Universal method for designing non-blocking multicast-supported on chip optical router

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Abstract: Optical routers constructed by waveguides and microring resonators (MRs) play an important role for realizing non-blocking multicast-supported communication of Optical Networks-on-Chip (ONoCs). Most of the prior methods use building blocks to construct optical routers that cannot support multicast communication. Some prior optical routers support multicast communication by using large number of MRs with low utilization. In this letter, a universal method for designing non-blocking multicast-supported optical routers is proposed. Given the topology of the router that satisfies some conditions, this proposed method leverages broadband MRs and perform recursion pruning algorithm to obtain a multicast-supported router design with fewer MRs and high utilization. Based on this method, a five-port non-blocking multicast-supported optical router is designed. It saves up to 73.3% MRs and enhances 100% of the utilization compared with previous reported five-port routers.

Keywords: optical router, non-blocking, multicast, broadband ring, silicon photonics

Classification: Optical systems

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1 Introduction

With the development of on-chip silicon photonic devices, ONoCs become a promising communication system for Chip Multiprocessors (CMPs). Compared with electronically-connected Network-on-Chip (NoC), ONoCs possess larger communication bandwidth, lower transmission latency and lower power consumption [1]. Fully ONoC with passive routing algorithm has been proposed as the trend of future NoC [2]. Most of the previously reported optical routers [3, 4, 5, 6, 7] use only one of the resonant wavelengths of the MRs and cannot support non-blocking multicast communication. Some universal designing methods that use MRs as building blocks have been proposed [8, 9], but the topology of the routers they generalized uses large number of MRs and gets low utilization. The router proposed in [10] uses small number of MRs but gets low utilization and cannot support non-blocking multicast. In order to use fewer MRs and enhance the utilization of the MR, non-blocking multicast-supported optical router constructed with broadband rings [11] can be a good solution. However, to build an optical router with broadband rings to support non-blocking multicast communication, the topology of the router will be more compact. Therefore, those wavelengths that the MRs cannot couple should be taken into account as well. In this letter, a universal method for designing non-blocking multicast-supported optical routers with broadband ring is proposed. The proposed method allows designers input their topology of the router to get the wavelength route table and wavelength assignment, which separate the design process of the topology of the router from passive routing algorithm. Since all the optical routers designed by our method use passive routing that has zero static power consumption, they all have low power consumption compared with those use active routing.
2 Designing method

The topology of the router needs to meet the following conditions to apply the proposed method, which ensures there is at least one possible solution to non-blocking multicast communication for the given topology of the router. These two conditions are listed as follows:

Condition I. There are enough paths for each input port to communicate with each output port. Besides, any port does not communicate with itself.

Condition II. There are at least N-1 MRs assuming that the total number of ports is N.

Condition I ensures that the topology of the router is a connected graph. Condition II ensures that there are enough MRs to distinguish the light coming from different input ports and direct them to the right output ports to support multicast communication. The designing process takes three steps:

Step One. According to the architecture of the router, use Procedure PATH_CALCULATION shown in Table I to arrange the path with least insertion loss for each input-output port pair, and record the state of each MR for each path. For example, we suppose that path $P_i$ connecting $I_m$ and $O_n$ passes by MR $S_k$. If the wavelength $P_i$ used should be coupled by $S_k$, then the state of $S_k$ is on for $P_i$, so $P_i$ should be added to the cell indicating $S_k$ is on in the MR state table. If the wavelength $P_i$ used should not be coupled by $S_k$, then $P_i$ should be added to the cell indicating $S_k$ is off in the MR state table.

Step Two. Given the maximal number of wavelengths to be used, use Procedure DESIGN to assign a set of wavelengths to all the paths, create the wavelength route table, and replace the paths in the MR state table obtained in Step One with corresponding wavelengths. For different topologies of the router, the least number of needed wavelengths is different.

Step Three. The resolution obtained in Step Two is verified in this step by Procedure JUDGE. Multicast is realized by an input port modulating the signal into different wavelengths of light, so no identical wavelengths should appear in the same column/row of the wavelength route table. MRs should be realizable, so no identical wavelengths should be both coupled and uncoupled for each MR. To distinguish the light with same wavelength from different input ports, paths in coupled set of wavelengths for each MR should use different wavelengths. Therefore, three rules are defined in this step:

Rule I. No identical wavelengths appear in same row/column of the wavelength route table.

Rule II. No wavelength appears both in Coupled and Uncoupled set of wavelengths for each MR.

Rule III. No paths in Coupled set of wavelengths for each MR use the same wavelengths.

If the three rules are obeyed, the resolution obtained in Step Two is an available solution. If not, we need go back to Step Two and reassign another set of wavelengths. If all the possible assignments of the wavelengths have been tried and no solution is found, we need to increase the maximal number of wavelengths by one and go from Step Two again.
Based on proposed method, a five-port non-blocking multicast-supported optical router is designed. The topology of the router is shown in Fig. 1(a), which satisfies Condition I and II.
Compared with waveguide crossings, MRs coupled with waveguides bring more insertion loss [8], so the path with least insertion loss should have the fewest MRs. Following Step One, we arrange the path with at most one coupling of MR for each input-output pair for this topology. After path calculating, MR state table containing the paths whose wavelengths should be coupled or uncoupled by each MR is obtained.

Following Step Two, algorithm provided in Table I is employed, and one possible wavelength route table is shown in Fig. 1(b). Then all the paths in the MR state table we obtain in Step One are replaced with corresponding wavelengths shown in Fig. 1(b), and Procedure JUDGE is employed.

An example can illustrate the process of the proposed router realizing non-blocking multicast communication. I1 modulates the signal onto the wavelengths $\lambda_3$, $\lambda_5$ and $\lambda_1$ simultaneously, and transmits them to O2, O3 and O5, respectively. At the same time, I5 modulates the signal onto the wavelengths $\lambda_4$, $\lambda_1$ and $\lambda_3$ simultaneously, and transmits them to O1, O2 and O4, respectively. As we can
see in Fig. 1(c), no blocking occurs. Additionally, the proposed five-port optical router can support non-blocking multicast communication at all kinds of conditions, which can be proved by enumerating all the possible communication cases.

4 Analysis and comparisons

We analyzed and compared the router we proposed in section 3 with previously reported optical routers including λ-router, optimized crossbar router, traditional crossbar router and Cygnus [6] and the router in [10]. The number of MRs used by an optical router will decide its area and cost. Lowering the number of MRs will reduce its die size and enhance its yield. The result is shown in Fig. 2(a) and we can see it saves up to 73.3% of MRs.

As a set of wavelengths can be coupled by a broadband MR, we should use as many wavelengths of each broadband MR as possible. We apply the average number of wavelengths of the MRs used by the router to evaluate the utilization of MRs. High utilization of the MRs can reduce the number of the MRs used by optical routers, and lowering the power consumption of the router. The result shown in Fig. 2(b) indicates that the average number of the wavelengths of the MRs used by the proposed router is twice as large as that of previously reported optical routers.

![Fig. 2.](image)

(a) Number of MRs used by optical routers, (b) Average number of wavelengths of MRs

5 Conclusion

A universal method for designing non-blocking multicast-supported optical router based on the topology of the router is proposed. Unlike previously reported methods design optical router with building blocks, our method uses the topology of a router to explore available routing algorithms and MR customization. Results show the proposed method uses fewer MRs and enhances utilization of the MRs of the router.

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