Clos-based All-optical Switching Architecture Supporting Mixed Unicast & Multicast Datacenter Services

Jiemin Lin
School of Electronic and Information Engineering,
Jiangsu Engineering Research Center of Novel Optical Fiber Technology and Communication Network,
Suzhou key Laboratory of Advanced Optical Communication Network Technology,
Soochow University
Suzhou, P. R. China

Yongcheng Li
School of Electronic and Information Engineering,
Jiangsu Engineering Research Center of Novel Optical Fiber Technology and Communication Network,
Suzhou key Laboratory of Advanced Optical Communication Network Technology,
Soochow University
Suzhou, P. R. China

Gangxiang Shen*
School of Electronic and Information Engineering,
Jiangsu Engineering Research Center of Novel Optical Fiber Technology and Communication Network,
Suzhou key Laboratory of Advanced Optical Communication Network Technology,
Soochow University
Suzhou, P. R. China
*shengx@suda.edu.cn

***Abstract*—We design a new multicast-enabled Clos optical switching (MCOS) architecture for datacenter networks. Simulation results show that the proposed architecture can significantly reduce the blocking probabilities of both unicast and multicast services compared with the conventional WSS-based Clos network. It is also found that when the ratio of splitters in the MCOS network is set to be the same as the proportion of multicast services, the proposed architecture can achieve an optimal blocking performance.**

Keywords—Multicast, Datacenter, WSS, Splitter

I. INTRODUCTION

With the rapid growth of bandwidth-intensive services, more switching capacity is required in datacenter networks (DCNs). Today's DCNs are mainly based on electronic switching, which suffers from several drawbacks, including low switching capacity and high power consumption. To overcome these issues, optical switching-based DCNs are being considered as a promising solution to provide high switching capacity with less power consumption [1]. For DCNs, the Spine-Leaf network (i.e., the folded Clos network) is found to perform efficiently [2], and therefore has been widely studied [3-4] and deployed [5]. The Spine-Leaf-based optical DCN architecture consists of switching elements such as WSSs, AWGs, and MEMSs, which excel at carrying unicast services [2-6]. However, in DCNs, there are typically two types of services, i.e., unicast and multicast (e.g., publish-subscribe) services. When employing the Spine-Leaf-based optical DCN to carry multicast services, it would be inefficient since each multicast service has to be split into multiple unicast services whose number is equal to the number of destination ports of the multicast service [8-10].

To tackle this issue, this paper proposes a novel multicast-enabled Clos optical switching (MCOS) network based on WSSs and optical splitters, in which the interconnection pattern between different modules is the same as the conventional Spine-Leaf network, but it can support all-optical multicast because of the use of optical splitters. We evaluate the blocking performance of the proposed architecture by simulations. The results show that the proposed MCOS network can significantly reduce service blocking probability when carrying mixed unicast & multicast datacenter services, compared with the conventional Spine-Leaf-based optical DCN without supporting multicast capability.

This work was jointly supported by the Key Research and Development Plan of Ministry of Science and Technology, China (2018YFB1801701) and Jiangsu Engineering Research Center of Novel Optical Fiber Technology and Communication Network.

II. MULTICAST-ENABLED CLOS OPTICAL SWITCHING (MCOS) ARCHITECTURE

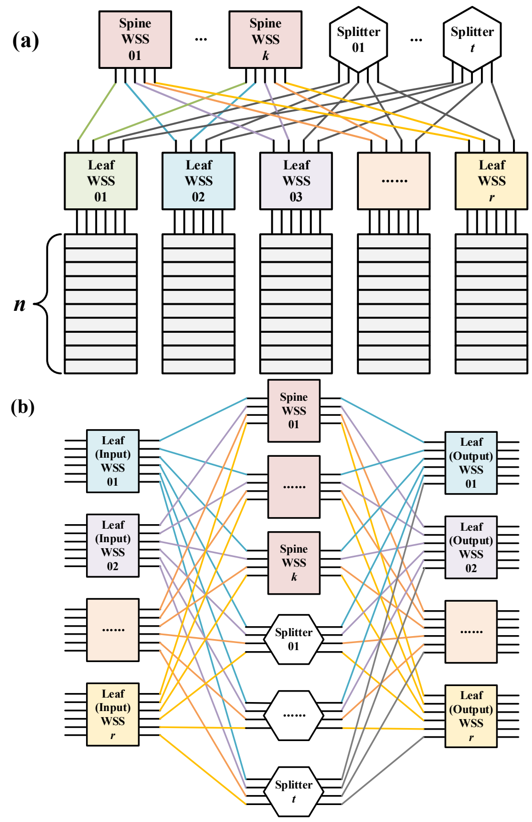


Fig. 1. Multicast-enabled Clos Optical Switching (MCOS) network.

