Limited Range Wavelength Converter Sharing in WDM Networks

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Abstract

In this paper, we propose multistage wavelength conversion by sharing limited range wavelength converters in wavelength division multiplexed (WDM) all-optical packet switching networks. By using multistage wavelength conversion and converter sharing technology expensive resources can be maximally utilized. Our interest is to investigate how converters of lower capability in terms of conversion limit can be effectively utilized for performance improvement rather than using converters of full conversion capability. We summarize the benefits of multistage wavelength conversion and wavelength converter sharing using limited range wavelength converters and demonstrate some outlines for the choice of conversion limit, number of converters, and the number of stages of conversion by simulation. Simulation results dictate that, with wavelength converters fewer than the number of wavelength channels to or from the optical cross-connect, significant improvement in performance in terms of packet loss probability before saturation can be achieved with multistage conversion at some lower limits of conversion.

1. Introduction

All-optical networks using WDM technology stand out to be the solution for the multi-Terabits/s bandwidth demand on the next generation network. It leverages its capacity on the development of all-optical packet switches working in time and/or wavelength domain [1]. Either as packet switched or circuit switched, all-optical network nodes require some degree of wavelength conversion to improve the network efficiency [2]. The limited wavelength conversion capable optical cross-connects provide flexible upgrading of the network as per the performance requirement and the budgetary support [3]. Since the wavelength converters are expensive, so their use is expected to remain limited by their economy. Limited conversion capability is desired for network performance improvement and for increasing network throughput. Moreover, shift towards shared architectures of wavelength converters of limited range conversion capability, from dedicated ones is gaining momentum as better economy and performance are expected from different sharing architectures. Therefore, the converters with limited conversion capability, and the sharing of the wavelength converters utilizing multistage conversion in the network nodes are important.

Jennifer Yates et al. in [4], considered all-optical wavelength translators based on four-wave mixing in semiconductor optical amplifiers to determine the blocking performance of two-hop and multi-hop paths for different topologies. They depicted that significant improvement in the network performance is obtainable when limited range wavelength translators with as little as one quarter of the full range is introduced. The analysis was done with focus on circuit switching in WDM optical network. They showed that networks employing limited range wavelength converters compare favorably with those utilizing converters of full range capability under certain conditions. Packet loss in a bufferless optical WDM switch employing shared tunable optical wavelength converters (TOWC) has been studied by V. Eramo et al. in [5]. They considered structure of the bufferless WDM optical switch architecture equipped with wavelength converters on shared-per-node basis. Kuo Chun Li, and Victor O. K. Li proposed wavelength-convertible routing network using wavelength converters in every switching node and showed that the efficiency of wavelength usage should be better thereby. Converter sharing was also demonstrated to have impact on the efficiency improvement in their work in [6]. Tack Yoong Chai et al. studied converter sharing architectures on share-per link and share-per-node bases extensively for implementing optical cross-connects (OXC) of different degree of complexity, expandability, upgrade ability, and sharing employing space switch matrices, delivery and coupling switches, various combinations of couplers and filters by conducting study on blocking performance at various values of traffic intensities [7].

The range of wavelength conversion can be increased if the wavelength after first stage of conversion is looped back to feed the converters array to attempt next stage conversion in cases when first stages are not enough. The probability of packet loss is expected to improve thereby. To the best of our knowledge multistage conversion by looping back the output wavelength from the converter to input to the converters pool is not reported yet. In our work we propose multistage wavelength conversion by sharing limited range wavelength converters in wavelength division multiplexed (WDM) packet switching for all-optical networks.

This paper is organized as follows. Section 2 contains aspects of WDM packet switching in all-optical node and limited range wavelength conversion, in section 3, characteristics of limited range wavelength converters have been introduced, in section 4, multistage conversion and the control of optical packet switching are discussed, section 5 illustrates the numerical results of simulation, and in section 6, we make some comments to conclude our work and give an idea of our future study.

2. WDM packet switching node architecture using limited range wavelength conversion

Optical packet switching is enormously advantageous over electronic packet switching as the former is free of large number of physical pin out interconnections, and electromagnetic interference. All-optical packet switches can work both in time and/or wavelength domain. In TDM schemes optical cross-connects require high speed optical logic gates. In WDM packet switching schemes aforesaid high speed optical gates requirement is overcome by utilizing the ability of individual wavelength channel to carry information as incoming or outgoing port in the optical cross-connect (OXC). Information on any wavelength channel is broadcast by optical passive splitters to same wavelength channels on the outgoing fibers and only filter on the channel in the fiber to the destination of the information receives the light signal. If the required output wavelength channel is busy the information carrying wavelength is received by an available wavelength converter in the converters pool and the wavelength is converted to another one and checked whether this is free on the same outgoing fiber or not. Upon failure the wavelength is looped back to the input of the converters pool for next conversion.

