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On the Support of Multimedia Traffic over Optical Burst-Switched Networks

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Abstract: Optical Burst Switching (OBS) is a promising switching paradigm that is very suitable to be deployed in the next generation internet. OBS combines the benefits of various evolving techniques to economize the network traffic through an optical network. However, OBS lacks mechanisms for congestion control and service differentiation, which impedes its support for the Internet multimedia traffic. In this study, new congestion control and service differentiation mechanisms are presented. These mechanisms are based on a new control packet structure, which provides constant transmission overhead and makes the control packet scalable to higher speeds. The simulation results show that these techniques allow the OBS edge nodes to control the network traffic flows and enable the core nodes to maintain a low burst drop rate and provide different services for different traffic classes.

Key words: Optical network, optical burst switching, congestion control and service differentiation

INTRODUCTION

Photonic networks are becoming the natural choice to be deployed as the backbone infrastructure to support the next-generation high-speed Internet. The emergence of Wavelength Division Multiplexing (WDM) technology, which supports multiple simultaneous channels on a single fiber, provided the network backbone with huge bandwidth. Optical Burst Switching (OBS) (Qiao and Yoo, 1999; Battestilli, 2002) makes it possible to support all-optical networks in spite of the current immature optical switching devices and the lack of efficient optical memory (optical buffers) (Vincent *et al*., 1998). OBS is intended to combine the benefits of both packet-switching networks (Blumenthal *et al*., 1994; Cruz and Tsai, 1996) and circuit-switching networks (Chlamtac *et al*., 1992; Mei and Qiao, 1997).

OBS is an adaptation of a stander known as Asynchronous Transfer Mode Block Transfer (ATM-ABT) developed by the telecommunication standardization sector of the International Telecommunication Union (ITU-T) for burst switching in Asynchronous Transfer Mode (ATM) networks. OBS network consists of edge (Ingress/Egress) nodes and core nodes-built from optical and electronic components-connected by WDM links. OBS differs from optical packet switching and the original burst switching concept introduced in the 80s (Kulzer and Montgomery, 1984; Amstutz, 1989) in that it separates the control and the data, both in time and physical space. In OBS, collections of IP packets, assembled into large-size data unites called Data Bursts (DBs), are sent an offset time after their corresponding Burst Control Packets (BCPs). The BCPs are generated at the network ingress and then sent on designated wavelengths over a WDM link to the OBS core nodes to announce and reserve the needed network resources for their upcoming data bursts. The offset time that separates a BCP from its corresponding DB is progressively consumed while the BCP is processed electronically as it passes through O/E/O conversions at the core nodes. In the core nodes, the BCPs information is used to configure the switching fabric before the arrival of the DBs. Without the need for data buffering, the DBs are switched all-optically, then disassembled back into the original IP packets at the network egress (edge node), where the BCPs are terminated.

The traditional OBS framework (a bufferless system based on the concept of one-way reservation) and its variants (Detti and Listanti, 2001; Wei and McFarland, 2000; Yoo and Qiao, 1997) do not provide an optimal solution to handle the internet multimedia traffic, due to their incompetence in congestion control and QoS

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provisioning. In OBS the DB (i.e., a set of IP packets) is discarded in its entirety, if the Burst Control Packet (BCP) fails to secure the full or even a part of the resources needed to establish an all-optical transmission path. Consequently and in order to reduce the burst loss probability, many approaches were considered (Hsu *et al*., 2002; Kim *et al*., 2002; Detti *et al*., 2002; Vokkarane *et al*., 2002). Some of the most promising techniques are those based on the concept of data burst segmentation, which reduce the packet loss probability and improved the network performance in term of packet delivery. Unfortunately, none of these proposals covered the feasibility issues related to the implementation of the burst segmentation techniques.

Based on the burst segmentation concept, a new BCP format is presented to facilitate the development and the implementation of a new congestion and flow control mechanism, as well as a service differentiation mechanism. The introduced mechanisms maintain the simplicity required in optical networks, yet providing an effective technique to support the internet multimedia traffic.

BURST SEGMENTATION TECHNIQUES

A measure of efficiency in OBS systems is the burst dropping probability. Bursts dropping is caused by contention, i.e., when two or more bursts are destined to use the same channel from the same fiber (i.e., output port) at the same time. In order to reduce the burst loss probability, many approaches were considered based on different techniques, such as the use of deflection routing to resolve contention presented by Hsu *et al*. (2002) and Kim *et al*. (2002). Based on the concept of burst segmentation, other promising techniques for partial burst dropping were introduced.

