensate for the missing wavelength conversion, optical buffers are used instead. In particular, the performance improvement of different delay line configurations is studied in this paper.

1 Introduction

The Just Enough Time (JET) protocol was first proposed back in 1997. The protocol works as follows. At the edge of the network packets are gathered into bursts of variable lengths. A control packet that corresponds to the header of the burst, is sent beforehand in a separate channel to allocate transmission channels. Meanwhile the burst waits at the edge node for a certain time, and is then sent along the path the control packet has allocated for it. The time a burst waits at the edge node, i.e., the offset time, depends on the processing time of the control packet in the intermediate nodes. The burst is sent through the network without buffering, and it arrives at the destination node immediately after the control packet. The channels are reserved only for the time they are used, i.e., the control packet allocates a channel for the actual time slot the burst will use.

The JET protocol has been studied first by Qiao and Yoo in the end of the 1990's [6, 5] and later also by other researchers,e.g., [1]. In particular, QoS based on different priority classes and offset times has been studied in [8, 2]. Until now, the JET protocol has been studied in networks that use wavelength conversion. In this paper the JET protocol is discussed in optical networks, where wavelength conversion is not possible, and thus the used wavelength channel is fixed at the edge router.

Using wavelength conversion in all the nodes of the network clearly improves the performance of the network, but, on the other hand, a great number of fast wavelength converters are needed at every node, and the network becomes expensive to implement. In the present work the JET protocol is studied in networks without wavelength conversion capability. The efficiency of the network suffers from this, but as will be shown, with a reasonable number of optical buffers, the loss can be remarkably decreased and will be more fairly distributed among different connections. Additionally, with irregular delay line configurations the performance of the network can be further improved.

The rest of the paper is organized as follows. In Section 2 the JET protocol and its characteristics are briefly discussed. Additionally, the version of JET protocol that does not use wavelength conversion is introduced. In Section 3 the network model used in thesimulations are presented, and the assumptions made are discussed. In Section 4 the simulation results are presented, and Section 5 is for conclusions.

2 The JET protocol

The operational principle of the JET protocol is the following. At the edge of the network packets are gathered to bursts of variable lengths. A control packet (i.e., the burst header) is then sent in a separate channel to allocate channels for the transmission. The burst waits at the edge node a certain time, and is then sent along the path the control packet has allocated for it. Note that no acknowledgement is waited but instead the burst is just sent after the control packet ”blindly”. The time a burst waits at the edge node is called the *offset time*. The offset time is at least as long as the time it takes to process the control packet in the intermediate nodes.[1] Hence, the offset time guarantees that every node knows about the burst before it arrives. This means that there is no need to buffer the packet in the intermediate nodes. If there are enough free resources, the burst can be sent directly through the network without buffering, and it arrives at the destination node immediately after the control packet. Figure 1 illustrates the situation.

If the control packet is unable to allocate a channel, it sends a NAK packet back to the source node. The NAK packet frees the allocated channels along the path. If the offset time is long enough compared to the propagation delay, the NAK packet might catch the burst before it is sent. If the burst has already been sent before the NAK packet arrives at the source node, the NAK packet meets it at some node along the path, and the burst is removed there. The NAK packet then continues to the sending node and informs it that the burst was lost.

[1] However, later we will propose optical buffering to avoid congestion.

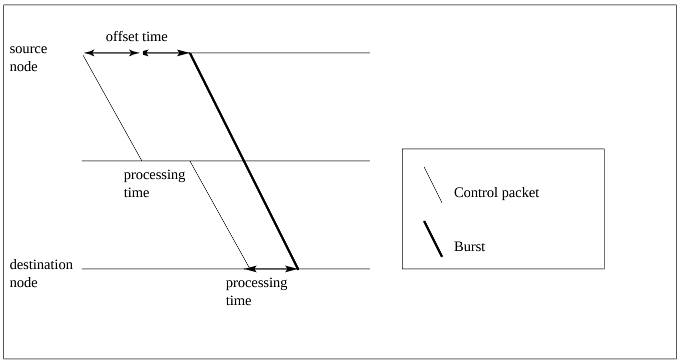

Figure 1: The JET protocol.

