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Improving performance and energy consumption of shared wavelength converters in OPS/OBS

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ABSTRACT

As Internet traffic will further increase in coming years, the current optical network infrastructure will have to grow along in terms of capacity. To this end, optical packet/burst switching have been proposed, allowing more efficient use of the available fibre capacity. To resolve packet contention in the involved optical switches, Fibre Delay Lines (for delay assignment) and wavelength converters (for wavelength conversion) are used to reschedule the contending packets, by means of a scheduling algorithm. Existing algorithms are effective in minimizing packet loss when employed with an infinite number of converters, but generally perform poorly when the number of wavelength converters is small, as is the case in most switch prototype architectures. In this paper, several parametric cost-based scheduling algorithms for a limited number of wavelength converters are proposed that take scarcity of both FDLs and converters into account. Results obtained by Monte Carlo simulation show that these algorithms not only enable improved performance (in terms of packet loss probability), but also reduce the usage of the wavelength converters, and thus, the switch's overall energy consumption. The new algorithms are of the same implementation complexity as existing cost-based algorithms, and thus are of immediate value to switch designers.

1. Introduction

As it is clear that demand for bandwidth keeps increasing due to new technological developments and increasingly Internet-nested business models, the limited utilization of available fibre capacity (bandwidths of up to 1 Petabit/s [1]) in Optical Circuit Switching (OCS) is a growing concern. OCS guarantees packet arrival and fixed delay but also reduces the available capacity due to the use of dedicated communication channels between two communicating nodes.

Promising solutions to address this problem are the packet-based switching techniques optical burst switching (OBS) and optical packet switching (OPS) in which network links can be shared among communication sessions, thereby increasing the usage of the available fibre capacity. Although OPS/OBS up to now have 'failed', they still are very hopeful technologies that in the future will be useful and probably even necessary. A concern in these packet-based switching techniques is the contention that may arise in the network nodes when more than one packet heads for the same output port at the same time. Since a ray of light cannot be stored, other solutions for temporary buffering are used. The optical signals are often converted into electrical signals to be buffered and converted back to light to transmit them to the next hop. Since electronic memories cannot keep up with the speed of optical fibre [2], the advantage of packet-based switching techniques is nullified. Moreover the conversions result in high energy

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consumption of these semi-electronic switches [3]. Therefore the buffering is currently implemented with Fibre Delay Lines (FDLs) [4] in which the optical signals are sent through long pieces of coiled fibre to delay it for a certain time. Together with the use of wavelength converters (WCs) packets can thus be scheduled in both time and wavelength domain to avoid contention. Since the available capacity for contention resolution is always limited in practice, it is necessary to schedule arriving packets in both time and wavelength domain as efficiently as possible in order to reduce the probability of unresolved contention, and thus packet loss, as much as possible. This is done by a scheduling algorithm, typically designed for minimal packet loss, as the algorithms discussed in [5–8].

To reduce packet loss further we propose a new type of parametric cost-based scheduling algorithm in [9], improving performance (in terms of packet loss probability) by up to 22% in comparison with current algorithms for a void filling setting and 7% without void-filling for the considered assumptions. Because WCs are known to contribute significantly to the energy consumption of the switching element [10,11,3], the trade-off between performance (packet loss) and energy consumption was also explicitly examined, resulting in a second type of cost-based algorithms with which energy consumption can be traded off for performance.

In [9], the main aim was to validate the usefulness of a cost-based approach, with results obtained under the assumption of unlimited wavelength conversion capability. Here, we consider the case of a limited number of shared WCs, as it occurs in practical implementations. As shown below, the scarcity of this resource results in substantially different behaviour for the underlying system, and consequently, in different requirements for the involved scheduling algorithms, motivating a dedicated performance analysis.

The structure of this paper is as follows: first the assumptions of our model and general characteristics of scheduling algorithms are explained. In Section 3 the scheduling algorithms, both existing and new, are analysed in detail. Section 4 focuses on the used simulation method. This section can be skipped by the reader who is not interested in this without losing understanding of the performance and energy consumption results which are analysed in Section 5.

2. Background

Below we focus on the assumptions of our model. Next we explain some scheduling algorithms basics. The actual algorithms are explained in more detail in the next section.

2.1. Assumptions

Throughout the paper a continuous-time setting is supposed. Fig. 1 shows the assumed $K \times M$ optical switch configuration. Because the exact future and applications of OPS/OBS are still undecided, we study a general switch configuration which is not limited to a single type of network infrastructure. Packets arrive on K incoming ports, on c different *wavelengths* $\lambda_1, \ldots, \lambda_c$, also called *channels*. Each packet arrives on a certain wavelength and is switched (still on this wavelength) to one of the M output ports according to the packet destination information. In OBS networks this packet destination information is sent in advance on a separate channel whereas in OPS networks this information is attached to the data in the packet header. In both cases each output port thus accepts packets from K ports, on c wavelengths. The output port is connected to a single fibre with the same c wavelengths.

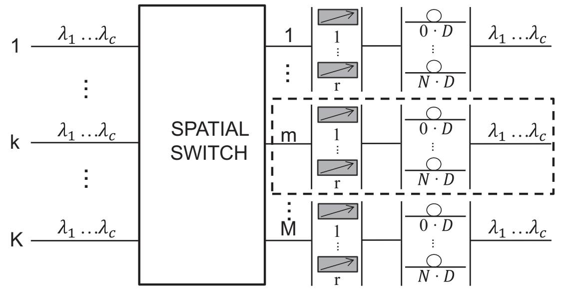

Fig. 1. The modelled output port (in dashed-line box) as part of a switch.

We assume at each of the M output ports the joint packet arrival process is a Poisson process with the wavelength w of each arriving packet randomly and uniformly distributed among the c wavelengths. A Poisson arrival process on each wavelength at the K input ports combined with a non-blocking switch architecture is an example of a set-up that results in this packet arrival process at the output ports.

In this paper an arbitrary single output port is thus analysed, marked by the dashed-line box in Fig. 1. At the output port, there are r WCs to change the wavelength w of an arriving packet at the output port if demanded so by the scheduling algorithm. WCs can convert any of the c incoming wavelengths to all other wavelengths of the set of c wavelengths. This set-up of the WCs corresponds to the shared-per-output-fibre case in [12], but differs from the configuration in [9], in which unlimited wavelength conversion is assumed.

Each output port (in Fig. 1) has an optical buffer in which $N+1$ FDLs are available to schedule incoming packets corresponding to the architecture in [13] named “dedicated FDL buffers per fibre”. The lengths of the FDLs are consecutive multiples of a basic value D called the granularity. This is called a degenerate delay buffer [14], in which incoming packets sent through the j-th ($j = 0 \ldots N$) delay line encounter a delay of $j \cdot D$. The length of arriving packets, B, is assumed exponentially distributed with an average of $E[B]$ time units. With the assumption of a Poisson process for the arrival process at the output port, the inter-arrival T time is thus exponentially distributed with an average $E[T]$. Given the nature of the Poisson process and the random and uniform distribution of the wavelength w among the c possibilities the inter-arrival times on each wavelength are also exponentially distributed but with an average of $c \cdot E[T]$. Related, the overall normalized incoming traffic load at the output port is given by $\rho = E[B]/(c \cdot E[T])$.

2.2. Scheduling algorithm basics

At the output port under study, scheduling is done upon arrival of each subsequent packet. Scheduling amounts to the assignment of two variables (i and j) to the given packet,