Pre-reservation of Resources and Controlled Loops for Contention Resolution in OBS Networks

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ABSTRACT—A new scheme to alleviate contention in optical burst switching networks is proposed. It consists of preventively reserving resources in a node, to be used if resources are busy on the next hop node. The burst is sent back to the preceding node and then resent forward. Simulations are carried out to assess the feasibility of the proposed scheme. Its performance is compared with that of contention resolution based on deflection routing.

Keywords—Optical burst switching, blocking probability, contention resolution mechanism.

I. Introduction

The optical burst switching (OBS) paradigm [1] has been recently gaining momentum as a solution which exploits the advantage of statistical multiplexing to make efficient use of bandwidth, reducing latency and achieving transparency in next generation all-optical networks. Different OBS signaling protocols have been previously proposed [1], [2], "just enough time" (JET) being the most widely recognized. The JET protocol is based on the delayed reservation (DR) paradigm [1] and offers good efficiency (resources utilization can be properly scheduled) and low latency. If, upon the arrival of the control message, no wavelengths can be reserved at the suitable time, then the corresponding burst will be blocked and lost, assuming that no contention resolution (CR) mechanisms are available.

In OBS networks the control packet is sent in advance to allow the optical nodes on the path to properly dispose their resources for the transmission of the data burst (DB), which is sent after a delay known as offset-time (T_{offset}). While the DB is transparently transmitted end-to-end within the OBS network, the control packet has to be processed at each node, so T_{offset} is reduced as the DB progresses on the network. The T_{offset} is properly calculated at the source node to be sufficient for the reservation process on all intermediate nodes. In fact, T_{offset} is a crucial issue in OBS networks and has been studied as a method to provide QoS [3]. The optical path is configured node-to-node by the transmission of the control packet. Each node checks the temporal availability for the correct switching configuration to the next hop. There is some contention and dropping probability of the bursts, which depends on the total number of hops that make up the optical path. Different CR policies have been previously proposed [3], [4], including time deflection (using optical buffering by means of fiber delay lines), space deflection (using alternative routing), wavelength conversion (using transparent optical channel changers), or a combination of these approaches. When a contention cannot be resolved by any of these techniques, one or more bursts are blocked and then dropped. In this work, a space deflection based mechanism is proposed re-using a link that was previously traversed by the burst. The proposed scheme is called "pre-reservation" because resources are not released just after the burst transmission; rather, they are preventively reserved, taking into account the fact that resources could be busy at the next node. If this is the case, the burst is sent back to the previous node (a loop is formed) whose resources are still available.

Manuscript received Mar. 7, 2007; revised June 18, 2007.

This work was partially supported by the EC through FP6 Project NOBEL phase 2 (contract 027305) and by the Spanish Ministry of Science through Project RINGING (TEC2005-08051-C03-02).

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II. Proposed Algorithm

The proposed scheme, pre-reservation of resources (PRR), is based on the JET protocol, but it introduces some mechanisms to ensure QoS guarantees. The ingress node checks all the different optical paths taking into account network topology and load statistics information. The resulting routing information is sent in the control packet. Then, intermediate nodes only need to check the temporal availability for the correct switching configuration to the next hop suggested by the ingress node. The ingress node calculates the T_{offset} according to the most restrictive path. Therefore, a supplementary delay is provided which allows a loop to be made at any hop on the path. The value of this extra delay corresponds to twice the node's control packet process time (in the range of few ms with current technology). In this way, it is guaranteed that the DB will not reach the control packet even if a loop is created. The PRR scheme provides better QoS, as controlled loops are made by using the previously reserved resources. In contrast to JET, resources are not released just after DB transmission but are preventively reserved. If there are no available resources at the next hop node, a loop is created by sending the burst back to the preceding node (where resources have been pre-reserved) and forwarding it again. Uncontrolled loops and the computation problems associated with rerouting are drawbacks of conventional deflection routing mechanisms which are avoided with our proposed scheme.