One advantageous feature of the JET protocol is the fact that the resources are reserved only for the time they actually are used. The control packet allocates a channel from the arrival time of the burst to the departure time of the burst. This additional information gives benefits over the traditional system, where the only information in the node is whether the channel is free or in use.

2.1 The Proposed Scheme: JET Protocol in Network without Wavelength Conversion

Earlier research on the JET protocol (e.g., [8, 1]) assumes that the wavelength conversion can be performed in every node along the path. This improves the performance of the network, but, on the other hand, a great number of fast wavelength converters are needed at every node, and the network becomes expensive to implement. In the present work the JET protocol is studied in networks without wavelength conversion capability. The efficiency of the network suffers from this, but as will be shown, with reasonable number of optical buffers, i.e., delay lines, the loss in a network without wavelength conversion capability can be decreased almost to the same level as in a network with wavelength conversion. For further information, see [3].

2.1.1 Optical Buffers

Optical delay lines, i.e., optical buffers are fibers that are connected back to the node. In practice this process is quite similar to the deflection routing. In deflection routing the packet is switched to some of the free link, if the desired link is allocated. In optical buffering the process is similar, but the chosen link leads back to the node.

Optical delay lines are particularly suitable for networks, in which the JET protocol is used, because if the control packet is unable to allocate the channel for a certain time slot, it knows when the desired channel will be available again. Therefore, the time the packet has to be buffered is known beforehand, and a suitable delay line can be chosen and allocated according to that information. The control packet is updated and the channel is allocated starting from the moment the burst will be out from the buffer.

2.1.2 Different Delay Line Configurations

Different delay line configurations in optical packet switching network have been studied in [4]. It was found that the best results were obtained with irregular configurations that include both short and long delay lines. Based on these findings we use similar configurations in this paper, and also compare them with regular configurations. The difference between these studies is that in [4] fixed length packets were used, while in this study the bursts are of variable length. Therefore also delay lines that are less than the maximum burst length can be used.

3 Network Model and Simulations

A small, symmetric network with five core nodes was used in the simulations. The core network is depicted in Figure 2. This network was studied in order to observe the features of the JET protocol in details.

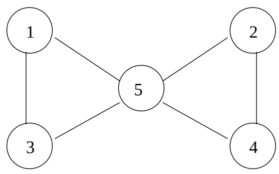

Figure 2: A small network with 5 nodes.

Each core node, i.e., the nodes in Figure 2, is assumed to be connected to several edge nodes (not depicted in Figure 2). The edge nodes gather IP packets to bursts and then send bursts at random fixed wavelength to the core node. The links between edge and core nodes are assumed to be non-blocking.

With the above assumptions we can limit ourselves to study the core network alone. The following assumptions are made:

- Number of wavelength channels per link is 40.
- Each node sends bursts to each of the other nodes as Poisson stream with the same intensity λ, i.e., uniform load.

- Data rate is 10 Gbit/s in each channel.
- Burst lengths have uniform distribution between 5μs and 15μs. This corresponds to a burst size of 50 - 150 kbit.
- Processing time of control packet at the nodes is assumed to be constant, 10 μs.
- There is an optical buffer system for each output channel.
- All links are bi-directional.
- Each link has the same propagation delay of 100 μs corresponding to approximately a distance of 2 km.

The network was studied a) with wavelength conversion (WI), b) without wavelength conversion (WS), and c) without wavelength conversion but with a number of optical buffers (WSB). In a network without wavelength conversion, a burst is lost if the required wavelength is not free, whereas in the case with wavelength conversion the burst can be converted to any of the free wavelengths.

