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An Optical Packet Switch employing Shared Tunable Parametric Wavelength Converters

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Abstract: The analysis of a shared-per-node OPS switch employing parametric wavelength converters (SPN-PWC) is reported. The results demonstrate a 38-63% reduction in the number of converters when SPN-PWC is compared with SPN employing single-channel wavelength converters.

Keywords: Parametric wavelength conversion, Optical Packet Switching, Contention Resolution

1. Introduction

One of the fundamental problems in optical packet-switched networks is contention resolution. Several methods of resolving contention have been proposed, such as the use of fiber delay-lines (FDL), deflection routing and wavelength conversion which exploit the time, space and wavelength domain, respectively. Although these methods can be combined, it is generally accepted that wavelength conversion is the preferred method for contention resolution [1].

For all-optical wavelength converters (WC), the key design criteria that can be identified are: wide wavelength conversion range, multi-wavelength conversion capability and signal transparency. To date, only parametric wavelength converters (PWC) based on four-wave-mixing (FWM) and difference frequency generating (DFG) offer these capabilities [2]. Multi-channel wavelength conversion based on single-pump FWM in SOAs [1] and in fiber [3] have been experimentally demonstrated. Recently, multi-channel wavelength conversion using DFG was demonstrated using a quasi-phase-matched $LiNBO_3$ (QPM-LN) waveguide for 64 and 103 x 10Gb/s channels [4] [5]. DFG provides linear transparent wavelength conversion using $LiNBO_3$ waveguides with extremely low crosstalk over wide wavelength range (~70nm).

Several OPS node architectures have been proposed that support wavelength conversion by dedicating a WC to each wavelength at each input fiber. Such an architecture requires FW converters where F is number of input/output fiber and W is the number of wavelengths [1]. Depending on traffic conditions, it may not be necessary for each optical packet entering the switch to be wavelength converted. In order to reduce the number of devices, it has been proposed that packets requiring wavelength conversion share a pool of single-channel wavelength converters; these can be shared on a per-link (SPL) or per-node (SPN) basis [1]. In this paper, we propose and analyze a shared-per-node OPS architecture with parametric wavelength converters (SPN-PWC). We propose and evaluate heuristic algorithms for the wavelength converter allocation. The results demonstrate a significant reduction in the required number of converters when compared to equivalent architectures utilizing conventional single-channel wavelength converters (CWC).

2. Shared-per-Node Architecture with Parametric Wavelength Converters (SPN-PWC)

Fig.1 shows the proposed architecture with *M* parametric wavelength converters. To maximize the utilization of the converter, x ($x \leq W$) outputs of the switch are aggregated by an x : 1 coupler allowing multiple packets to be admitted and simultaneously converted in the PWC. Therefore, the proposed switch size will follow $(FW + M) \times (FW + xM)$.

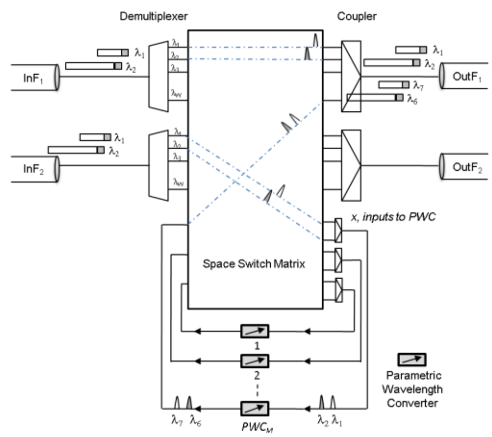

Figure 1: Shared-per-Node OPS switch employing multi-channel wavelength converters.

Fig. 1 illustrates the mode of operation for a scenario in which four packets on λ_1 and λ_2 asynchronously enter the switch from input 1 and 2 and are destined to output fiber 1. The first two packets to arrive on InF_1 are switched directly through without conversion. The first packet to arrive on InF_2 contends with the λ_1 packet from InF_1 and a decision is made to convert this packet to λ_7 within PWC_M by setting $\lambda_p=\lambda_4$, as shown in fig. 2. When a continuous wave (CW) pump, λ_p is applied to the WC waveguide, this results in a conversion by second harmonic generation to $\lambda_p/2$. By the parametric process, arriving packets at λ_s mix with the pump to produce the converted signal at $2\lambda_p - \lambda_s$. Given the choice of λ_p, the number of wavelengths that can be converted is reduced when compared to setting λ_p closer to the grid center. This can severely impact the converter utilization. For this reason, we assume in this paper that, on the pump allocation, central wavelengths will receive priority over the edge wavelengths. Another critical factor for the switch performance is the PWC selection. As shown in Section 3, avoiding the selection of unused PWCs has an important impact on the switch performance. A final consideration that has been examined is the impact of a guard band (GB) around the pump wavelength that is normally necessary due to crosstalk effects [5]. As illustrated in Fig 2, the size of GB affects the number of usable wavelengths as well as the wavelength conversion range.