Fig. 1(a) shows the proposed MCOS network, which consists of a spine layer, a leaf layer, and a server layer. The leaf layer switches service traffic from servers in the server layer, and the spine layer interconnects all the leaf-layer switches in a bipartite manner. In the spine layer, WSSs and optical splitters are deployed in a mixed manner. By unfolding the MCOS network, we can obtain a network architecture as shown in Fig. 1(b). This architecture is essentially a Clos network [11], in which the input and output layers correspond to the original leaf layer and the middle layer corresponds to the original spine layer. WSSs and optical splitters are mixed in the middle layer.

We represent the MCOS network as $v(k,t,n,r)$, where n is the number of servers under each input/output-layer WSS,

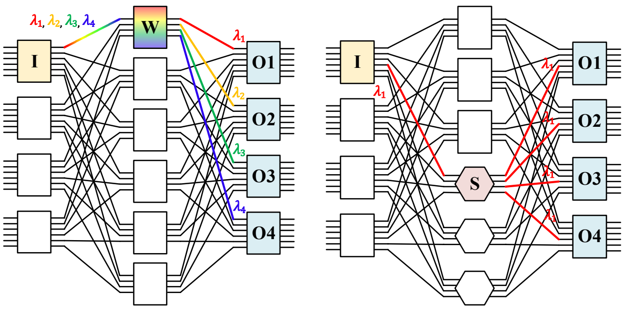
r is the number of input/output-layer WSSs, k is the number of middle-layer WSSs, and t is the number of middle-layer splitters. In the input/output layer, the size of each WSS is $n \times (k+t)$ or $(k+t) \times n$), and in the middle layer, the size of each WSS or splitter is $r \times r$.

Compared with the WSS-based Clos (or Spine-Leaf) network, the key concern for the MCOS network is its high insertion loss (IL) due to the use of optical splitters. Specifically, the IL (in dB) of an $r \times r$ splitter is $IL = 10 \cdot \log_{10} r$. It is reported that the maximum IL of a 16-port WSS is 14 dB [12], which corresponds to the IL of a 25-port splitter. This means that as long as r does not exceed 25, we can guarantee that the MCOS network will have an IL not exceeding that of WSS-based Clos network.

III. Unicast & Multicast Service Provisioning in MCOS Network

We provision unicast & multicast datacenter services in the MCOS network based on the following strategy. For unicast services, we always first employ WSSs in the spine layer to set up connections between the input and output layers. If there are no eligible middle-layer WSSs for setting up the unicast connection, but there are eligible middle-layer splitters for setting up the connection, then one of the splitters will be used to set up the connection. Specially, to avoid extraordinary using splitters for unicast services, we set the following rule: if the ratio of splitters in the middle layer is greater than the proportion of multicast services in the total services, then the exceeding portion of splitters is considered to be available for carrying unicast services. If neither splitters nor WSSs are available for the unicast service, the service request will be blocked. On the other hand, for multicast services, we always employ splitters in the middle layer to set up connections between the input and output layers. If there are no eligible middle-layer splitters for setting up the multicast connection, we will block the request. Here, as a special case of the MCOS network, if there is no splitter in the middle layer (which is essentially a WSS-based Clos network), then we will set up the multicast service as multiple unicast services.

Because there is no wavelength converter deployed in the switching node, the wavelength continuity constraint must be satisfied when setting up service connections.



(a) WSS-based Clos network (b) MCOS network

Fig. 2. Provisioning a multicast service in two types of Clos networks.