Two factors limit the number of delay lines used. First, the length of the longest delay line should be relatively short, because otherwise the delay could increase too much. Additionally, a lot of capacity is needed for the calculations of how packets are to be delayed and how time slots are reserved. Therefore, only a few buffers are used at each output channel. Four different buffered (WSB) systems were studied. In all systems the longest buffer is 5 times the maximum burst length. In each test case, every output channel had identical optical buffer system. Optical buffer systems were the following:

- 5 delay lines with lengths corresponding to from 1 to 5 times the maximum burst size
- 5 delay lines with lengths corresponding to 1, 2, 7, 9 and 10 times one half of the maximum burst size
- 10 delay lines with lengths corresponding to from 1 to 10 times half of the maximum burst size
- 10 delay lines with lengths corresponding to 1, 2, 4, 5, 8, 11, 14, 18, 19 and 20 times one fourth of the maximum burst size

4 Numerical Results

Figure 3 illustrates the mean loss probability with different number of delay lines. Average traffic load in the x-axis is defined as $\rho = \frac{\lambda_{\text{tot}} \frac{1}{\mu}}{WL}$, where λ_{tot} is the total arrival intensity, i.e., 20 times the arrival intensity λ of one connection, W is the number of channels, L is number of links and μ is the mean length of a burst. The continuous line presents the loss probability in a system with wavelength conversion. As can be seen, the increase in loss probability caused by the missing wavelength conversions is considerable. However, with delay lines this loss can be decreased. The number of buffers is the greatest factor affecting to the loss probability, but the loss probability can also be decreased with suitable irregular delay line configurations, as was expected.

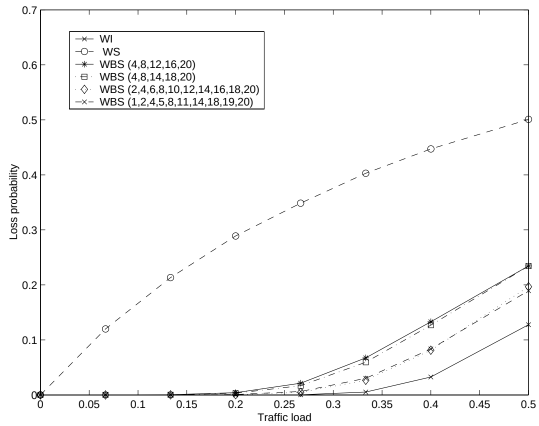

Figure 3: The average loss probability in different networks.

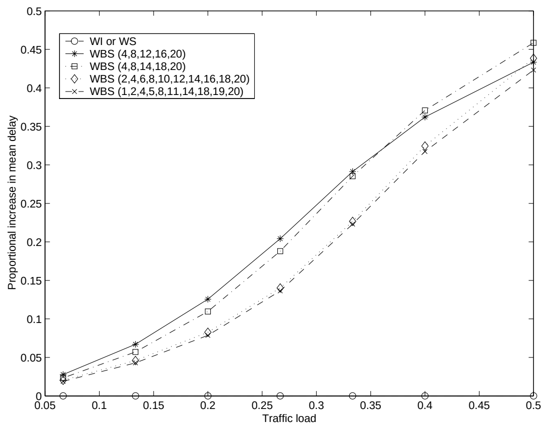

Figure 4: The proportional increase of delays in buffered networks.

With five buffers that have irregularly distributed lengths were better results obtained than with configuration with 5 uniformly distributed delay lines. Similar results can be achieved with 10 delay lines. However, with the configuration used for the results illustrated in Figure 3, the average loss is equal for both configurations with 10 delay lines. As will be shown, other benefits are obtained with the chosen irregular configuration. The improvements achieved with irregular configurations are small compared to the effect of increasing number of the delay lines, but, on the other hand, these improvements are obtained without additional component costs. The number of delay lines used is the same for both regular and irregular configurations. A possible drawback with delay lines is that the order of the bursts can change. [2]

Figure 4 illustrates the proportional increase of the corresponding delays compared to the delay in the network without buffers. Because the length of the maximum delay added at each node is short, also the increase of the delay is minor. With the highest load simulated the maximum average delay is one and a half times the average delay of an unbuffered network. However, it should be noted that in the simulations the longer processing times caused by the additional processing in the nodes due to the buffering are not taken into account. The figure also illustrates that several shorter buffers cause a smaller delay than few longer ones. The uniformity of the configuration does not considerably affect to the average delay.

Traffic in this network can be classified into four different connection types as depicted in Figure 5.

