Chapter 3

Optical Label Processing Techniques for Intelligent Forwarding of Packets in All–Optical Packet Switched Networks

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ABSTRACT

In this chapter, the authors review several optical label processing techniques providing a comparison based on the potential for each technique to allow for implementation of a scalable and low latency optical packet switching cross-connect node. They present and demonstrate an optical packet switch sub-system employing in-band labeling to allow for transparent forwarding of multi-wavelength packets with multiple data formats at multiple data bit-rates. The optical packet switching sub-system employs a scalable, asynchronous, and low latency label processor. Experimental results are provided that confirm the operation of the label processor in optical packet switching system testbeds. Moreover, the authors discuss applications of the optical packet switching node based on optical label processor and the potential to allow the implementation of intelligent systems for optimal routing of the packets in the optical domain.

INTRODUCTION

The exponential growth of the Internet data traffic will demand high capacity optical networks (Swanson, 2008). High capacity optical links will carry optical packets at data rates above 100 Gb/s using a variety of data-formats such as OTDM data packets, multi-wavelength optical packets with highly spectral efficient modulation formats such as D(Q)PSK, OFDM, M-QAM. On the other hand, routing of packets by today electronic circuit switching may have fundamental limits due to the speed and the scalability of multi-rack electronic switching fabrics, and the associated power consumption by opto-electronic conversions.

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Switching of the optical packets transparently in the optical domain eliminates power hungry opto-electronic conversions and improves the latency of the system. However, there are several issues to be addressed for realizing such Optical Packet Switch (OPS) sub-system. The OPS sub-system should be able to handle optical packets with multiple data formats. This implies that both the label processor, which determines the packet destination and controls the switching fabric, as well as the optical switching fabric, should operate independently of the data-format and data rate of the packets. The OPS sub-system should be scalable, that means that the number of input/output ports is not limited by the switch architecture. For instance a large NxN switching matrix based on multi-stage architecture can be realized starting from a 1xN switch. Essential in realizing a 1xN optical switch is the implementation of a scalable label processor. Moreover, the OPS sub-system should introduce little latency for increasing the node throughput. In this architecture the control complexity and the configuration time (latency) is proportional to the label processing time. Therefore, key issue to realize a low latency OPS, scalable, and data format independent OPS is the implementation of an extremely fast label processor (and labeling technique) that allows for processing a large amount of labels for controlling the large port count OPS with a limited increase of the latency.

In this chapter we first review several optical label processing techniques providing a comparison in terms of processing speed (latency), scalability, data format and data rate dependency. Such requirements for the optical label processor are essential to implement a scalable OPS node. After the reviewing of the label processing techniques, we focus on and demonstrate in-band labeling technique that allows for transparent routing of multi-wavelength packets with multiple data formats and at different data bit-rates. The label processor discussed in this chapter is scalable in terms of label bits, operates in asynchronous fashion, and the processing speed and latency is independent of the number of label bits. We present operation of the label processor for multiple data rate and data format and present experimental results that confirms dynamic operation of the label processor in 640 Gb/s dynamic switching and in a cascaded of three optical packet switching nodes spaced by 52 km. The chapter is concluded with a discussion on future research direction in the fields of OPS.

BACKGROUND

To date, several optical labeling techniques have been proposed and demonstrated. Those techniques can be divided in two areas: all-optical label processing techniques, in which all the operation required to recognize the labels are performed in the optical domain, and opto-electronics label processing techniques, in which optical and electronics processing are combined to optimally perform the label recognition.

Several works have been presented in literature that demonstrate all-optical label processing (Vegas Olmos, 2004; Klonidis 2005; Wang 2006, 2010; Takenaka 2006; Wai 2005; Herrera 2008; Calabretta 2004, 2005, 2006, 2007, 2008; Scaffardi 2010; Hamilton 2002; Wada 2007; Le Minh 2006). Despite the ultrafast operation of processing the labels in the optical domain, the main issue in all-optical label processors is the low amount of labels that can be processed and the lack of mature digital photonic circuits (logics) for complex operation required for implementing algorithms and schedulers for routing the optical packets. Moreover, the complexity of those circuits and the lack of mature and generic photonic integration technology prevented the realization of small footprint, and low power consumption circuits for processing large number of labels. Future breakthrough in the field of photonic integration could lead to efficient and scalable all-optical label processing circuits.