Optical Network Design Algorithms that Consider Optical Path Add/Drop Ratio Restrictions for OXC Hardware Scale Reduction

F. Naruse, Y. Yamada, H. Hasegawa, K. Sato
Nagoya University, Furo-cho, Chikusa-ku, Nagoya, 464-8603 Japan
{f_naruse, yo_yamad}@echo.nuee.nagoya-u.ac.jp, {hasegawa, sato}@nuee.nagoya-u.ac.jp

Abstract: We develop network design algorithms that consider constraints on the number of added/dropped optical paths at nodes in terms of wavelength and of fiber. The strategy is demonstrated to significantly reduce node hardware scale.

OCIS codes: (060.4251) Networks, assignment and routing algorithms; (060.4510) Optical communications

1. Introduction

The traffic volume is expected to explode in the near future spurred by the introduction of new broadband services. Photonic networks utilizing reconfigurable optical add-drop multiplexers (ROADMs) have been widely adopted in North America and Japan to handle the rapidly increase in Internet traffic. The expected future broadband services, which include optical VPN services and ultra-high definition TV program distribution, will drive the introduction of dynamic optical path operation capability. To develop agile and flexible nodes, Colorless, Directionless and Contentionless (CDC) [1] capabilities are the key; they also allow for the efficient use of costly high-bitrate transponders/receivers. However, perfect realization is very difficult; for example if 10 fibers are input to a node and 96 wavelengths are carried in each fiber, basically 960 x 960 switching capability is required. Several studies have targeted this problem [1-3]. A large space switch can be divided into several smaller ones [1], however the required switch scale is still tremendous. One study [2] proposed to restrict the ratio of added/dropped wavelength paths to each incoming optical fiber set to reduce the switch scale. However, the impact of restricting add/drop ratios on the network was not clarified. It can only be examined after the development of network design algorithms that consider the add/drop ratio restrictions. This omission is rectified here.

In this paper, we introduce two kinds of add/drop ratio restrictions that restrict the ratios on each fiber and on each wavelength. These restrictions are commonly attained with different switch architectures that utilize WSSs or matrix-type switches. In this paper, only WSS-based optical cross-connect architectures are discussed for simplicity. The add/drop ratio restrictions significantly reduce the required number or the degree of WSS. In order to elucidate their impact on networks, we then propose network design algorithms that consider each restriction. Numerical experiments on a 5x5 regular mesh and the COST266 topology reveal that the add/drop ratio can be set at 0.6 to 0.8 while the number of additional fibers needed is negligible. These results verify, for the first time to the best of the authors knowledge, the impact of setting add/drop ratio constraints on the development of optical path networks and the hardware scale reduction in realizing CDC. Here, please note that carriers do not need to recognize the add/drop restriction ratios. It is sufficient that they estimate the necessary number of terminating/originating wavelength paths (demand) at a node and necessary node degree (the estimation may include future node expansion), and then the network design tool automatically determines the necessary switch hardware scale to accommodate the demands while implementing the optimal add/drop ratio restriction.

2. Optical cross-connect node architecture with add/drop ratio restriction

2.1. Add/drop ratio restriction on each fiber

This restriction is defined by the bound ratio, the number of added/dropped optical paths to all paths in each outgoing/incoming fiber. The bound ratio lies in the range (0,1) and is fixed in advance. The maximum number of added/dropped paths for each fiber is the product of the bound ratio and the number of wavelengths in the fiber. An example of the WSS-based node architecture that accommodates this constraint is shown in Fig. 1. The use of this constraint reduces not only the necessary number (or degree) of WSSs placed before the matrix switch to attain CDC, but also the size of matrix switches, so node cost can be significantly reduced. Please note that the hardware portion that realizes CDC represents the major part of the OXC hardware.