1. Algorithm Steps

The ingress node looks for the possible paths, considering only the network topology. As DB lengths are less than 1 s, it makes no sense to take into account link states, so distance vector routing is used. The T_{offset} is calculated according to the number of hops for the longest possible route and the priority of the processed burst, which defines the possibility of using PRR. A data structure including the possible routes is created. It indicates to each node when the burst will be received and to which node it must redirect it. This data structure includes the following fields: Hop, TimeID, and Bit-Loop. Hop identifies each individual hop number on the route at each node. TimeID allows the node to know the burst input instant. The node updates this label taking into account its own introduced delay. Bit_Loop indicates the possibility of using PRR.

The intermediate nodes check the temporal availability by comparing their local databases to the required T_{offset} for the correct switching to the suggested next hop node. If the connection is feasible both in time and space, the node will carry out the DR and will update the database of channels availability and T_{offset}. If the connection is not viable, that is, if the channel will be in use when the DB would arrive, that path is discarded and the inspection of the next path indicated by the ingress node starts. If none of the routes are feasible, a Nack (negative acknowledgement) message is sent to the ingress node. However, there are some alternatives to discarding the burst. As the ingress node has overestimated the T_{offset}, it seems reasonable to think that re-routing the burst is possible, as in deflection routing (DR) [4].

2. Contention Resolution Using PRR

When a node receives a request to send a burst over a busy channel, making a loop to the previous node introduces a known delay (twice the link propagation delay). This allows the DB to be sent to the next node in the future, thus, avoiding discarding it. Loop usage has some drawbacks. The reservation and use of more resources obviously implies overloading the network. Also, the latency effect and physical impairments increase. Taking these constraints into account, we propose the following rules for implementing PRR-based loops. First, loop usage is only for DBs with high priority (gold). Bit_Loop identifies these DBs. Second, loop usage is more efficient in the last jumps. Losing a DB is worse if it has already passed some hops, that is, if some resources have already been spent.

The procedure for establishing an optical path using a loop is shown in Fig. 1. The loop messages (request to create a loop) and the accept (loop acceptance) messages are introduced in the signaling protocol.

The CR using PRR is divided into two steps: 1) Node 2 receives the setup message (with Bit_Loop activated), and decides to send the burst to node 3. Once the burst has been sent, resources are not released, but a PRR is done, taking into account the fact that a loop could be required. 2) As node 3 cannot route the burst to node 4 over any proposed path and Bit_Loop is activated, it sends the loop message to the previous node.

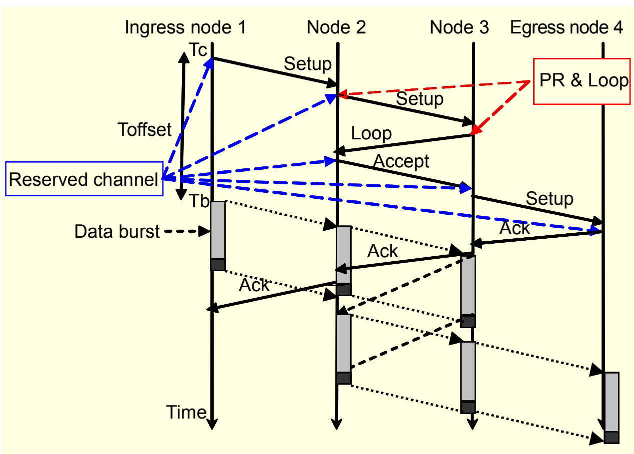

Fig. 1. Time diagram of the optical path set-up using PRR and loop.