Optical Composite Burst Switching (OCBS): Detti *et al*. (2002), proposed the Optical Composite Burst Switching (OCBS) technique that introduces the idea of dropping only the initial part of the burst if all the resources are occupied at the time of the burst arrival. The final part of the burst is transmitted as soon as the needed recourses become free.

Though that this technique reduces the packet loss probability, therefore, improving the performance of the network compared to the traditional OBS architecture where the entire burst is dropped, OCBS suffers from the need for Fiber Delay Lines (FDLs). FDLs are needed to delay the data bursts while their control packets are being electronically updated with the new burst lengths, which induces an additional cost and complexity.

Burst segmentation: Burst Segmentation was proposed by Vokkarane *et al*. (2002), to reduce packet loss in optical burst switched networks. It was designed upon Just-Enough-Time (JET) architecture (Yoo and Qiao, 1997) and it assumes fixed packet size. This study is comparable to OCBS in that it uses burst segmentation concept. In this technique the data burst is broken into multiple segments that consist of a single or multiple packets. Combined with deflection routing, the authors showed that their approach performed better than the entire-burst-dropping policy. Two ways were proposed to implement this scheme:

- Segment-first: The remaining length of the original burst is compared to the contending burst. The contending burst is deflected in case it is the shorter, otherwise, the original burst is segmented and its tail is deflected or dropped if the alternate port is busy.
- Deflection-first: The contending burst is deflected if the alternate port is free. If the alternate port is busy then a similar process to segment-first takes place and the lengths of both original and contending bursts are compared and the tail of the shorter one is dropped, as the alternate port is busy.

BURST CONTROL PACKET

The BCP's format provides constant transmission overhead and makes the BCP scalable to higher speeds, as it uses the *Segments indicator* (SI) as the segments' length pointer instead of flags (Xiong *et al*., 2000), which will additionally streamline the burst segmentation techniques implementation. Furthermore, the introduced BCP's structure facilitates the development and the implementation of new congestion control and service differentiation mechanisms (Fig. 1).

Label: Multi-Protocol Label Switching (MPLS) label is used. The MPLS label provides simple forwarding and supports explicit routing without requiring each BCP to carry an explicit route by using a fixed length label; which will reduce the control packet processing time.

λID: Wavelength identifier, 16 bits are provided to permit the identification of several hundreds of individual channels that they may be available in a single fiber in the near future.

Flag: Is a sequence of 8 bits with a recognizable pattern that identifies the end of the Segments indicator field (as its size is not fixed) and the beginning of the QoS indicator field.

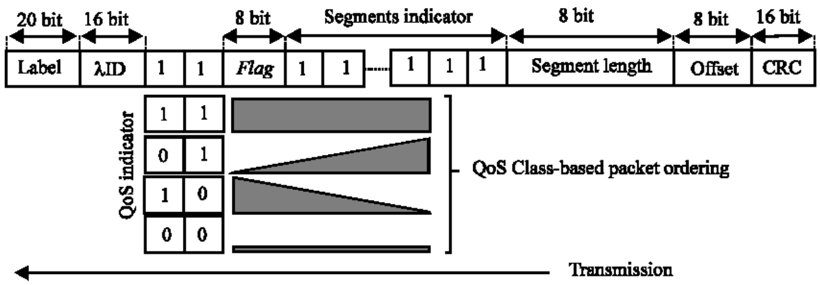

Fig. 1: Burst Control Packet (BCP) structure

Segments Indicator (SI): SI field is created by the ingress-node to reflect the permitted segmentations. In the core-nodes, the SL is multiplied by the number of 1_2 in SI to obtain the actual size of the corresponding DB. For example 001111_2 is an indication that the length of the DB (or truncated DB) is (4 * SL) and it might be segmented into four segments. Additionally, the presence of 00_2 in this SI indicates that this DB had lost two of its segments. The size of SI is dynamic that may vary from one DB to another and the burst assembly algorithm controls it.

Segment Length (SL): Contains the length of one segment. However, Segment-length combined with SI provides sufficient information about both the DB's length and segments number. To avoid congestion in OBS control-channels, Segment-length should comply with a minimum length, which is the minimum permitted data burst length transmitted over the optical links. Switching fabric configuration speed affects the burst size that should be much larger than the switching time. As the optical switching technology matures, the restriction due to switching speed becomes minimal. Therefore, 8 bits field is provided for the length of one segment, to cater for the larges IP packet (65,535 B).