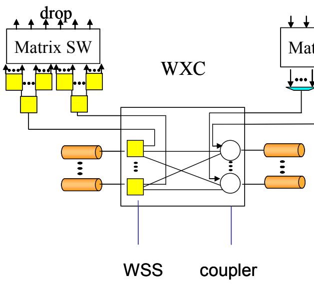


Fig.1 OXC node with add/drop ratio restriction on each fiber

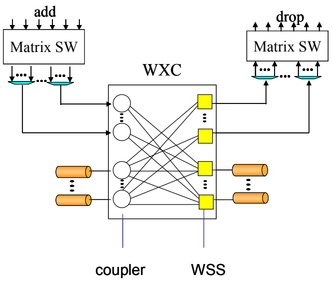


Fig.2 OXC node with add/drop ratio restriction on each wavelength

Fig.3 COST266 pan-European network

2.2. Add/drop ratio restriction on each wavelength

This bound ratio is the number of added/dropped optical paths to all paths for each wavelength index. It lies in the range of (0,1) and is fixed in advance. The maximum number of added/dropped paths for each wavelength is the product of the bound ratio and the number of outgoing/incoming fibers. An example of the WSS-based node architecture that accommodates this constraint is shown in Fig. 2. This constraint also reduces the number and degree of WSSs required in the wavelength cross-connect (WXC) part and the size of the matrix switch that realizes CDC.

3. Proposed RWA algorithms considering each add/drop ratio restriction

The major processes of the proposed RWA algorithms that consider the add/drop restrictions defined in Sec. 2 are briefly summarized as follows.

Step 1. Find a path connection demand whose shortest hop count between source and destination nodes is longest among all demands that are not accommodated yet. Calculate its route candidates (ex. all shortest hop routes or k-shortest paths).

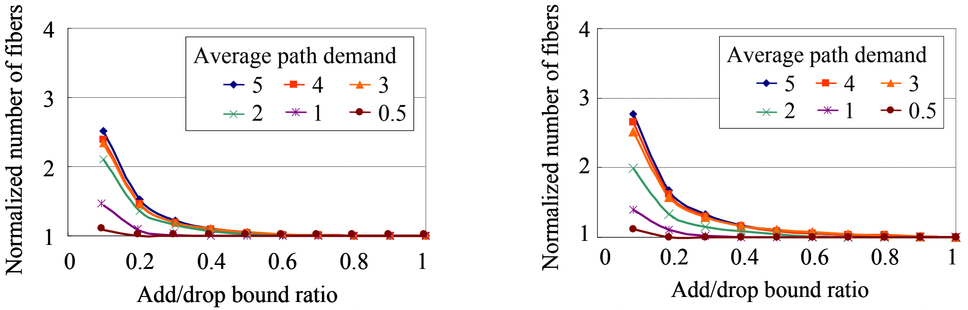
Step 2. For the demand and its route candidate set found in Step 1, find the pair of route and wavelength that minimizes the number of fibers that must be newly added to accommodate the demand. If multiple pairs of routes and wavelengths are possible, select the one with shortest hop count.

Note : If the restriction on each fiber is applied, fibers will be added immediately when the ratio exceeds the bound. If the restriction on each wavelength is applied, the number of fibers necessary to fix the violation is calculated and reserved since we do not need to determine the links to which the fibers are added at this stage (incoming fibers come from several different nodes and there can be different choices of what link the fiber(s) should be added to at this stage). Reserved fibers are utilized if they have already been established for the next route determination.

Step 3. If all path connection demands are accommodated, count up the necessary fibers. Otherwise, go back to Step 1.

4. Numerical Experiments

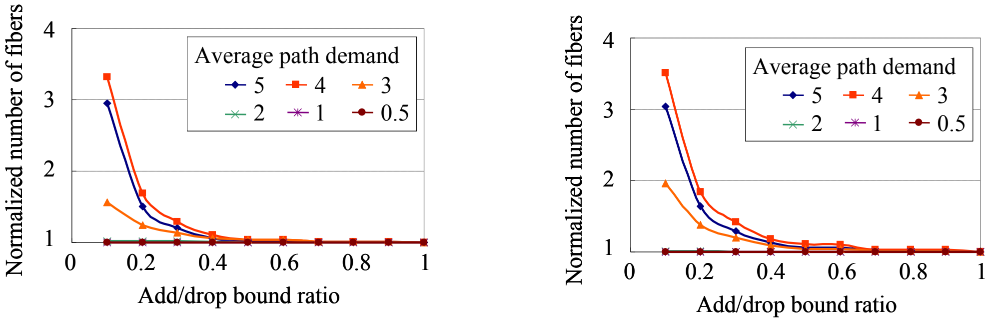
The simulation considered a 5x5 regular mesh network and the COST266 pan-European network, see Fig. 3. Each fiber can accommodate 80 wavelengths. Wavelength path demands were uniformly and randomly distributed where the averaged number of paths between each node pair was set at 0.5, 1, 2, 3, 4, and 5. We evaluated the number of total fibers necessary to accommodate each demand. Twenty different traffic patterns for each demand are tested and the ensemble average was calculated.



