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Median-pump wavelength assignment scheme for optical networks with parametric wavelength conversion

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ABSTRACT

This paper proposes a wavelength assignment scheme for optical networks with parametric wavelength conversion to minimize the number of wavelength converters when the number of wavelengths is given. Wavelength conversion is needed to reduce the number of wavelengths required in the network, since the number of wavelengths is limited. A parametric wavelength converter (PWC) can be used to reduce the number of wavelength converters because of its multiple wavelengths conversion function. PWC uses the pump wavelength to define original and converted wavelengths. The setting of the pump wavelength affects the converted wavelengths. Thus, the number of transmission wavelengths depends on the position of the pump wavelength. The proposed scheme is a heuristic scheme that considers the position of pump wavelength. An output wavelength that sets the pump wavelength near to the middle of the transmission wavelength band is selected. The proposed scheme designs each PWC to maximize the number of wavelength conversions supported. Numerical results with our examined networks indicate up to 37% reduction in the total number of converters required, compared to a scheme that the position of pump wavelength is not considered. Moreover, the reduction is 42% reduction compared to an optical network with single channel wavelength converters.

1. Introduction

Wavelength assignment in optical networks is needed for data transmission. A lightpath is a path taken by an optical signal from its source to its destination through intermediate links. In each lightpath, a wavelength is continuously assigned from the source to the destination if the wavelength is available at the intermediate links. This requires the network to have a large number of wavelengths. However, the number of wavelengths available for use is limited.

Wavelength conversion is used to reduce the number of wavelengths required in the network [1–4]. With wavelength conversion, the wavelength of a signal is converted to another (available) wavelength at some nodes on the lightpath. Therefore, the number of wavelengths is reduced. This creates a trade-off between the number of wavelengths and wavelength converters [3]. If the number of wavelength converters is large enough, the number of wavelengths can be minimized. One of the most popular wavelength converters is the tunable wavelength converter (TWC) [5,6]. TWC is able to convert the original wavelength into a target wavelength. However, conversion capability is not efficient since each conventional TWC can process only one wavelength at a time.

The parametric wavelength converter (PWC) [7–10] is an alternative because it can convert multiple wavelengths, multi-channels, simultaneously. To define both the original wavelength, λ_w, which requires conversion, and the new wavelength, $\lambda_{w'}$, continuous pump wavelength, λ_p, is set to $\lambda_p = (\lambda_w + \lambda_{w'})/2$. Therefore, the selection

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of λ_p defines the conversion pairs of λ_w and $\lambda_{w'}$. Note that the same PWC supports reversion conversion. For example, if λ_p is set to convert λ_a to/from λ_b, where λ_a and λ_b are transmission wavelengths, then λ_a can be selected to be the original wavelength and λ_b can be selected to be the converted wavelength or vice versa, but not at the same time of course.

We want to assign wavelengths to particular lightpaths in the optical network in which PWCs are employed, while minimizing the number of wavelength converters. The optimization problem of wavelength assignment to lightpaths and pump wavelength assignment for PWCs can be formulated as an integer linear programming. However, it is an NP-complete problem. It is difficult to solve it in a practical time for large networks. Our solution is a heuristic that assigns wavelengths while reducing the number of wavelength converters; the condition is that all traffic demands and routes of lightpaths are given as SNDlib [16].

A heuristic algorithm for wavelength assignment is incremental assignment. Requested lightpaths are given. Each lightpath is indexed to express the assignment order, which is determined, for example, randomly, or in decreasing order of path lengths. A wavelength is assigned to each lightpath starting from the lowest index to the highest index, one by one. Once a wavelength is assigned, it is fixed. Already assigned wavelengths make it harder to assign wavelengths to the remaining lightpaths. The process is finished when the wavelength assignment of the lightpath with the highest index is completed. The first-fit assignment scheme is based on incremental assignment [11,12]. This scheme was, in fact, adopted for an optical cross connect (OXC) with TWCs. Transmission wavelengths are generally indexed in a sequential manner [13,14]. An available wavelength with the lowest index is selected to be converted from the wavelength of a request. There is a problem when the first-fit assignment scheme is adopted for the OXC with PWCs; the presence of gaps between consecutively indexed wavelengths. This degrades the utilization of converters in terms of their multi-channel conversion capability. With the first-fit assignment scheme, the conversion pairs often tend to be consecutive indices.