By means of wavelength conversion packet can be transmitted on a different wavelength channel of the designated output fiber. WDM not only provides increased transmission capacity, but also allows for highly effective contention resolution through wavelength conversion [8]. We consider Figure 1 which shows the optical switch architecture equipped with wavelength converters as shown in [5]. The wavelength converters used here are tunable optical wavelength converters (TOWC). We assume that there are k wavelength converters which are capable of limited range conversion. For facilitating the sharing and multistage conversions, the required connectivity and looping back of the optical information signal to input to another wavelength converter in the array to achieve wider range of conversion and thereby increasing the probability of success in packet transfer is also assumed to be present in the OXC.

Suppose, there are W number of wavelengths in each fiber. Wavelengths are indexed as i where $(i \in \{1, \cdots, W\})$ and F number of fibers are indexed as j where $(j \in \{1, \cdots, F\})$. Therefore, the number of total input or output wavelengths in the system is $N = W \times F$. The input or output wavelength channel is identified as $\lambda_{i,j}$. If there were dedicated full wavelength converters for all wavelength channels then the cross-connect size would be $N \times N$, that is $(F \times W \times F \times W)$ in terms of optical on-off gates. When the k number of wavelength converters centrally shared by the wavelength channels are introduced in the cross-connect, the complexity of the switch expressed in terms of on-off optical gates is $C = (F + k) \times W \times F + F \times k$, where C is the number optical on-off gates [5]. If the OXC is equipped for multistage wavelength conversion with k number of converters in the array, the OXC complexity will be $(F + k) \times (FW + k)$. The control and working of the total system is explained in section 4. If the number of stages of conversion is m, then the conversion range will vary from 0 to $(2 \times m \times d + 1)$ for conversion limit d. The brief discussion on limited range wavelength conversion follows in section 3.

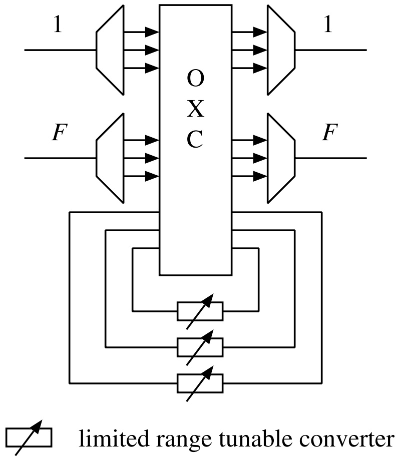

Figure 1. Central sharing architecture. Share-per-node based architecture using multistage wavelength conversion. OD-Optical Demultiplexer, OM-Optical Multiplexer, F-No. of fibers.

3. Characteristics of limited range wavelength conversion

In limited range wavelength conversion if the conversion limit is d, then the conversion range is $(2d+1)$. Wavelength conversion is assumed to be circularly symmetric as described in [4]. Four-wave mixing-based all-optical wavelength converters provide only a limited-range conversion capability. If the range is d then an input wavelength λ_i can only be converted to $\lambda_{max(i-d,1)}$ through $\lambda_{min(i+d,W)}$, where W is the number of wavelengths in the system (indexed 1 through W) [2]. Wavelength conversion is required to improve the efficiency of WDM networks. By increasing the conversion limit d, however we can increase the conversion range and the performance of WDM switch is seen to have been improved by limited range conversion as shown in Figure 2 which depicts the plots of packet loss probability p versus conversion limit d curves.

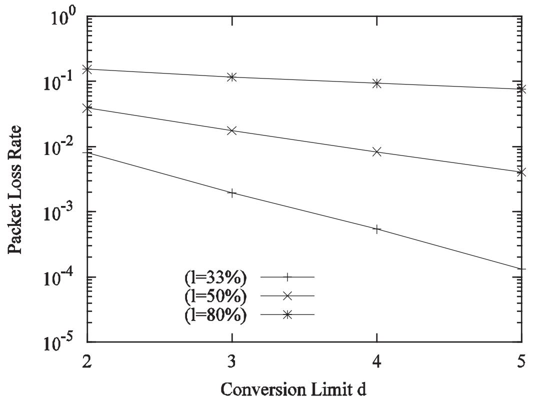

Figure 2. Packet loss probability p versus conversion limits d curves. Cross-connect size is 100 $\times$ 100. F=5, W=20.

