

Performance analysis of limited number of wavelength converters by share per node in optical switching network

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Abstract

In this paper, we present studies of an optical switching (OS) node utilizing a limited number of WCs (wavelength converters) in order to reduce the implementation cost of an OS node. The study stems from practical observation that WCs are expensive. Consequently, each output wavelength may not necessarily have its own WC and has to share a limited pool of WCs with other output wavelengths. In order to improve the utilization of the limited number of WCs, a share per node (SPN) method is proposed for the OBS node. Subsequently, a multi-dimensional Markov chain model of SPN is presented to evaluate its performance. To reduce the complexity of the multi-dimension Markov analysis, we propose a suite of methods, called randomized states (RS) multi-plane Markov chain analysis, followed by self-constrained iteration (SCI) and eventually ending with the sliding window (SW) update method, to solve for the solution. Numerical results are presented to verify the accuracy of the analytical model. With SPN, about 50% and 80% of WCs can be saved in high load and low load scenarios respectively.

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1. Introduction

Many promising optical switching (OS) networks, e.g. OBS (optical burst switching) [1], OPS (optical packet switched) [2], wavelength routed [3] networks, utilizes optical switches to switch traffic through a node. Optical switches use wavelength converters

rather than OEO (optical-electronic-optical) elements to achieve higher degree of statistical wavelength multiplexing performance. Consequently, a bufferless, all-optical switching path can be achieved end to end.

In OS networks, it is crucial to exploit bandwidth efficiently; therefore, contention resolution methods are very important for achieving low drop probability. There are normally three areas where contention resolution methods are employed. Firstly, in the time domain using FDLs (fiber delay lines); when

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a new optical data cannot find a suitable output wavelength, the optical data will be channeled into a FDL to delay the data for some time until at least one wavelength is available. This method is used mainly in OBS and OPS. (In OCS, i.e., optical circuit switching, the connection time is often too long for any conventional FDL to provide useful delay values.) Secondly, in the space domain using deflection routing, i.e., when a new data cannot find a suitable output wavelength, the data will be transmitted via a secondary route to its destination. Thirdly, in the wavelength domain; when a fiber contains more than one wavelength, the optical data may be converted to an available wavelength via a wavelength converter. While it is possible that one can also combine any of these three contention resolution techniques to further the performance, the focus of this paper is on the technique of wavelength conversion for contention resolution. Hence, in this paper, we do not consider the use of FDL (i.e., the optical data cannot be delayed), or the use of deflection routing (i.e., it is not possible for an optical data to be deflected to an alternative output fiber if the intended output fiber do not have an available output wavelength).

Currently, there are two architectures of deploying wavelength converters within an OS node. The architecture often assumed in the literature is full wavelength conversion (FWC). The lesser known architecture is non-full wavelength conversion (NFWC). FWC provides conversion capability from any input wavelength range to any output wavelength and every wavelength has its own dedicated wavelength converter (WC is also known as full-range tunable wavelength converter in certain literature). Hence, for the case of FWC node, it is not possible to have any contention issues with the use of a WC since every wavelength has its own private WC. However, FWC architecture requires the use of many WCs (one each for each wavelength), hence it has a high implementation cost [4,7]. It is likely that the number of WCs is less than the number of output wavelengths in the system. This leads to a WC contention problem that needs to be addressed. This paper thus presents analytical solutions to addressing the WC contention problem and answers an important question of whether it is possible to use limited number of wavelength converters to achieve similar performances to a system with a full number of WCs.

When limited WCs are used, some form of sharing policy must be implemented. In this case, a WC

is not dedicated to a particular wavelength [3,4], but instead, all WCs are placed in a common pool and shared amongst the wavelengths. The sharing mode can be share per fiber (SPF), where every output fiber has their own pool of WCs only for use by wavelengths belonging to that output fiber. Alternatively, the sharing mode can be share per node (SPN), where all WCs in the optical node is pooled together for use by any output wavelength belonging to any output fiber in the node. In this paper, the former will be referred to as WC-SPF and the latter as WC-SPN.

In a WR network, because the lightpath is established first before data transmission and because of the link load correlation (LLC) [14] factor, most researchers study the WC-placement [15] and WC-allocation [16] problems. The focus of these studies is on the network performance.

In OPS and OBS, if NFWC is used, research studies are often focused on switching node performance. A related work on limited WCs is found in Eramo [4,5]. Eramo proposed a mathematical method (not based on Markov chain analysis) to evaluate the number of WCs required in a *synchronous slotted* optical packet network under both WC-SPF and WC-SPN mode. His method is also applicable in a synchronous slotted OBS system. Later, *theoretical* models determining the minimum number of WCs for WC-SPF [6] has also been contributed. However, there is currently little or no theoretical analysis for the performance evaluation of limited WCs in the case of *asynchronous* traffic in WC-SPN node. In this paper, the case of asynchronous Poisson traffic with variable optical data length is considered.

For WC-SPN model, an exact multi-dimensional Markov chain analysis is presented firstly in this paper. However the complexity of the multi-dimensional Markov chain analysis is intractable. Therefore, a suite of methods, called randomized states (RS), self-constrained iteration (SCI) and sliding window (SW) iterative update, is presented. These methods reduce the multi-dimensional Markov chain to a more tractable multi-plane Markov chain where each plane is a two-dimensional Markov chain.

The traffic model considered in this paper will be asynchronous Poisson traffic arrivals with optical data length of some generic distribution. We consider Poisson arrivals mainly for its amenability to bring forth further theoretical analysis/conclusions so that certain trends in the saving of wavelength

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