Design of Large-Scale OXC for the Next-generation ROADM

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Abstract: Using multiple MEMSes sandwiched between two columns of WSSes, this paper designs a low-loss, nonblocking, and scalable OXC that is suitable for the future SDM optical network with a smaller number of wavelengths per fiber. © 2024 The Author(s)
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1. Introduction

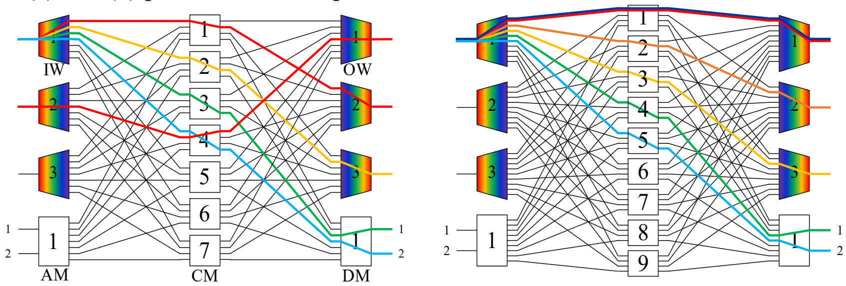
Over the past decades, optical networks continue to evolve to accommodate the rapid growth of Internet traffic. Installing parallel (or multi-core) fibers on each network link, known as spatial division multiplexing (SDM), and doubling the channel spacing of wavelength division multiplexing systems every 3 years is considered an effective way to boost link capacity. This means that the number of fibers per link will grow rapidly, while the number of wavelength channels per fiber will decrease gradually over time.

Designing large-scale optical cross-connects (OXCs) to adapt to the changes of optical networks is currently a challenging topic. The OXC is the key component of reconfigurable optical add/drop multiplexer (ROADM), which is the mainstream technology for optical node. An $N\times N$ traditional OXC is composed of two columns of $2N$ $1\times N$ wavelength selective switches (WSSes) interconnected by a shuffle network. In a ROADM, one part of the ports of the OXC serves as the input/output directions, and the other part serves as add/drop ports. An OXC can establish bypass lightpaths from input directions (or fibers) to output directions (or fibers) in a nonblocking manner, and add/drop local/remote wavelengths to output/input fibers. The number of ports of OXC N is limited to 48 by the dimension of commercial WSSes [1] and is not easy to be enhanced. Classical theory of multi-stage switching network cannot be directly applied to improving the scalability of OXCs, due to ~6dB loss of WSSes [2]. Some new OXC structures [3-5] have been proposed to address this issue, but at the expense of nonblocking property, which will in turn complicate the routing and spectrum assignment in optical networks [5].

To this end, this paper focuses on the design of a low-loss and scalable OXC, which consists of a number of space switches, e.g., micro electro-mechanical system (MEMS), sandwiched between two columns of WSSes. We prove that this type of OXCs is scalable since the dimension of WSSes needed to fulfill nonblocking bypass switching function and colorless-directionless-contentionless (CDC) add/drop function is independent of the number of directions of ROADM. Our simulation also shows that the requirement on the dimension of WSS can be remarkably reduced if we can tolerate a very small blocking rate of lightpath requests.

2. WSS-Space-WSS (WSW) OXC Architecture

As Fig. 1 shows, an $N\times N$ WSW OXC is a symmetric three-stage network, where N is the number of modules in the first (or third) stage. An $N\times N$ WSW OXC includes r $1\times m$ input WSSes (IWes) acting as r input directions of the ROADM, r $m\times 1$ output WSSes (OWes) serving as r output directions of the ROADM, r' $n\times m$ MEMS-based modules, named AM, to add local wavelengths, r' $m\times n$ MEMS-based modules, named DM, to drop remote wavelengths, and m $(r+r')\times(r+r')$ MEMS-based central modules (CMs) in the middle stage, where $N=r+r'$. If $n=W$, r'/r is called add/drop ratio. Each input of an AM and each output of a DM are attached by a Tx and a Rx, respectively. Fig. 1(a) and (b) present two examples of WSW OXCs.



(a) r=3, r'=1, n=2, and W=4 (b) r=3, r'=1, n=2, and W=6

Fig. 1. Nonblocking-and-CDC WSW OXCs.

The WSW OXC has three types of routing constraints. First, the lightpaths from the same IW cannot share a CM if they visit different third-stage modules (OWs or DMs), because the CM is a MEMS and cannot separate different wavelengths. For example, the red, yellow, and green lightpaths from IW 1 in Fig. 1(a) have to employ different CMs because they visit OW 1, OW 2 and DM 1, respectively. Second, the lightpaths that visit the same OW but originate from different first-stage modules (IWs or AMs) cannot share a CM, due to the similar reason.

Third, the lightpaths originating from the same AM or destined for the same DM cannot use the same CM. For instance, the green and cyan lightpaths visit DM 1 in Fig. 1(a) and thus should use distinct CMs.