4. Multistage wavelength conversion and the control of optical packet switching

We assume a WDM optical cross-connect for optical packet switching with limited range wavelength conversion capability for our work. The cross-connect is equipped with limited range wavelength converters. The node architecture has the converter pool connected on shared-per-node basis, that is central sharing architecture. As for example, five incoming and five outgoing fibers each of 20 wavelengths are supporting the node.

Let the 3rd wavelength channel $\lambda_{3,1}$ from input fiber 1 after de-multiplexing be designated as $\lambda^{in}_{3,1}$. If the information signal on the input wavelength $\lambda^{in}_{3,1}$ is to be routed onto the 5th outgoing fiber, the first attempt is to see if any wavelength conversion is required or not. Upon finding wavelength channel $\lambda^{out}_{3,5}$, the 3rd wavelength channel on 5th outgoing fiber free it is directly routed to $\lambda^{out}_{3,5}$ by the space switch matrix without wavelength conversion. If $\lambda^{out}_{3,5}$ is not free the information packet on $\lambda^{in}_{3,1}$ is routed to the converter array for first stage conversion and checked if in the range of wavelengths $(3 + d) - (3 - d) = 2d$ around reference $\lambda^{out}_{3,5}$ (corresponding to $\lambda^{in}_{3,1}$) any wavelength is free or not. If there is no free wavelength channel in that range the second stage conversion is accomplished and the search range is extended over $2 \times 2d$. Following this approach the control system provides more freedom to the incoming packets to find the outgoing wavelength channel. In Figure 3 the multistage conversion is explained for $d = 1$. Thereby, the packet loss probability is reduced and the cross-connect performance is improved.

Optical signal on each wavelength channel is split up into required number of separate streams of rays by passive optical splitter to feed the wavelength channels on the outgoing fibers, and also the converters input and combined when required by the optical passive combiners. The routes of the split up rays after the splitter are controlled by optical on-off gates. The control system for the WDM cross-connect is electronically operated. The array of TOWCs to form the converter pool and looping back operations of the light signals for multistage conversions can be implemented in some way as shown schematically in Figure 3.

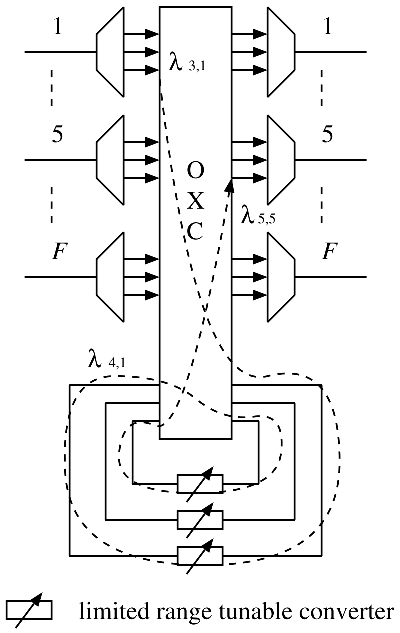

Figure 3. The multistage wavelength conversion for m=2 and d=1.

5. Numerical results

We considered WDM optical packet switching to see the multistage wavelength conversion effect using limited range wavelength converters connected on share-per-node basis for our simulation. Link speed is 10 Gbps, The traffic model is assumed to have packet origination following the same binomial distribution at each channel, and packet length being exponentially distributed with the mean of 500 bytes. Incoming packets on all fibers will be targeted to all the other output fibers uniformly. We considered two node system sizes as 100×100 ($F = 5, W = 20$) and 250×250 ($F = 5, W = 50$). The number of converters k and the number of stages of conversion m for these cross-connect sizes are estimated for 33% ,50%, and 66% traffic load intensities with the conversion limit d as parameter. The packet loss probability results are discussed.

Figure 4 through Figure 11 show the packet loss probability p versus number of converters k curves. Corresponding traffic load intensities l and conversion limits d are shown in the figures. In Figure 4, for $d = 2$, $k = 15$, packet loss probability p saturates around 10^{-2} for $m = 1$ when the traffic intensity is $l = 33\%$. Figure 5 shows that for $d = 2$, the packet loss probability p is improved to 10^{-3} and saturates around that value at $k = 15$ for $l = 33\%$ but with $m = 2$. In Figure 6, when $k = 18$, p saturates around 10^{-4} for $m = 3$ with same conversion limit and traffic intensity. Figure 7 shows that for $d = 2$, the packet loss probability p improves to almost 10^{-5} when the performance saturates around this value at $k = 26$ for $l = 33\%$ and here $m = 4$. Therefore, if the number of stages of conversion is increased through $m = 1$ through $m = 4$ at the limit of conversion as low as $d = 2$, the packet loss performance is improved significantly for comparatively light traffic. This improvement is achievable by increasing the number of converters and through maximization of utilization of the converters by employing multistage conversion. Even if we trade off the performance with the number of converters, yet it is evident from the figures that the performance significantly gains from the introduction of multistage conversion. When $d = 6$, packet loss probability falls from the value for $m = 1$ to that one for $m = 2$, at $l = 33\%$ and then there are minor performance improvement for $m = 3$, and $m = 4$. The conversion limit $d = 10$ shows that the performance is independent of m as seen in Figures 4, 5, 6, and 7. In these figures for $l = 50\%$ packet loss is reduced significantly at $d = 2$, and mildly at $d = 6$, and almost insignificantly at $d = 10$ for $m = 1$, 2, 3 and 4 respectively. Because that $d = 10$ stands for the full conversion case, where $W = 20$.