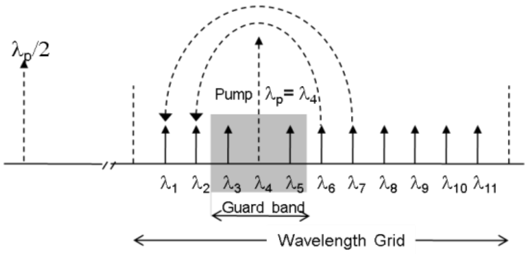

Figure 2: Parametric wavelength conversion process showing the limited range due to pump position.

3. Numerical Results and Analysis

In this paper three algorithms are considered for selecting the PWC: Sequential (*SEQ*), Random (*RAN*) and Used Converter First (UCF). SEQ attempts converters in a fixed order until one capable of converting the packet wavelength to an available channel on the output fiber is found; RAN attempts the PWCs randomly; *UCF* prioritizes PWCs with allocated λ_p over non-used converters.

We simulated an asynchronous OPS switch with F = 4 input/output fibers, W = 80 wavelengths per fiber and offered load per wavelength ρ=0.6. The packet inter-arrival time and packet size are independent and exponentially distributed, with each arriving packet having the same probability to be sent to any output fiber. In fig.4, the packet blocking probability is obtained for a given number of wavelength converters when x = 2, 4 and 8, *SEQ* PWC allocation algorithm is used and no guard band is assumed. Notice that, to achieve the same performance as full wavelength conversion (FWC) switch (where FW = 320 CWCs), SPN-CWC requires 50% fewer conventional single-channel WCs. The proposed SPN-PWC is shown to substantially reduce the overall number of converter devices required. For example, when x = 2, the number of PWCs required to achieve the same performance as FWC is 100, a 38% reduction in the number of converters when compared to SPN-CWC. As x is increased to 4 and 8, it is observed that the required number of parametric converters is 70 and 60, which represents reductions of 56% and 63%, respectively, compared to SPN-CWC. As x tends towards W = 80, which would provide the lowest possible blocking probability of the switch, the savings that can be achieved saturates at a value of 50 PWCs. Therefore, in the analyzed scenario, x = 8 seems to provide a good compromise for the number of inputs to the PWC.

Fig 5 analyses the switch performance when x = 8 is used, GB = 4, 8 and 16 channels are considered around the pump wavelength and the cited PWC selecting algorithms are assumed. It is interesting to note that, for GB = 16, which implies that the maximum number of available channels when the pump is in the center of the wavelength grid is 64 (rather than 80), the blocking probability of the switch does not reach the achievable FWC blocking probability. Fig. 5 also highlights the importance of a proper PWC selection on the required number of PWCs. With respect to *RAN, SEQ* and *UCF* allows dimensioning values for the PWCs to be low. The latter two provide better performance since unused PWCs (where one has the freedom to set the pump in any position) are left for future stringent situations. Clearly, the choice of the main switch design parameters determines the overall switch performance, but it is evident that, regardless of the PWC selection algorithm, the proposed architecture always requires fewer wavelength converters when compared to architectures with CWCs.

4. Conclusion

The performance of an OPS shared-per-node architecture employing parametric wavelength converters is verified through numerical simulations with respect to various design parameters including different PWC selection algorithms. The results demonstrate significant reductions in the number of converters when compared with equivalent architectures employing single-channel wavelength converters.

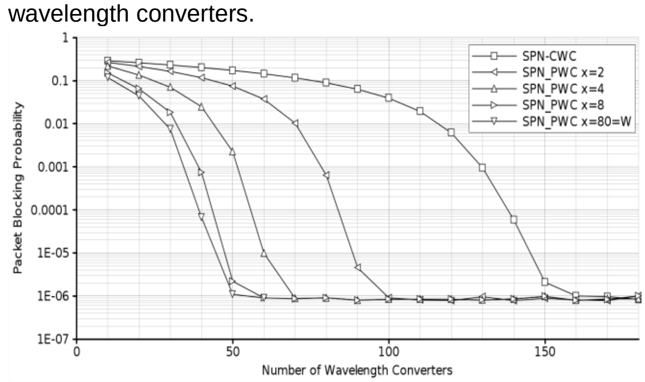

Figure 4 : Packet blocking probability as a function of the number of converters (w.r.t to FWC and SPN-CWC) x=2,4 and 8, F=4, W=80 and ρ=0.6

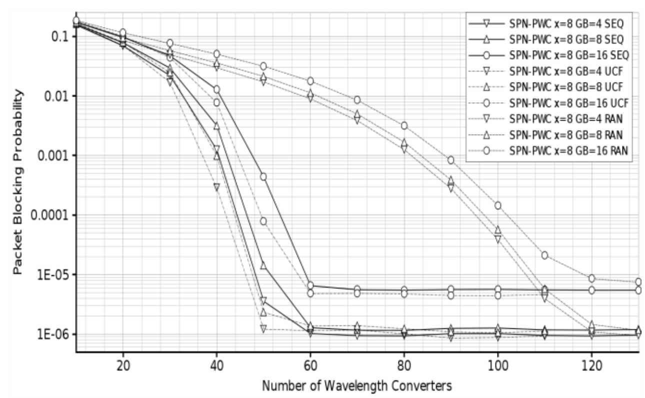

Figure 5 : Packet blocking probability for SPN-PWC (w.r.t to FWC) with different *GB* and PWC selection algorithms (x=8 F=4, W=80 and ρ=0.6)

5. Acknowledgment

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