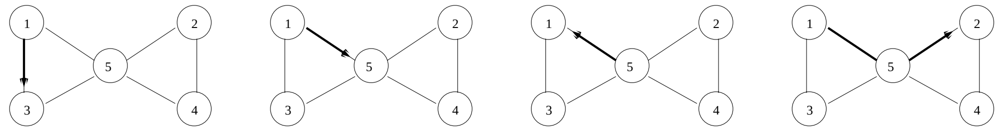

Figure 5: Connection classes 1, 2, 3 and 4.

- **Class 1** is constituted of traffic flows $1 \to 3$, $2 \to 4$, $3 \to 1$ and $4 \to 2$. This traffic does not compete with other classes, but has the whole link solely for itself.
- **Class 2** contains traffic flows from the other nodes to node 5. This class contends for the resources with class 4. For instance, the traffic flow $1 \to 5$ uses the same resources as the traffic $1 \to 2$.
- **Class 3** contains the traffic flows from node 5 to other nodes. Also this traffic uses same resources with other classes. For instance, the traffic flow $5 \to 2$ competes with the traffic flow $1 \to 2$.
- **Class 4** consists of the traffic flows $1 \to 2$, $1 \to 4$, $2 \to 1$, $2 \to 3$, $3 \to 2$, $3 \to 4$, $4 \to 1$ and $4 \to 3$. Unlike the other classes, this traffic has paths that are two links long.

In Figures 6, 7, 8, 9 and 10 the loss probabilities of different types of connections are shown. In the figures it is shown that the networks that use buffers perform more fairly than the networks, in which wavelength conversion is used. Although the average loss was the smallest in the network with wavelength conversion, the lower maximum loss probability of a separate traffic class is obtained with a buffered system.

Figure 6 illustrates the loss in the wavelength selective (WS) network, where no buffers are used. The loss is huge for all the connections, but the loss differences between different

[2] If necessary, the order of the burst can be explicitly maintained at each intermediate node.

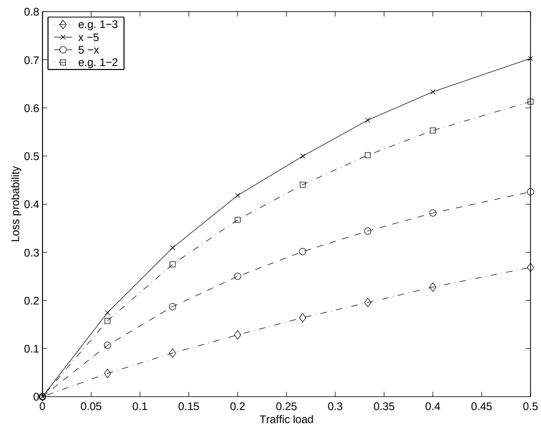

Figure 6: The loss probability of different connection (WS).

connection types are also considerable. Because the traffic class 4 bursts have longer offset times than in the other classes, they can always allocate the channels before the bursts in class 2. Therefore, the loss in traffic class 2 is the highest. However, the loss probability of a path increases considerably, when the number of the links increases. Therefore, also the loss in class 4 is high.

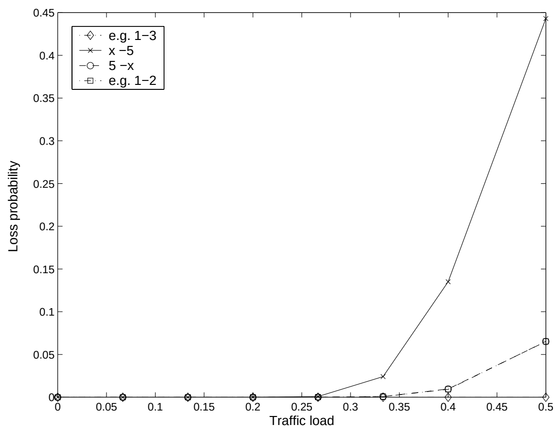

Figure 7: The loss probability of different connection (WI).

