Available online at www.sciencedirect.com
SCIENCE DIRECT®
ELSEVIER
Computer Communications 28 (2005) 754–764
computer communications
www.elsevier.com/locate/comcom

Efficient techniques for improved QoS performance in WDM optical burst switched networks

G. Mohan*, K. Akash, M. Ashish

Department of Electrical and Computer Engineering, National University of Singapore, Engineering Drive 4, Level 5, Singapore, Singapore 117576

Received 11 November 2003; revised 7 October 2004; accepted 26 October 2004
Available online 10 November 2004

Abstract

In this paper, we address the problems of *burst scheduling*, *network fairness*, and *service differentiation* in *wavelength division multiplexing* (WDM) *optical burst switched* (OBS) networks. We propose two approaches—*time-slotting* and *burst fragmentation*—to provide efficient solutions for the above problems. We also propose a path selection algorithm to distribute label switched paths (LSP) based on load balancing. Time slotting refers to the quantization of time into slots of fixed sizes. Time slotting aids fast implementation of scheduling algorithms. Further, the slotting is local to the nodes and they need not be synchronized across the network. In burst fragmentation, a burst is fragmented instead of being dropped if it cannot be accommodated on any wavelength as a whole. These fragments are then sent on different wavelengths on the same path. Only in the event, that a fragment cannot be scheduled on any wavelength of the link, is the burst dropped. We develop a new scheduling algorithm based on time-slotting and fragmentation. This algorithm has several attractive features such as fast and simple implementation and improved burst dropping performance. Using the hop-based shortest path algorithm to route a burst without accounting for the link load results in poor burst dropping performance. This is because, some links could be heavily loaded forming a bottleneck for network performance. Load balancing approach aims at reducing the bottleneck of data traffic in the network. We develop a path selection algorithm based on load balancing with the objectives of improving network performance in terms of burst dropping probability and improve fairness among bursts traversing paths of different lengths. We then develop an offset-based algorithm to provide inter-class service differentiation and intra-class fairness for the bursts belonging to classes with different levels of priority. An attractive feature of this algorithm is that it works with a constraint of maximum permissible initial offset time in order to reduce the burst transfer delay and also to reduce the buffer requirements at the ingress edge routers. It also ensures that shorter-hop bursts of a low-priority class does not perform better than the longer-hop bursts belonging to a high-priority class. Extensive simulation results have been used to demonstrate the effectiveness of the proposed approaches and algorithms for various *identical* and *non-identical* traffic demand scenarios.

Keywords: Wavelength division multiplexing (WDM); Optical burst switching (OBS); Network fairness; Service differentiation; Time-slotting; Fragmentation; Load balancing

1. Introduction

Potential bottlenecks of electronic processing to carry Internet protocol (IP) traffic over wavelength division multiplexing (WDM) optical networks can be overcome by aggregating multiple data packets into a super packet, called burst which is assembled at the ingress router. Bursts have the same network properties like ingress and egress routers and QoS requirements. In burst switching, resources are reserved in a one-way process and the burst cuts through the intermediate nodes, without any need for buffering, thus reducing nodal complexity and alleviating synchronization problems as opposed to packet switching [1–4].

A burst consists of a *header* and a payload called *data burst*. The burst header is also called the *control packet*. The payload and the header are sent separately on different wavelengths/channels. The burst header contains all the necessary information to be used by the switch control unit (SCU) at each hop to schedule the data burst, and configure the optical switching matrix to switch the data burst optically [5]. The difference between the times at which a control packet arrives and leaves a node is called

* Corresponding author. Tel.: +65 6874 4688; fax: +65 6779 1103.
E-mail address: elegm@nus.edu.sg (G. Mohan).

0140-3664/$ - see front matter © 2004 Elsevier B.V. All rights reserved.
doi:10.1016/j.comcom.2004.10.007

the *control processing time*, denoted by Δ. In order to avoid buffering of the burst at the intermediate nodes, the control header precedes the payload by a minimum duration of $h\Delta$ where h is the number of hops along the path. The separate transmission and switching of data bursts and their headers help to facilitate the electronic processing of headers and lower the opto-electronic processing capacity required at core routers. Further, it provides ingress to egress transparent optical paths for transporting data bursts.

