Available at
www.ElsevierComputerScience.com
POWERED BY SCIENCE DIRECT®

Computer Networks 44 (2004) 569–582

COMPUTER NETWORKS

www.elsevier.com/locate/comnet

Wavelength and time domain exploitation for QoS management in optical packet switches ☆

F. Callegati *, W. Cerroni, C. Raffaelli, P. Zaffoni

DEIS, University of Bologna, Viale Risorgimento 2, 40136 Bologna, Italy

Abstract

This paper addresses the problem of congestion resolution and quality of service differentiation in optical packet switching. The paper shows that by designing congestion resolution algorithms that combine the use of the wavelength and the time domain it is possible to significantly reduce information loss phenomena and also to guarantee quality of service differentiation among traffic classes. In particular this is achieved by means of QoS algorithms specifically designed to exploit the characteristics of optical technology. The results are different from the QoS techniques typically implemented in electronic networks. Performance evaluation obtained by simulation shows the influence of the main system parameters on packet loss probability and delay for two service classes.

Keywords: Optical networks; Wavelength multiplexing; Optical packet switching; Congestion resolution; Quality of service

1. Introduction

The combination of all-Optical Packet Switching (OPS) with the very high capacity of DWDM optical fibers promises to be the most powerful and flexible networking technology developed so far. OPS is still a medium-to-long term networking solution because of the still immature state of technology and of the current difficulties in the telecommunication market, but it represents an important research topic for the scientific community because of its huge potential.

Several research projects, such as the UE funded KEOPS and DAVID [1–3], demonstrated the feasibility of switching matrixes able to switch all-optical packet payloads. In these cases synchronous switching operation is considered in order to simplify the switching matrix design. The drawbacks of this approach are the need of all-optical synchronization, implying a substantial increase in hardware complexity, and the inefficient interworking with network protocols based on variable-length packets, such as IP. The adoption of asynchronous and variable-length optical packets overcomes these drawbacks at the cost of a more complex switching matrix design both from the physical and from the logical point of view [4]. In

☆ This work is partially funded by the Commission of the European Community, Project IST-1999-11742 "DAVID—Data And Voice Integration over DWDM" and by the Italian Ministry of Scientific Research, project "INTREPIDO—End-to-end Traffic Engineering and Protection for IP over DWDM Optical Networks".

* Corresponding author.

E-mail addresses: fcallegati@deis.unibo.it (F. Callegati), wcerroni@deis.unibo.it (W. Cerroni), craffaelli@deis.unibo.it (C. Raffaelli), pzaffoni@deis.unibo.it (P. Zaffoni).

1389-1286/$ - see front matter © 2003 Elsevier B.V. All rights reserved.
doi:10.1016/j.comnet.2003.12.010

the last few years, several important studies have analyzed this scenario and investigated the related switching control problem and optical queuing performance [5–8]. In this context congestion resolution becomes one of the most critical issues. Optical memories are not available and congestion resolution in the time domain can usually be implemented by means of Fiber Delay Lines (FDLs), emulating a normal queue by means of lengthy fiber coils used to delay the signal. FDL buffers are not very effective in this scenario, both because of the very limited capacity and because of the mismatch between the variable packet sizes and the fixed length of the FDLs.

In spite of these limitations, this paper shows how congestion can be effectively limited to tolerable values by designing suitable congestion resolution algorithms that combine the use of the time and the wavelength domain, and how such algorithms can also provide support for quality of service differentiation. Some heuristic congestion resolution algorithms proposed in previous works for connectionless operation [9] and for connection-oriented operation are reviewed here [10]. Then we propose extensions to these congestion resolution algorithms in order to manage the quality of service in an all-optical packet-switched network scenario, according to the *Differentiated Service* model [11]. In particular, it has to be taken into account that in an optical network scenario QoS management cannot be performed by means of queuing priorities or fair queuing scheduling algorithms [12], because of the very limited queuing space and, most of all, because queuing by delay lines does not allow a new incoming packet to overtake other packets already queued, a function that is necessary to implement conventional queuing priorities. Under these considerations we aim at showing that QoS differentiation among different traffic classes can be provided with good flexibility and very limited queuing resources, by means of resource reservation both in the time and in the wavelength domain.

The paper reviews the overall problem of congestion resolution in OPS with variable length packets in Section 2, providing related results in Section 3. Then in Section 4 the problem of QoS management is addressed and results are presented in Section 5. In Section 6 some conclusions are drawn.

2. OPS and the congestion resolution problem

It is well known that in conventional routing the network layer functions of the routers can be separated into two basic components: *control* and *forwarding*. The former element has the task to build up and manage the forwarding table, whereas the latter makes the forwarding decision using the information carried in the packet header. Furthermore, feasible optical packet-switched networks can be realized by introducing an additional partition of the forwarding component into *forwarding algorithm* and *switching*. The former allows establishing the correct next-hop destination by exploring the routing tables, while the latter performs the physical transfer of a packet to the proper output interface. In particular, the execution of the forwarding function is carried out in the electronic domain after optical-to-electrical header conversion, whereas the payload is dealt with in the optical domain without any conversion. Acting in this way it is possible to limit electro-optical conversions and achieve better interfacing with optical WDM systems.

Taking into account these considerations, a generic architecture of an all-optical packet switch is illustrated in Fig. 1. It is worth outlining that the figure represents a general diagram and will be only used to show the main logical building blocks of the switch architecture. The switch has N inputs and N outputs, each connected to a WDM fiber carrying W wavelengths. The wavelengths of each

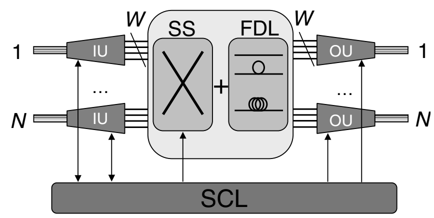

Fig. 1. Generic architecture of a WDM all-optical packet switch with FDL buffer.