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Packet loss analysis of shared-per-wavelength multi-fiber all-optical switch with parallel scheduling

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ABSTRACT

This paper discusses a multi-fiber all-optical switch which shares wavelength converters for contention resolution. The proposed switch architecture employs fixed-input/tunable-output wavelength converters (expected to be less complex than tunable-input/tunable-output ones). The space switching matrix is modular and simple with respect to switching architectures with different wavelength converters sharing schemes (i.e. shared-per-node architecture). A parallel scheduling algorithm is defined to control optical packet forwarding in a synchronous scenario as well as an analytical model to evaluate packet loss performance. The analytical model is validated against simulation and previous analysis and the results obtained show good accuracy in most cases of interest for optical switch design.

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1. Introduction

Contention resolution is one of the critical aspects in any optical packet switched (OPS) network [1,2]. In addition to conventional time and space domains, in optical packet switches contention can also be solved by exploiting the wavelength domain [3]. The basic contention resolution principle provides that when two or more packets need the same forwarding resource, one is forwarded without conversion and if enough wavelengths on the destination output interface are available then the others are converted to a different wavelength.

The application of tunable-input/tunable-output wavelength converters (TTWCs), with full or limited conversion range capability, to switch packets in the wavelength domain has been widely studied in the literature [3]. Full range TTWCs (FR-TTWCs) can be considered as a general approach. TTWC can convert any wavelength on input to anyone else on output, so they represent in principle a very flexible way to solve contention. The drawback of FR-TTWCs is that they are very complex and expensive components. Experimental results show that performance of TTWCs depends on the combination of input and output wavelengths [4]. For a given input wavelength, translations to far output wavelengths result in a significantly degraded output signal. A realistic all-optical wavelength converter may only allow for the translation of any given input wavelength to a limited-range of near output wavelengths. An ideal FR-TTWC can be realized by cascading a given number of limited-range TTWCs (LR-TTWCs) [5]. This makes the cost of FR-TTWCs very high.

Switch architectures that limit the employment of these converters by sharing them among input/output interfaces have been proposed [6]. A typical solution is the shared-per-node (SPN) scheme where a pool of FR-TTWCs serve all the input channels. It has been demonstrated that such architecture can provide the same performance as the fully equipped wavelength conversion case with a limited number of FR-TTWCs, thus leading to some cost savings [6]. The sharing of TTWCs typically requires some additional space switching capability to allow packets that need conversion to access the wavelength converter pool and then to reach the proper output fiber [6].

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Further cost saving solutions, which reduce the conversion range of TTWCs, have been studied in the past. The first idea was to exploit LR-TTWCs instead of FR-TTWCs, and it was demonstrated that a switch equipped with an adequate number of LR-TTWCs and an appropriate conversion range can achieve the same performance as a switch equipped with FR-TTWCs [5].

As an alternative, the space domain can be exploited to solve contention. In this case each of the N Input Interfaces (IIs)/Output Interfaces (OIs) is equipped with a bundle of F fibers, for a total amount of NF input/output fibers (IF/OFs) in the switch, with M wavelengths each. This solution is called a multi-fiber optical packet switch, [7–9] and allows you to reduce both the number and the conversion range of the TTWCs. In the multi-fiber switch up to F packets carried by the same wavelength may be sent at the same time on the same OI without conversion, saving the number of shared TTWCs with respect to the mono-fiber case (a particular case with $F = 1$). In addition, the multi-fiber switch reduces the number of wavelengths needed on each fiber to support a given number of channels per interface, so that the employed TTWCs operate on a narrower bandwidth with respect to the mono-fiber solution. For this reason, any such full range converters have a smaller range.

In this paper a new strategy to share wavelength converters is proposed, and called shared-per-wavelength (SPW). The idea is that each wavelength has a dedicated pool of shared converters. Each converter in a pool has the same input wavelength, so fixed-input/tunable-output wavelength converters (FTWCs) instead of TTWCs can be employed. FTWCs are expected to be less costly than TTWCs. In this paper FR-FTWCs are considered and they are simply referred as tunable wavelength converters (TWCs). An architecture relying on this kind of converters is presented in [10,11] together with a proper scheduling algorithm. The SPW concept is applied jointly with the multi-fiber concept, so a switch equipped with a limited number of simple FTWC with a reduced tuning range is obtained.

A proper scheduling algorithm (SA) manages packet forwarding and assigns switching resources on a time slot basis. The proposed SA is an extension of the one proposed for the multi-fiber shared-per-node switch in [8]. To reduce the computational complexity, a parallelized organization of the scheduling algorithm is proposed.

Packet loss probability is obtained by an analytical model within a synchronous context for any fixed size optical packets. It is compared with results coming from a previous analysis approach proposed in [12] and with simulation results, showing some improvements in model accuracy.

The paper is organized as follows. Section 2 presents the proposed multi-fiber SPW switch. Section 3 describes the parallel SA for the proposed switch. Section 4 illustrates the analytical model to evaluate the packet loss of mono-fiber ($F = 1$) and multi-fiber ($F > 1$) SPW architectures. Section 5 shows the validation of the model by comparing analytical and simulation results. Section 6 proposes a parametric approach for switch cost estimation. Finally, Section 7 concludes the paper.

2. Multi-fiber shared-per-wavelength switch

The SPW concept as applied to the multi-fiber switch and the resulting architecture is called MF-SPW and is shown in Fig. 1. The diagram details where there are N II/OIs and F fibers per interface carrying M wavelengths each. Please note each wavelength has its own pool of dedicated TWCs. In this way, r_w TWCs are shared by packets coming on the same wavelength. The total number of converters in the switch is Mr_w. The large strictly non-blocking space switching matrix needed in the SPN architecture [6] can

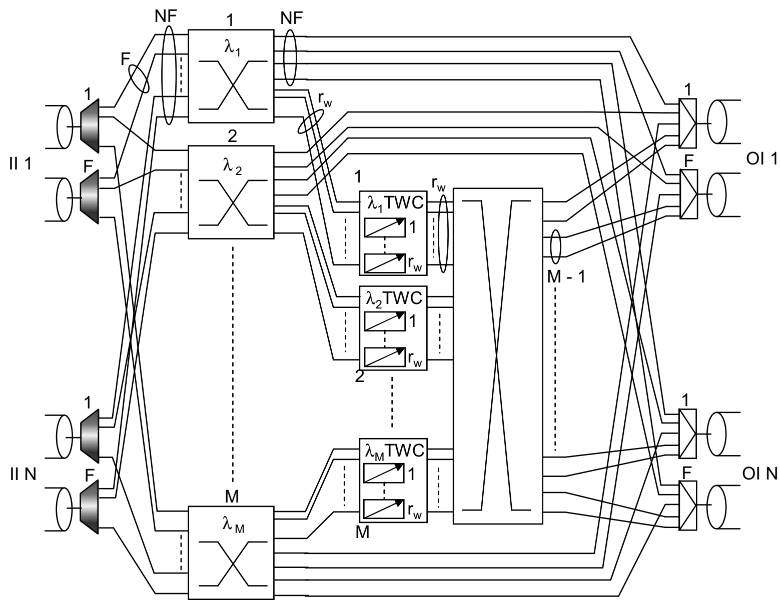

Fig. 1. Multi-fiber shared-per-wavelength (MF–SPW) architecture.

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