Figures 8, 9, 10, and 11 are the packet loss performance plots for cross-connect size 250×250. At low conversion limit like, $d = 4$, the achievable better performances are, $p = 10^{-3}$, at $m = 1$, $k \geq 22$ (Figure 8), $p < 10^{-5}$, at $m = 2$, $k \geq 34$ (Figure 9). Increasing d at this traffic load intensity shows almost no gain. At 50% loading, for $d = 4$, p gains slowly with $m = 1$ through 4 and also increasing d to 8 or 12 results in insignificant benefit. At higher traffic intensities like 66%, neither multistage conversion nor the conversion limit shows any substantial performance improvement. The way out to reducing packet loss to some extent in this situation is to increase the number of wavelengths and converters for higher traffic intensities. From the plots it is evident that the multistage wavelength conversion is more useful while the conversion limits and traffic intensities are in the low to medium range values and this happens when the number of converters centrally shared is in the range of approximately 20% to 35% of the total number of wavelength channels in the cross-connects (100 in the cross-connect size of 100 × 100 and 250 in the cross-connect size of 250×250). This is significant saving in cost.

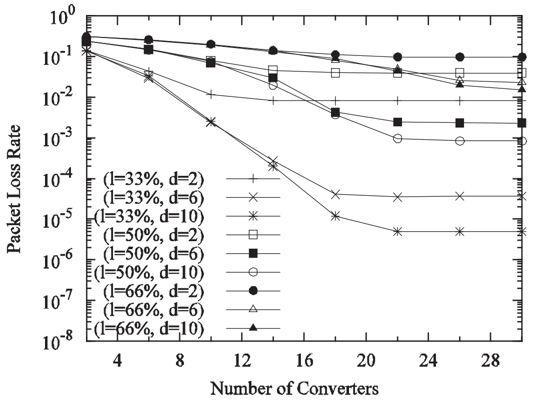

Figure 4. Packet loss probability p versus number of converters k plots. System size is 100 × 100. F=5, W=20, m=1.

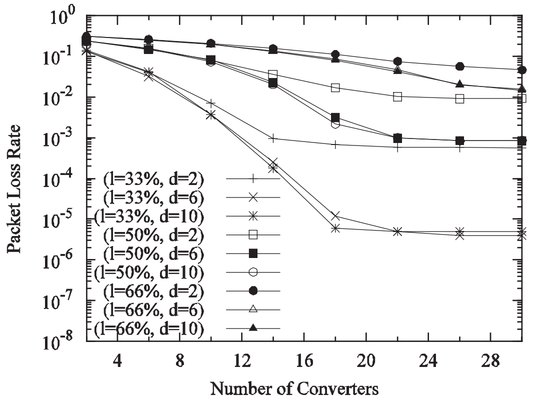

Figure 5. Packet loss probability p versus number of converters k plots. System size is 100 × 100. F=5, W=20, m=2.

6. Conclusions

In this paper, we investigated multistage wavelength conversion using converters array connected on the ba-

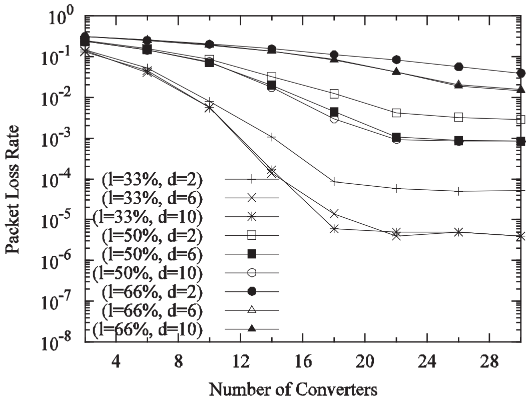

Figure 6. Packet loss probability p versus number of converters k plots. System size is 100 × 100. F=5, W=20, m=3.