As an important advantage, the MCOS network can significantly save wavelength resources when setting up a multicast service compared with the conventional WSS-based Clos network. Fig. 2 shows examples of multicast service establishment in the two types of networks. In Fig. 2(a), four wavelengths are required to set up a multicast service in the conventional WSS-based Clos network with one wavelength assigned to each output port. In contrast, to set up the same multicast service, only a single wavelength is required by taking advantage of the splitter's multicasting capability (see Fig. 2(b)), thereby avoiding the wastage of wavelength resources. It is clear that the MCOS network is efficient to provision unicast and multicast services and it is expected to achieve better blocking performance than the conventional WSS-based Clos network.

IV. Simulations and Performance Analyses

We evaluate the blocking performance of the proposed MCOS network by simulations. Here, we assume that the MCOS network is $\nu(k, t, 10,5)$ and the number of wavelengths in each fiber is 5. We also assume that unicast & multicast datacenter services are uniformly distributed, under which the arrival of service requests follows a Poisson distribution at rate λ, and the holding time of each established service follows an exponential distribution with mean $1/\mu = 1.0$. therefore, the traffic load of service requests is $\rho = \lambda$ in units of Erlang. A total of 10^6 service requests are simulated for the calculation of service blocking performance.

A. Blocking Performance

We evaluate the blocking performance of the MCOS network with $k = 4$ and $t = 1$, which corresponds to four WSSs and one splitter in the middle layer. We assume that the ratio of multicast and unicast services is 1:4 and all the multicast services are 1-to-5. For performance comparison, we consider the conventional WSS-based Clos network with the same parameters as those of the MCOS network.

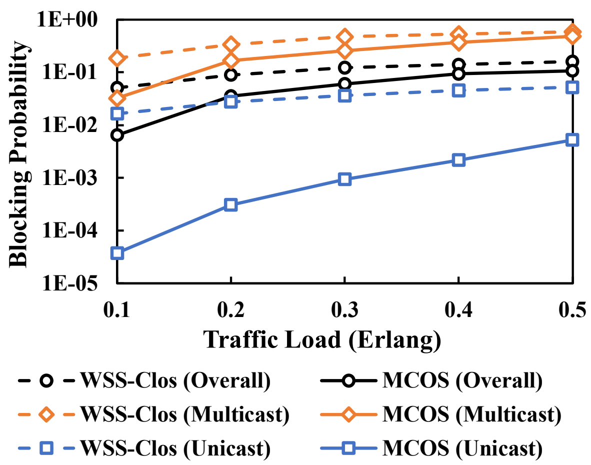


Fig. 3. Service blocking probabilities

Fig. 3 shows the overall service blocking probabilities of the two types of networks. We note that the MCOS network is effective to achieve a much lower blocking probability than the WSS-based Clos network. This is because the splitter in the MCOS network avoids the wastage of wavelength resources when setting up multicast services. Fig. 3 also shows the blocking probabilities of unicast and multicast services. It is found that the MCOS network can still achieve lower blocking probabilities for both types of services. This is because using WSSs to set up multicast services would waste many wavelengths resources, which affects provisioning of unicast services.

B. Impact of Number of Splitters

We evaluate how the number of splitters in the MCOS network will impact the service blocking performance. For this, we define *the ratio of splitters* as $\rho = t/(k+t)$, which calculates the proportion of splitters in the middle layer in the

Clos network. In this study, we set $k + t = 5$, and therefore the ratio of splitters is $\rho = t/5$. In addition, the traffic load is 0.5 Erlang with the ratio of multicast and unicast services to be 1:4.

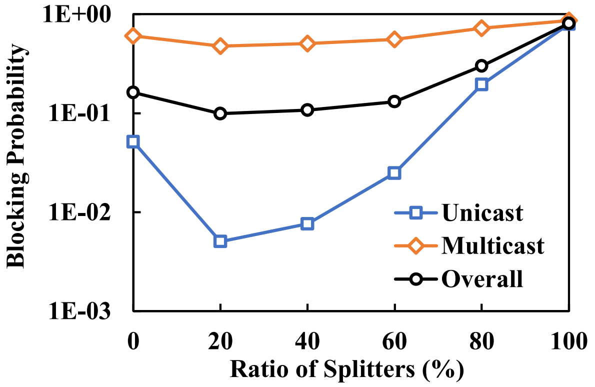


Fig. 4. Service blocking probability change with the ratio of splitters.