Offset time: is defined as the interval of time between the transmission of the first bit of the BCP and the transmission of the first bit of the data burst. The offset time indicates the difference between the arrival time of the BCP and the arrival time of the DB. The offset time should be quantized to a discrete set of values as multiples of 256 (8 bits).

CRC: Cyclic redundancy check, one of the most powerful redundancy checking techniques. CRC is used for error detection.

QoS indicator: This field indicates what QoS arrangement is deployed.

MULTIMEDIA TRAFFIC SUPPORT

With the multimedia traffic taking an ever-increasing portion of the Internet bandwidth, it is becoming increasingly important to develop some form of congestion control and service differentiation mechanisms. Those mechanisms, in addition to being effective, must be simple to be deployed over an optical network infrastructure in which the traditional mechanisms are not that efficient.

Congestion control mechanism: Congestion is a complex phenomenon and it occurs when the traffic load (number of bursts) on the network begins to approach the network capacity. Therefore, a congestion control mechanism is needed to maintain the number of the bursts being transmitted through the network within the limits at which the network performance is acceptable.

By using an explicit congestion avoidance technique, the edge nodes can use as much of the network capacity as possible, while reacting to the congestion in a controlled manner. In the proposed explicit signaling technique, the bits of SI are used to indicate explicitly the amount of data (i.e., the number of data segments in the DB) sent and the arrived amount. This signaling approach can work in one of two directions: Forward (to notify the Egress), or Backward (to notify the Ingress).

- Forward signaling: Forward signaling notifies the egress node that congestion procedures should be initiated where applicable for traffic in the opposite direction of the received bursts. It indicates the number of the dropped data segments and that the received burst has encountered congested resources. This information could be sent back to the source node and the end system will exercise flow control upon the traffic sources at the higher layers (e.g., TCP).
- Backward signaling: Backward signaling notifies the ingress node that congestion procedures should be

initiated where applicable for traffic in the same direction as the sent bursts. It indicates the number of data segments dropped and that the sent burst has encountered congested resources. The ingress node will then lower the number of data segments sent in each DB to be equal to the number of data segments that could get through the network to the destination. Then the number of data segments is augmented by one DS whenever a DB is transmitted, until the maximum size of the data burst is reached, or until the SI field reports congestion.

Service differentiation mechanism: Based on the introduced BCP structure, specifically, the Segments indicator and the QoS-Indicator, a new service differentiation mechanism is proposed. In this mechanism, the QoS requirements of the upper layer packets are defined based on their service class. Packets of the same class and destination are assembled into the same data segment, which will be labeled with a priority number accordingly. A data burst may contain data segments of the same or different priorities. Using appropriate assembly algorithm, the data segments are assembled into data bursts in one of the following four arrangements. 1) The high-priority DSs are located at the head of DB, while the low-priority DSs are located at the tail of the DB. 2) The low-priority DSs are located at the head of DB, while the high-priority DSs are located at the tail of the DB. 3) All the DSs in the DB are of high-priority. 4) All the DSs in the DB are of low-priority. In the BCPs, using the QoS-Indicator field, these arrangements are indicated respectively with the following values: 01_2, 10_2, 11_2 and 00_2, as shown in Fig. 1.

In the core nodes, the contention is resolved by dropping the low-priority DSs, allowing the forwarding of the high-priority DSs. That is, the tail-dropping, the head-dropping, or the entire-burst-dropping strategy is adopted depend on whether the high-priority DSs are located at the head, tail, or the entire DB (according to value of the QoS-Indicator field). In case that the contending DSs are of the same priority, the DSs are arbitrarily dropped to resolve the contention.

PERFORMANCE EVALUATION

The performance of the congestion control mechanism is evaluated using a modified version of NCTUns 2.0 (Wang *et al*., 2003). Using a simple network topology as shown in Fig. 2; four optical switches are used, without wavelength converters and FDLs.

In the simulation, JET is used as the OBS signaling protocol and the links used are of 10 Gbps, with 3 wavelengths. 1500 bytes upper layer packets are assumed, the data segments are limited to 5 packets and the data burst generation is controlled using a burst-length threshold of 6 data segments or a timer threshold of 400 micro seconds (Fig. 2).

Figure 3 shows the packet drop rate versus the traffic load. In the network using the proposed congestion control, the improvement in term of packet drop rate is significant, particularly with high traffic loads.