On the other hand, the lightpaths can share a CM, if they (i) originate from the same IW and go to the same OW, or (ii) start from different first-stage modules and head for different third-stage modules. For example, the red and blue lightpaths in Fig. 1(b) are both from IW 1 to OW 1 and thus can share a CM, and the lightpath from IW 2 to OW 1 and that from IW 1 to OW 3 in Fig. 1(a) can do the same thing. Following (i), we specify:
Route-sharing Rule: the lightpaths coming from the same IW and going to the same OW must use the same CM, to reduce the occupation of CMs as much as possible when the network is running.

When studying the nonblocking condition and the CDC condition of WSW OXC, we consider two situations due to the routing constraints and the route-sharing rule. Let W be the number of wavelengths supported by the optical network. In the case where $r+r'n \geq W$, an IW could simultaneously launch W lightpaths that visit different OWs and different outputs of the DMs, or an OW may be accessed by W lightpaths that originate from different IWs and different inputs of the AMs at the same time. The W lightpaths should use W different CMs, according to the routing constraints. An example is the W=4 lightpaths from IW 1 in Fig. 1(a). In the case where $r+r'n<W$, there must exist at least two lightpaths that start from the same IW and visit the same OW, and thus has to use the same CM to comply with the route-sharing rule. In this case, the W lightpaths from an IW (or destined for an OW) will at most use $r+r'n<W$ CMs. An example is shown in Fig. 1(b).

Based on the above analysis, it is easy to prove the following statement.

Theorem 1. Under the route-sharing rule, a WSW OXC can fulfill the nonblocking bypass-switching function and CDC add/drop function, if and only if the number of CMs satisfies: (1) $m \geq \max\{n, W\}+W-1$, when $r+r'n \geq W$; and (2) $m \geq 2(r+r'n)-1$, otherwise.

For example, the OXCs in Fig. 1(a) and (b) need 7 and 9 CMs, respectively. Theorem 1 clearly reveals that the number of required CMs m and thus the dimension of WSSes is mainly determined by W, rather than port count $r+r'$, which is especially true when $n=W$. This theorem suggests that the WSW OXC is suitable for the future applications, where the number of wavelengths W is small while the number of fibers per link is large. Consider a ROADM as an example, where the nodal degree is 4, the number of fibers per degree is 40, the add/drop ratio is 60%, and the channel spacing is 400GHz, which implies W=12THz/0.4THz=30. We assume $n=W$. It is clear that the ROADM needs an OXC with r=4×40=160 and r'=160×60%=96. Table 1 shows that a nonblocking-and-CDC WSW OXC only needs 1×59 WSSes though $N=r+r'$=256.

Remember that the port count of current commercial WSSes is 48, and the 1×59 WSS may be unavailable in the coming years. Fig. 2 thus explores the blocking performance of WSW OXCs when conditions (1) and (2) in theorem 1 are not satisfied via simulation, where the traffic load offered to each wavelength is ρ=2. In addition to the route-sharing rule, our simulation considers two routing strategies. In Fig. 2, the "random" is to randomly assign an available CM to each request and the "most-used" always selects the one that is available and carries the maximum number of lightpaths. Fig. 2(a) indicates that, with a carefully designed routing strategy, 36 CMs are enough if we can tolerate a negligible (<10^{-5}) blocking rate. Also, the blocking rate is dominated by that of add/drop requests, since the route-sharing rule is beneficial for the establishment of bypass requests.

TABLE 1. COMPONENTS REQUIRED BY A 256×256 NONBLOCKING-AND-CDC WSW OXC.

	Dimension	Quantity
WSS	1×59	320
MEMS	30×59	192
	256×256	59

Note: r=160, r'=96, n=W=40

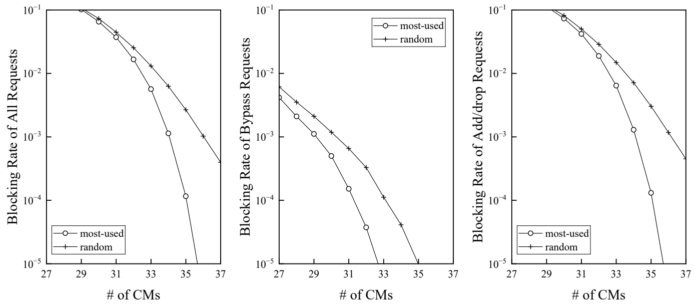


Fig. 2. Blocking rate of lightpath requests vs. # of CMs.

3. Conclusion

This paper studies the nonblocking and CDC conditions of a hybrid OXC architecture, named WSW OXC. Our results show that the port count of WSSes in this structure is determined by the number of wavelengths in the system. This suggests that it is suitable for the multifiber optical network with a small number of wavelengths.

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5. References

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