With wavelength conversion the loss of all the connections can be reduced. However, as can be seen from Figure 7, the loss is even more unfairly distributed between differnt types of connections than in the WS network. In the network with wavelength conversion the effect of the different offset times is clear, and longer connections that belong to the connection class 4 use resources in the first link so efficiently that the traffic belonging to connection class 2 considerably suffers. The loss in class 4 has decreased compared to the WS network, because wavelength conversion can be performed also at intermediate nodes.

In the networks where buffers are used, the problem caused by different offset times is partially solved. If wavelength conversion is used to forward a burst that would be lost, it is either converted to a wavelength that otherwise would not be used, or it is lost. With buffers the burst is delayed and it therefore uses resources that were otherwise possibly used by a burst that arrives later. With wavelength conversion the network is better utilized. However, the buffered system seems to suit better to the JET protocol that uses offset times. With wavelength conversion connection class 2 can use only the resources that are left from the class 4 whereas in buffered systems the bursts that were to be lost and belong to class 2 can use time slots that were otherwise used by the next bursts belonging to connection class 4.

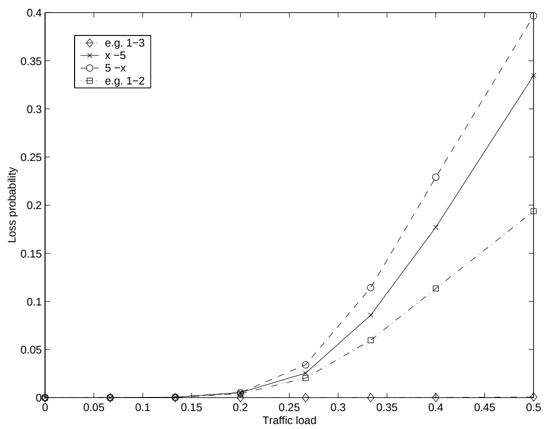

Figure 8: The loss probability of different connection (WSB, 5 regular buffers).

Figure 8 illustrates the loss probability of different connections in the network with five regularly distributed buffers. Compared to the previous figure the loss is more fairly distributed , but even the maximum loss in the traffic class 2 is still higher in the buffered system. Traffic class 3, i.e. traffic from node five to other nodes has the greatest loss, because some of the bursts that belong to traffic class 4 are buffered at the first node of the path and they have longer offset times at node 5.

In the network with 10 buffers the maximum loss probability of an individual connection class is smaller than in the WI network. With wavelength conversion, all loss probabilities are near zero, if the average load ($\rho = \frac{\lambda_{\rm tot}\frac{1}{\mu}}{WL}$, where $\lambda_{\rm tot}$ is the total arrival intensity, i.e., 20 times the arrival intensity λ of one connection, W is the number of channels, L is number of links and μ is the mean length of a burst) is below 0.3. Beyond that point the loss probability of class 2 increases rapidly, because the load at these links approache value 1. With 10 short buffers the loss increases with lower speed, but starts to increase earlier. As illustrated in Figures 9 and 10, the loss difference between different connections is smaller with the irregular delay line configuration. Thus, by choosing a suitable configuration, the loss can

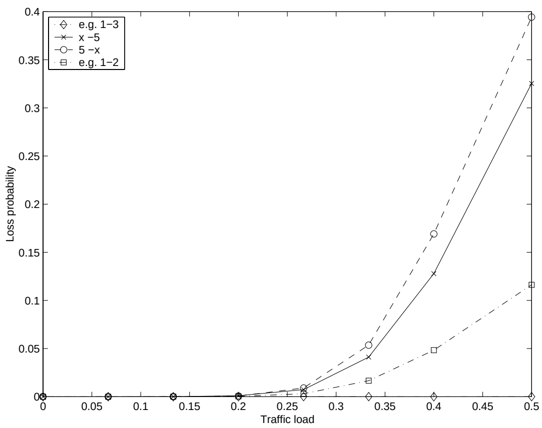

Figure 9: The loss probability of different connection (WSB, 10 regular buffers).

be more fairly distributed among different connections. Again, the effect is minor, but still notable.