(a) 5x5 regular mesh network

(b) COST 266 pan-European Network

Fig.4 Normalized fiber count for each fiber restriction



(a) 5x5 regular mesh network (b) COST 266 pan-European Network

Fig. 5 Normalized fiber count for each wavelength restriction

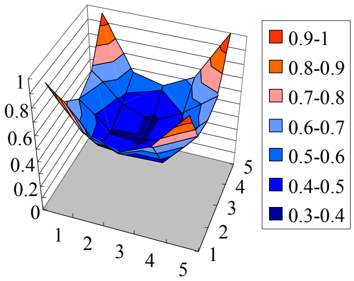


Fig. 6 Drop ratio distribution with no restriction case

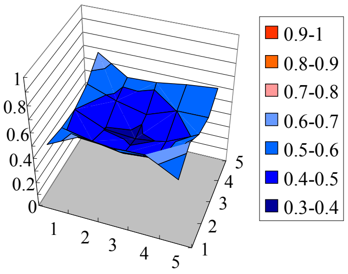


Fig. 7 Drop rate distribution restricted by 0.6

Figure 4 shows the required number of fibers normalized by that required in the no restriction case, subject to the add/drop ratio bound on each fiber. The result for the 5x5 regular mesh network shows that the increment is negligible (< 2-3%) when the add/drop ratio bound is 0.6 while that for COST266 requires the larger bound of 0.8. The difference is due to by the asymmetric nature of the COST266 topology. The fiber count represents WXC input port number, so the add/drop ratio restriction can significantly reduce CDC related hardware, the major cost of an OXC node, with a marginal (< 2-3%) hardware increase for WXC so as to support traffic cross-connection.

Figure 5 shows the required number of fibers normalized by that in the no restriction case subject to the add/drop ratio bound on each wavelength. For both topologies, the numbers of fibers are equivalent (i.e. increment < 2-3%) when the bound is 0.7. For the CDC part matrix switches in Fig. 1 and 2, the number of switch elements is proportional to the square of the number of optical paths to be processed so hardware scale can be halved. Please note that the increment in fiber includes fibers that are empty; they represent the necessary increment of WXC input fiber port number (the empty fibers should not really be set) to satisfy the add/drop ratio constraints.

Figures 6 and 7 show the variations in add/drop ratios defined for each wavelength when the average path demand is set at 3; Figure 6 shows the result for the no restriction case while Figure 7 shows the case for the bound of 0.7. We can verify that the ratio is restricted to less than 0.7 in all network nodes (in Fig. 7).

4. Conclusion

We proposed RWA algorithms that consider constraints on each fiber and on each wavelength. Numerical experiments show that the ratio can be set from 0.6 to 0.8 while the number of additional fibers/ports is kept negligible (< 2-3%). The add/drop ratio restriction can significantly reduce CDC-related hardware, the major hardware portion of an OXC node, with only a marginal (< 2-3%) hardware increase in WXC to support traffic cross-connection.

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5. References

[1] S. L. Woodward, M. D. Feuer, P. Palacharla, X. Wang, I. Kim, D. Bihon, “Intra-Node Contention in a Dynamic, Colorless, Non-Directional ROADM,” Proc. OFC/NFOEC 2010, PDPC8, March 2010.

[2] R. Jensen, A. Lord, N. Parsons, “Colourless, Directionless, Contentionless ROADM Architecture Using Low-Loss Optical Matrix Switches,” Proc. ECOC 2010, Mo.2.D.2, Sept. 2010.

[3] P. Ghelfi, F. Cugini, L. Poti, A. Bogoni, P. Castoldi, R. D. Muro, B. Nayar, “Optical Cross Connects Architecture with per-Node Add&Drop Functionality,” Proc. OFC/NFOEC 2007, NTuC3, March 2007.