The median flip-flop indexing based first-fit wavelength assignment (MFF) scheme [15] reduces the number of converters in the optical network with PWCs when compared to that with TWCs. In this scheme, the consecutively indexed wavelengths are chosen alternatively from the left and right halves obtained by dividing the transmission band into two approximately equivalent parts. A simulation showed that the number of converters, using PWCs, could be reduced to 57% of that with the first-fit with sequential indexing approach, compared to using TWCs. However, this scheme considers only the available output wavelengths. The set of pump wavelengths is not considered. Thus, the utilization of the converters in terms of multi-channel conversion capability may be achieved for only one PWC in each switch. It may not be achieved in the other PWCs.

This paper proposes a wavelength assignment scheme for an optical network with PWCs; it considers the position of the pump wavelength. This scheme is called the median-pump wavelength assignment (MPA) scheme. Transmission wavelengths are sequentially indexed. A pump wavelength is selected so as to convert an original wavelength to an available output wavelength that makes the pump wavelength occupy the middle of the transmission wavelength band. If the PWC is not able to satisfy a request, a new PWC is needed. The process of pump wavelength selection is repeated until wavelengths for every request are assigned. It has been shown in [9] that setting pump wavelengths near the middle of the transmission wavelength band yields more conversion pairs and a greater variety of conversion patterns. Fewer converters are needed if more conversion pairs are supported. In the proposed MPA scheme, the number of converters is effectively reduced, while it has the same time complexity of the algorithm as that of the MFF scheme and uses a simple technique by considering the position of the pump wavelength instead of an output wavelength. We examine the performance of the MPA scheme in several conditions and confirm that the MPA scheme outperforms the MFF scheme in the wide-range conditions. Simulation results show that the MPA scheme decreases the number of PWCs by up to 37% compared to the MFF scheme in the network examined. The maximum reduction is 42% compared to the first-fit assignment scheme.

2. Optical cross connect with parametric wavelength converters

An OXC with PWCs consists of two parts, a switch fabric and a set of PWCs, as shown in Fig. 1. The switch fabric consists of N input and output fibers. Each fiber carries W different wavelengths. w is the transmission wavelength index, where $1 \le w \le W$. The multiplexed wavelengths from an input fiber are demultiplexed into individual wavelengths. The individual wavelengths are sent to input

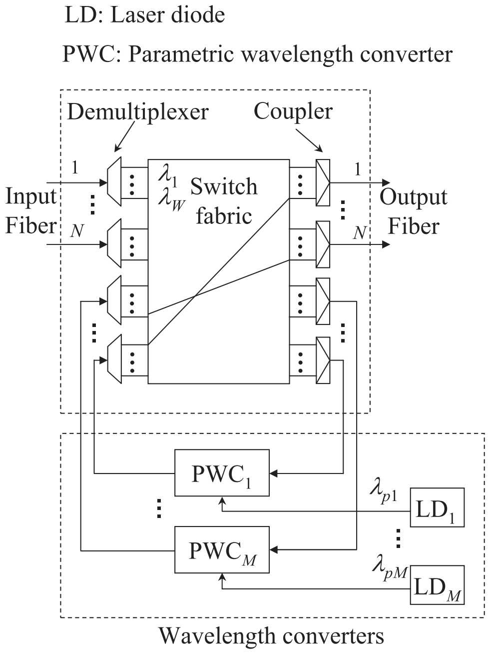

Fig. 1. Switch with PWCs.