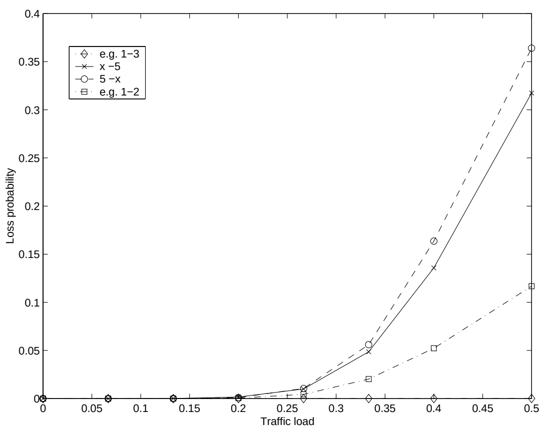

Figure 10: The loss probability of different connection (WSB, 10 irregular buffers).

In Figures 11 and 12 the corresponding delays of systems with five and ten buffers are illustrated. Figures illustrate the proportional increase in the delay compared to the base delays caused by the propagation and processing times. The delays are relatively low. The short connections, i.e., connections that belong to classes 2 and 3 have the greatest proportional increases in delays. With ten delay lines the delays obtained are slightly smaller, but the difference is minor. The delays are distributed among different connections independently of the number of the delay lines. The delays obtained with five irregular or ten regular buffers are not illustrated here, since the delays obtained with irregular and regular configurations are in practice the same.

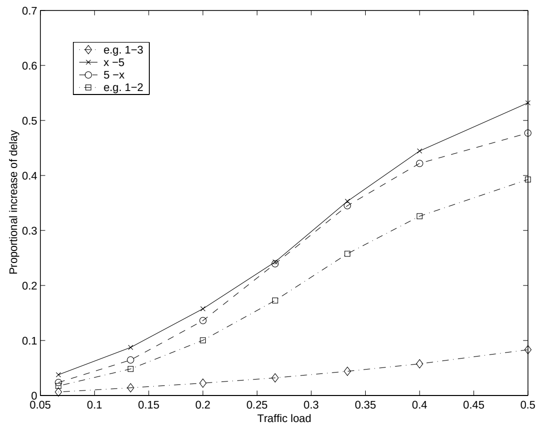

Figure 11: Delay of different connection (WSB, 5 regular buffers).

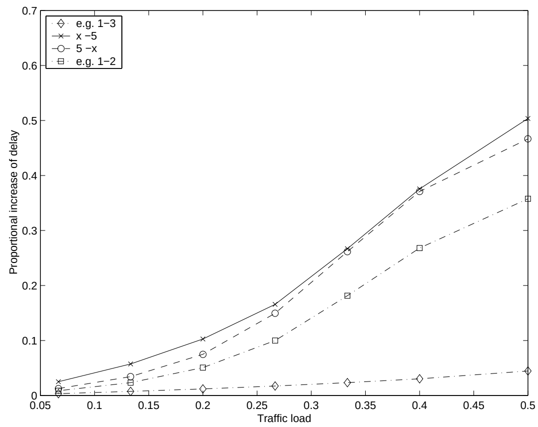

Figure 12: Delay of different connection (WSB, 10 irregular buffers).

5 Conclusions

The numerical results show that with a few delay lines the loss probability can be reduced, while the delay still remains low. Building more delay lines becomes probably remarkably cheaper than using a number of wavelength converters, though it has to be taken into account that the reservation system needed for each delay line increases complexity of the nodes, which eventually limits the number of delay lines that can be used.

The length of the longest buffer was the same in all the configurations, 5 times the maximum burst length. Two configurations include five delay lines and two configurations include 10 shorter delay lines. With several shorter delay lines considerably better results were obtained. Additionally, two of configurations include uniformly distributed delay lines that are multiples of a basic length, and two of them are irregular delay line configurations, in which the lengths of the delay lines are multiples of the minimum length but irregularly distributed. With the latter approach slightly better results were obtained. The benefit was minor, but it was obtained without additional costs. Additionally, with irregular configurations, a loss that is more fairly distributed among different connections can be obtained.

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