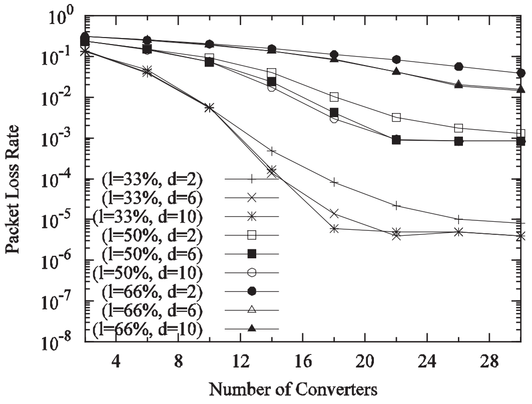

Figure 7. Packet loss probability p versus number of converters k plots. System size is 100 × 100. F=5, W=20, m=4.

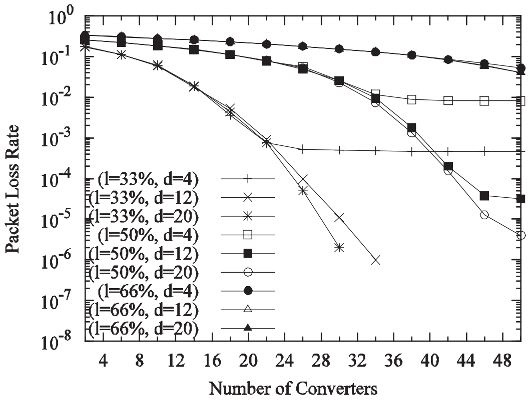

Figure 8. Packet loss probability p versus number of converters k plots. System size is 250 × 250. F=5, W=50, m=1.

sis of share-per-node architecture for wavelength division multiplexed (WDM) nodes using limited range wavelength converters in all-optical networks. We have shown the effective values of wavelength conversion limits and the number of stages of wavelength conversions to meet network performance goals for different node sizes. As the cost of wavelength converters is likely to remain high in near future, our simulation shows the estimates for the important factors like conversion limits, and the number of stages of conversion may support management and investment decisions for a flexible network evolution.

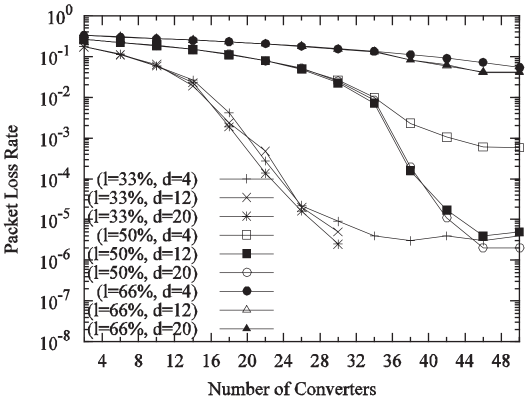

Figure 9. Packet loss probability p versus number of converters k plots. System size is 250 × 250. F=5, W=50, m=2.

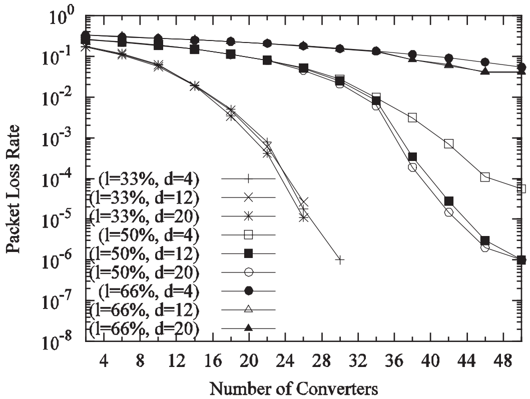

Figure 10. Packet loss probability p versus number of converters k plots. System size is 250 × 250. F=5, W=50, m=3.

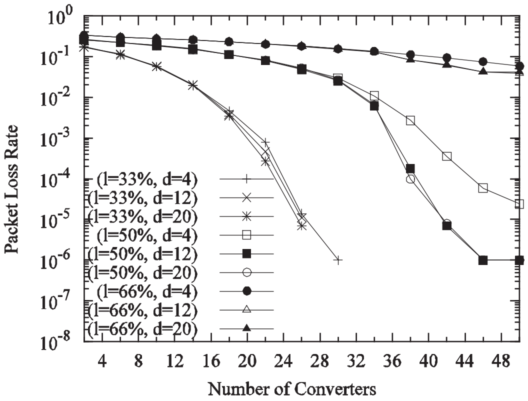

Figure 11. Packet loss probability p versus number of converters k plots. System size is 250 × 250. F=5, W=50, m=4.

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