In the literature, several burst switching techniques have been proposed. These include close-ended resource reservation techniques like Reserve-a-fixed-duration (RFD) and open-ended reservation techniques like Tell-and-go (TAG) and In-band-terminator (IBT). Among the protocols available, Just-enough-time (JET), an RFD based OBS protocol is attractive [2]. The JET protocol works as follows. After the burst assembly is complete, the ingress node sends out a control packet followed by the data burst after an initial offset time. The control packet carries information such as burst duration and offset time. Because the burst is buffered at the source for a sufficient amount of time, no fiber delay lines (FDL's) are necessary at intermediate nodes to delay the burst. When the control packet arrives at a node, a wavelength is reserved on the relevant outgoing link at the node from the time when the burst is expected to arrive for the duration of the burst. If no wavelength is available, the burst is said to be blocked and will be dropped.

As bursts arrive dynamically and multiple bursts may attempt to traverse a link simultaneously, resource contention may occur. Therefore, an efficient scheduling algorithm is required to allocate wavelengths to various contending bursts. In the literature, a few burst scheduling algorithms have been proposed [1,5]. They include First Fit Unscheduled Channel (FFUC), latest available unscheduled channel (LAUC) and, latest available unused channel with void filling (LAUC-VF) [5]. The *scheduling horizon* algorithm developed in [1] is similar to LAUC scheduling algorithm.

Both FFUC and LAUC [5] do not examine and fill voids formed on the wavelength channels. Instead, they use only the last burst information on each wavelength. By doing so, they become computationally simple but the scheduling efficiency is compromised. The worst case time complexity is $O(W)$ where W is the number of wavelengths per link. Among all the eligible wavelengths FFUC chooses the first free wavelength whereas LAUC chooses the one whose latest available time is closest to the arrival time of the new burst. By doing so, LAUC attempts to pack the bursts as tightly as possible. This improves the chances of successfully scheduling future bursts. LAUC-VF performs significantly better than LAUC by allowing a new data burst to fill the voids between the existing bursts. However, it is computationally complex. Its worst case time complexity is $O(NW)$, where N is the number of voids or bursts currently scheduled.

Internet traffic has different service requirements in terms of delay and loss. Therefore, several classes of bursts with different grades of QoS requirements such as burst loss performance need to be handled. In the literature, different kinds of approaches have been proposed to deal with service differentiation. In the first approach, class isolation is ensured by assigning extra offset time of $3L$ to high-priority class bursts, where L is the mean burst duration [6]. This approach might over-penalize the low-priority class in order to ensure class isolation. In the second approach proportional QoS is ensured between different classes. In [7], proportional QoS is provided by intentionally dropping low-priority bursts when relative performance between classes is violated. This method ensures a fair level of performance by low-priority bursts. However, it could lead to poor utilization of bandwidth or wavelength resources due to the intentional dropping.

An important issue in OBS networks is fairness. In most networks, the dropping probability of a burst increases with the number of hops in its path. This implies that for any given ingress–egress pair the burst dropping probability is not uniform but depends on the path length from the ingress to the egress, which is undesirable. In the literature, a solution has been suggested to achieve fairness in OBS networks. In this, the initial offset is made a function of the number of hops the burst has to traverse, typically $5hL$ or $10hL$, where h is the number of hops and L is the mean burst duration [2]. Increasing offset time improves the probability of the burst getting transmitted through the network and hence helps in reducing the dropping probability for the longer-hop bursts. This, however, increases the time a burst spends in the network and can become quite undesirable. Further, due to the increased offset time, large buffers are required at the ingress edge routers. We note that the fairness problem can also be caused due to other reasons such as length of burst duration. In our work, we consider the network fairness problem caused by differing hop lengths of the paths traversed by bursts.

We propose two new approaches—*time slotting* and *burst fragmentation* and a new path selection algorithm based on *load balancing*—as the effective ways of improving burst dropping performance, network fairness, inter-class service differentiation, and intra-class fairness. Based on the time-slotting and fragmentation approaches, we develop a new scheduling algorithm called Best fit void filling with fragmentation (BFVFF). This algorithm has advantages of computational simplicity and improved burst dropping performance. Time slotting refers to the quantization of time into slots of fixed size. The burst duration is specified as the number of slots and every node performs scheduling in terms of slots. This helps reduce the number of bits required to encode the burst duration. Further, the maintenance of the status of slots and implementation of scheduling at the core nodes become simpler. Fragmentation allows a burst to be fragmented when it cannot be scheduled as a single entity on any wavelength. It enables allocation of multiple wavelengths on the same path to different fragments of a burst.

With the use of multi-protocol label switching (MPLS) capabilities in OBS networks, label switched paths (LSPs)