To evaluate the Service differentiation mechanism, only two traffic classes are assumed, with the same offered traffic load. First traffic class “class 1” is the higher priority, whereas “class 0” is for the second traffic class, which is the lower priority. Figure 4 shows that the lower priority data segments (therefore lower priority packets) experience more dropping rate. The higher priority data segments are given a higher quality of service.

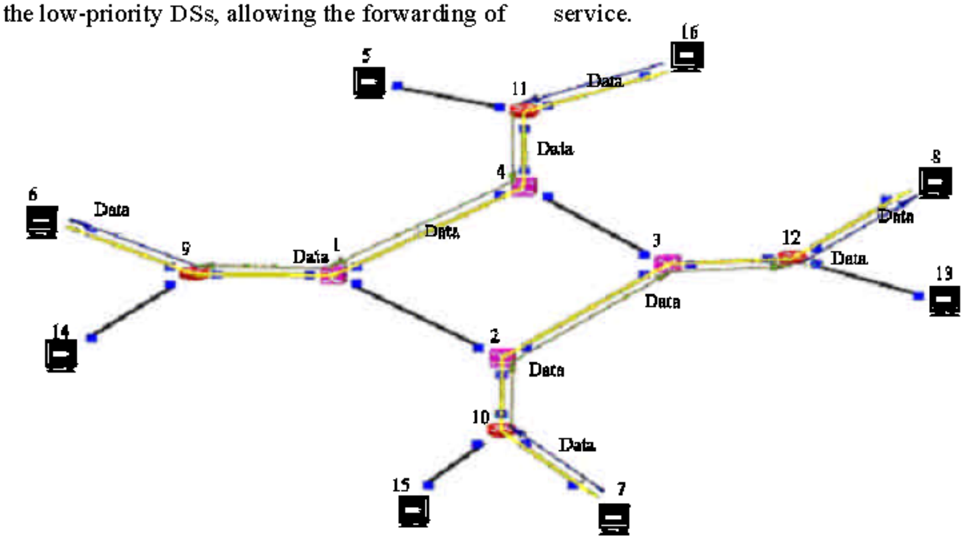

Fig. 2: Simulation topology

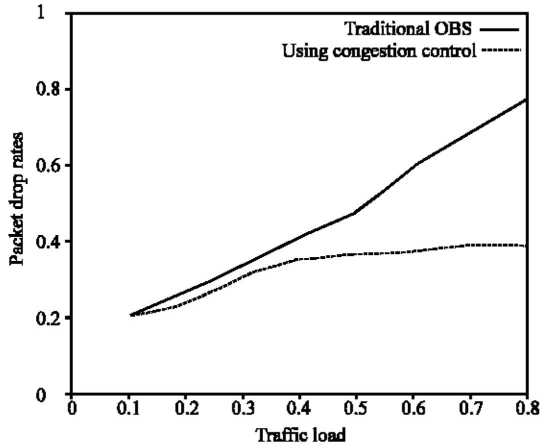

Fig. 3: Packet drop rate versus traffic load

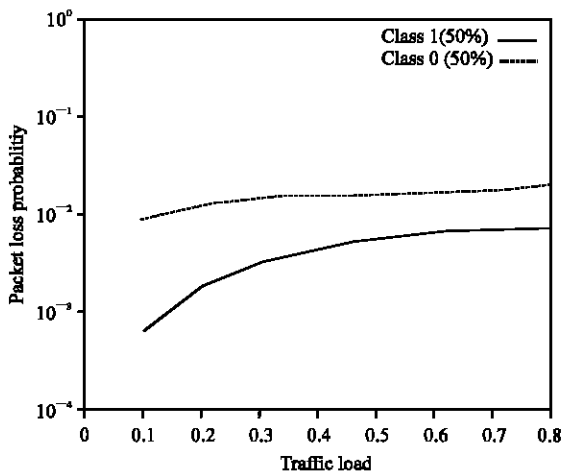

Fig. 4: Packet drop rate versus traffic load

CONCLUSIONS

In this study, an overview of the Burst segmentation techniques, namely Optical Composite Burst Switching (OCBS) and burst segmentation, is provided. A new technique to control the network traffic congestion has been introduced, based on a new Burst Control Packet structure, by which a relatively small control packet size is maintained; nevertheless, the new BCP carries all the essential control information. The data transparency is preserved, yet the segments delineation is possible, since the length of the segments and DBs is clearly reflected in the BCP. The introduced congestion control and the service differentiation mechanisms comply with the simplicity required in optical networks and provide suitable functionality for the OBS networks to support the Internet multimedia traffic with an adequate performance.

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