III. Simulation Results and Discussion

To assess the feasibility of the proposed CR scheme, simulations were carried out. A 17-node metro network with a mean nodal degree of 3.5 was simulated. Links were considered to be bi-directional with 4 wavelengths per direction. The maximum theoretical network throughput was defined as the load supported in a hypothetical case where all the bursts are directed to an adjacent node (one hop). The maximum network load corresponds to 17×3.5×4=238 bursts carried by the network. The actual network load was then normalized to this value during simulations. The traffic characteristics were the following. Bursts could be generated from any source to any destination node (uniformly distributed) and time between bursts (IAT) as well as burst length (HT) was considered to be exponential. To simulate increasing network loads, the HT was adjusted while the IAT was kept at a fixed value.

Two different burst classes were generated: gold (bursts which use CR mechanisms) and best-effort (bursts which are blocked and lost when contention occurs). The T_{offset} was calculated for every burst, adjusting it to the number of hops of the path, and adding a fixed value (twice the control packet processing time, whose value was assumed to be 1 ms) to the gold bursts. The mean T_{offset} value during simulations was 6 ms. Two different CR strategies were simulated: PRR and classical DR, in which blocked bursts are re-routed from the node where the blocking is produced to the destination node. The results obtained from simulations focus on the blocking probability (BP) in the network. The BP is calculated as the ratio between dropped bursts to the total offered bursts (10^4 bursts per simulation give a confidence interval > 95%) when the simulation ends.

When carrying only best-effort (BE) bursts, the network reached a BP of 0.1 when the carried traffic was 0.23 times the theoretical maximum load (bursts generated have HT=300 ms and IAT=5.5 ms, so there are always roughly 55 bursts being transmitted over the network). This load was fixed during all the cases plotted in Fig. 2. Different fractions of generated burst traffic are considered to be gold class. If 10% of the offered load is considered gold, their BP decreases to a value near 10^{-4}, while the rest of the traffic only suffers a slight BP increment to 0.105. If gold traffic is increased to 30%, its BP holds under 10^{-3}, while the BP for BE traffic increases to 0.18. Due to the network overload induced by PRR, the BP for BE traffic reaches unacceptable values, greater than 0.3, when the ratio of gold traffic exceeds 30% of the total traffic. While gold values are similar for both strategies, the BE traffic reaches a worst BP value of 0.2 when the proportion of gold bursts is 40%. Nevertheless, our proposal offers a significant advantage when compared to DR. The previous node has already reserved the resources when it has transmitted the burst, so no new paths have to be calculated. This allows computational resources to be saved and reduces the number of signaling messages to be conveyed over the network.

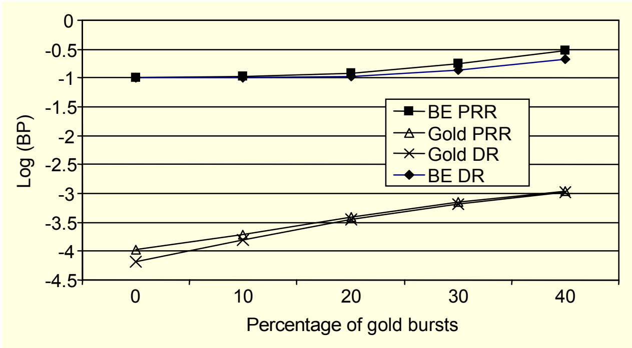

Fig. 2. Log (BP) vs. percentage of gold bursts for a network load 0.23 times the maximum theoretical load. BE and gold BP values are shown for both CR strategies, PRR and DR.

In addition, the delay introduced by the PRR mechanism is known in advance (this is also true when fiber buffering is used, but in that case, extra hardware is introduced). Assuming this feature, the offset time can be set at the source node when PRR and the controlled loop will be used. This simplifies OBS network control.

Other network topologies with different nodal degrees were simulated, and the results lead to two main conclusions. First, when reducing the ND, PRR outperforms DR because there are less alternative routes. Second, when reducing ND, the BP for BE bursts becomes higher using PRR because the total number of resources is lower and PRR induced network overload has a higher impact. The usefulness of PRR has been demonstrated as the gold burst BP is kept low for different ND values.

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