Fig. 4 shows the change of service blocking probability with an increasing ρ. Here, $\rho = 0\%$ corresponds to the conventional WSS-based Clos network and $\rho = 100\%$ corresponds to the case that there are no WSSs but all splitters in the middle layer. It is noted that with an increasing ρ, the unicast service blocking probability and the overall service blocking probability both decrease at the beginning and then increase with a further increase of ρ. This is because when ρ is small, adding splitters can reduce wavelengths used by multicast services, thereby reducing the blocking probability of both unicast and multicast services, and also the overall service blocking probability. However, when ρ is large, there are too many splitters in the middle layer, and many unicast services are set up via splitters, which wastes many wavelength resources, thereby degrading the service blocking probability of unicast services and the overall service blocking probability.

Also, it is interesting to note that both the overall service blocking probability and the unicast service blocking probability are the lowest at $\rho = 20\%$. This is because the proportion of multicast services among all the services is just equal to the ratio of splitters, which ensures the splitters to be most efficiently used by the multicast services. Therefore, as an important conclusion, we should set the ratio of splitters in the MCOS network to be the same as the proportion of multicast services to achieve an optimal blocking performance.

V. Conclusion

To construct an all-optical switching datacenter network for provisioning unicast & multicast services, we proposed the MCOS network by mixing WSSs and splitters in the middle layer of a Clos network. We showed that an optimal service blocking performance can be achieved for the MCOS network when a proper ratio of splitters (i.e., same as the proportion of multicast services) is set, which is significantly lower than that the conventional WSS-based Clos network.

References

[1] H. Ballani *et al.*, "Sirius: a flat datacenter network with nanosecond optical switching," in *Proc. ACM SIGCOMM*, 2020, pp. 782-797.

[2] Y. Liu, H. Yuan, A. Peters, and G. Zervas, "Comparison of SDM and WDM on direct and indirect optical data center networks," in *Proc.* European Conference on Optical Communication *(ECOC)*, 2016, pp. 1-3.

[3] J. Lin *et al.*, "Performance evaluation of wss-based all-optical spine-leaf data center network," in *Proc. Asia Communications and Photonics Conference (ACP)*, 2022, pp. 1-6.

[4] R. S. Luis *et al.*, "Multicore fiber interconnects for multi-terabit spine-leaf datacenter network topologies," *IEEE/OSA Journal of Optical Communications and Networking*, vol. 15, no. 7, pp. C41-C47, 2023.

[5] A. Singh *et al.*, "Jupiter rising: a decade of clos topologies and centralized control in Google's datacenter network," in *Proc. ACM SIGCOMM*, 2015, pp. 183-197.

[6] J. Lin, Z. Chang, L. Zong, S. K. Bose, T. Chang, and G. Shen. "From small to large: Clos network for scaling all-optical switching," *arXiv preprint*, arXiv:2302.06238, 2023.

[7] J. Lin, T. Chang, Z. Zhai, S. K. Bose, and G. Shen, "Wavelength selective switch-based Clos network: blocking theory and performance analyses," *IEEE/OSA Journal of Lightwave Technology*, vol. 40, no. 17, pp. 5842-5853, 2022.

[8] H. Wang, Y. Xia, K. Bergman, T. S. E. Ng, S. Sahu, and K. Sripanidkulchai, "Rethinking the physical layer of data center networks of the next decade: using optics to enable efficient *-cast connectivity," in *Proc. ACM SIGCOMM*, 2013, pp. 52-58.

[9] R. Malli, X. Zhang, and C. Qiao, "Benefits of multicasting in all-optical networks", in *Proc. All-Optical Networking: Architecture, Control, and Management Issues*, 1998, pp. 1-12.

[10] M. Moharrami, A. Fallahpour, H. Beyranvand, and J. A. Salehi, "Resource allocation and multicast routing in elastic optical networks," *IEEE Transactions on Communications*, vol. 65, no. 5, pp. 2101-2113, 2017.

[11] J. Lin, T. Chang, Z. Zhai, S. K. Bose, and G. Shen, "Wavelength selective switch-based Clos network: blocking theory and performance analyses," *IEEE/OSA Journal of Lightwave Technology*, vol. 40, no. 17, pp. 5842-5853, 2022.

[12] Z. Yuan *et al.*, "8 × 16 wavelength selective switch with full contentionless switching," *IEEE Photonics Technology Letters*, vol. 31, no. 7, pp. 557-560, 2019.