Computer Networks 72 (2014) 99–112

Contents lists available at ScienceDirect

Computer Networks

journal homepage: www.elsevier.com/locate/comnet

Cost evolution model to design optical switching fabrics with wavelength converters

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ARTICLE INFO

Article history:
Received 23 October 2013
Received in revised form 22 May 2014
Accepted 22 July 2014
Available online 7 August 2014

Keywords:
Optical switching
Wavelength conversion
Evolution cost model

ABSTRACT

Optical switching is expected to provide high degree of flexibility in future Internet networking. Exploitation of sub-wavelength domain based on emerging optical technology is attractive from a functional and performance perspective but its feasibility must be proven also in relation to the costs of components. In this paper a new methodology to compare optical switching matrices based on different wavelength converters sharing strategies is presented, which introduces component cost evolution in time. The methodology is applied to compare different switch configurations by taking into account possible evolution in component costs relationship in relation to technology availability. Design guidelines are drawn based on extensive simulations.

1. Introduction

The emerging network service scenarios, increasingly based on large data centers and clouds, calls for high performance network infrastructures characterized by extremely enhanced performance and flexibility [1–3].

Optical technology is a challenging candidate for future communication infrastructures, since Wavelength Division Multiplexing (WDM) provides optical links with several multi-Gigabits channels to achieve extremely high bit-rates. Flexible grid ITU standard has been also defined to optimize spectrum usage and push forward transport capacity even beyond 100 Gbit/s [4].

The higher degree of flexibility expected from future networks can be provided by switch architectures which combines a wide range of functionalities operating on different dimensions, namely time, space, wavelength, possibly enhanced by much higher configuration capability compared to todays' architectures [5]. Indeed electronic technology for the switching is reaching its limits, thus being unable to keep pace with the aforementioned advances on the transport side. Moreover, switching represents the bottleneck of the network, not only in terms of speed/flexibility but also in terms of power consumption. Accordingly, optical technology and devices have been considered even for switching, since they could provide lower power consumption while increasing the speed of the switching functionality. This is of extreme importance in both long-haul optical networks and short-range optical interconnects, such as those required in data centers, where lowering power consumption represents a main target [3].

Packet-based optical switching is still viewed as the best paradigm in terms of flexibility thanks to the sub-wavelength statistical multiplexing gains it provides [6]. Nevertheless, many people share the opinion that in the future optical packet switching (OPS) will be combined with Optical Circuit Switching (OCS) in hybrid/integrated optical networks to provide a full set of transport services [7]. This will allow to combine guaranteed services in terms of delay and loss (through OCS) with the flexibility

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http://dx.doi.org/10.1016/j.comnet.2014.07.009
1389-1286/

and better bandwidth management typical of packet based networks. These both and other transport approaches could be controlled within the unified emerging Software Defined Network context [8,9] while taking advantage of new generation of programmable photonic devices [10].

To properly support these transport services, flexible optical switching fabrics are required, able to efficiently manage contention resolution, which arises when many information units/flows require the same resources at the same time, possibly at different levels of granularities. Many solutions have been proposed in the past for solving contention directly in the wavelength domain [11], without the need to convert the information back to the electronic domain at every node of the network, leaving this task to network edge nodes. This represents a very flexible approach compared to contention resolution in the time domain, considering the lack of the equivalent of Random Access Memories (RAM) in the optical domain.

Different kinds of Wavelength Converters (WCs) and sharing schemes have been considered in the past in order to assess their feasibility with the state-of-the-art technology to achieve target loss performance at the lowest cost. Switch architectures employing fixed input/output WCs [12] and parametric WCs [13] have been recently studied to understand relevant strengths and weaknesses.

The widespread deployment of optical switching is expected to need support not only in terms of performance but also as far as CAPEX cost forecasting is concerned. Optical wavelength converters are complex and thus expensive components, leading to the need to optimize their usage with respect to cost. Also the number of Optical Gates (OGs) resulting from a particular architecture must be included in the cost evaluations. Nevertheless, to the best of the authors' knowledge, a cost model allowing to compare different kinds of components and optical switch architectures in an evolving scenario is still lacking.

This paper aims at introducing a framework for cost evaluation of flexible optical switches in view of their deployment in future networks. With the aim to perform comparisons among different architectural solutions which takes into account component cost evolution in time, an evolutionary cost model of optical components [24] is applied to a modular representation of different wavelength converter sharing schemes. This results in a parametric cost model whose effectiveness in providing design guidelines is proved by extensive simulation, partially based on performance evaluation obtained in [14]. While in [14] the model is mainly used to figure out when WC sharing is cost-efficient compared to the case of fully equipped switches, this paper points out which sharing scheme leads to the lowest cost according to the switch configuration (number of wavelengths/fibers). Furthermore, here the analysis is extended taking into account the cost evolution of the optical device in time, thus providing a useful means for optical switch cost forecasting possibly in the mid/long term.

The paper is organized as follows. Section 2 introduces the related works on the subject of this paper, including the main contribution of this work. Section 3 illustrates a modular description of the four sharing switching fabrics considered in this paper and their scheduling algorithms. Section 4 presents a complexity analysis of the fabrics and the parametric cost model adopted. Section 5 draws an example of dimensioning for the fabrics in terms of number of WCs and Optical Gates (OGs). Section 6 compares the four architectures in terms of complexity and cost. Finally Section 7 gives the conclusions of this work.

2. Related works

Many researchers have focused their attention on the design of switch architectures which exploit WCs for contention resolution in the wavelength domain. In particular, tunable WCs (TWCs) are able to convert the input signal to sets of wavelengths, typically requiring complex and expensive tunable pumps and tunable filters on output [11]. On the other hand, Fixed WCs (FWCs) convert the input signal to a fixed output wavelength, thus eliminating the need for tunable laser pumps and filters [15]. Recently, Parametric Wavelength Converters (PWCs), which can perform many conversions simultaneously, have been considered for contention resolution, proving the great advantage they can provide in terms of cost compared with devices performing single conversion [13]. Furthermore, the process is independent from the bandwidth and modulation format of the input signal, thus representing a possible solution even for networks exploiting OFDM and/or flexi-grid techniques [16,17].

Many architectures and schemes have been proposed for sharing the above mentioned WCs in optical switching fabrics [12,18]. Each scheme can be characterized in terms of performance (in our case packet loss probability), complexity (number of optical devices required), and cost. Further studies focused on the scalability of the proposed solutions, to evaluate the maximum throughput and aggregate bit-rate achievable [19].

In the remainder of this section, the different sharing schemes will be briefly reviewed to highlight their advantages and drawbacks. The first sharing scheme taken into consideration is the well-known Shared-Per-Node (SPN) scheme, where WCs are completely shared among all the input/output channels [20]. This scheme is usually considered as a reference sharing scheme, with WCs completely shared among wavelength channels, which allows to minimize their number for given performance. The WCs employed are tunable-input and tunable-output WCs and the required complete sharing lead to high number of OGs. The resulting flexibility is high at high cost of the switching matrix and of a single WC. A modular graphical representation of this reference scheme is presented here to facilitate the comparison with other sharing schemes.

In particular two alternative schemes have been proposed to reduce SPN complexity and cost.

The first one, named Shared-Per-Input-Wavelength (SPIW), considers fixed-input and tunable-output WCs [21,22]. This allows a reduction in the number of OGs required, since not all the input channels need to be connected to the WCs, as will be explained in detail in the next section. This leads to relevant cost saving depending on switch configurations, as will be discussed in Section 6. This can be achieved even though in some configurations