

# An Electro Optical Honeycomb Networks-on-Chip based on a New Nonblocking Switch

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**Abstract:** Network-on-Chip (NoC) is an emerging paradigm for communications within large VLSI systems implemented on a single silicon chip. However, the electronic network on chip design faces many problems like energy consumption, bandwidth and QoS. Compared with traditional electronic NoC, optical Network on Chip exhibits advantages of high-bandwidth, low latency and power dissipation. In this paper, a new 4×4 optical non-blocking switch is introduced on the basis of the latest development of nanophotonic technologies and of the prompt progress of optical integration technologies. The new approach can solve the problem of internal blocking with a fine symmetrical feature, while it needs the minimal number of resonators. Optical-loss budget under this architecture is also evaluated, calculated and compared with currently existing optical switches in this paper. An **electro optical** honeycomb network-on-chip is constructed based on the new switch architecture. It functions with low power dissipation and high bandwidth for the future network on chip.

**Key Words:** optical NoC, non-blocking, switch, honeycomb

## 1. Introduction

The techniques of integrated circuit have witnessed rapid developments in the past few decades. Interconnecting techniques are to become the bottleneck of the overall system performance when the mainstream craftwork of integrated circuit descends to only 22-45nm. Feasible, functional and spacious, the advantages of electronic NoC are obvious. However, the transmission bandwidth per line on an electronic NoC is limited.

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\*This work is supported by Xidian University under the framework of the National Innovative Experiment Plan for College Students.

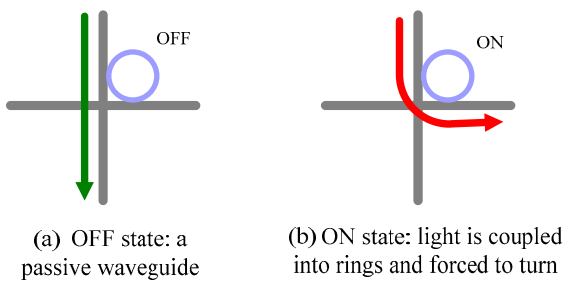
Optical NoC is introduced by many research institutions to resolve the many problems of electronic NoC [1, 2]. With combined advantages of photonics, the optical NoC can satisfy current requirements of low-latency, high-bandwidth and also minimized energy losses. With regard to optical NoC, there remain some issues to cover: buffering and processing.

When it comes to the design of optical NoC routers, obvious internal blocking is to potentially emerge in [1] that has proposed a design solution to optical switch, nevertheless it doesn't have qualities of high-bandwidth, low-latency and minimized energy losses. [3] has proposed another solution to that without blocking, yet it is not symmetrical enough and the optical losses of the Straight-forward path (optical signal heads ultimately in its opposite direction only) remain high. When used in mesh/torus networks, the energy cost ascends with the average distance of the network using XY routing.

In this paper, a 4×4 nonblocking optical switch is initially proposed. Then we put forward the exact proof for internal strictly nonblocking. Also the optical loss budget of our architecture is estimated and compared with other existing architectures in detail in Section 2. Our main concern in Section 3 is the exact conditions and how is the electro optical honeycomb NoC based on the new switch architecture, and with that we conclude this paper.

## 2. The new Switch Architecture

Several designs of optical Networks-on-Chip by using microring resonators have been proposed in literature [1, 3]. An optical microring resonator is an integrated optical structure which is shown in Fig.1 [4]. If the optical signal's wavelength differs from the resonating frequency, it will go through the waveguide as Fig.1 (a) shows. Otherwise, the signal will be forced to turn around to another port, shown as Fig.1 (b).

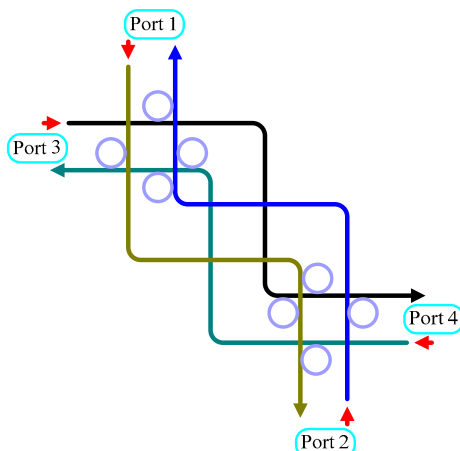


**Figure 1.** Fundamental optical switching element

## 2.1 Introduction to the New Switch Architecture

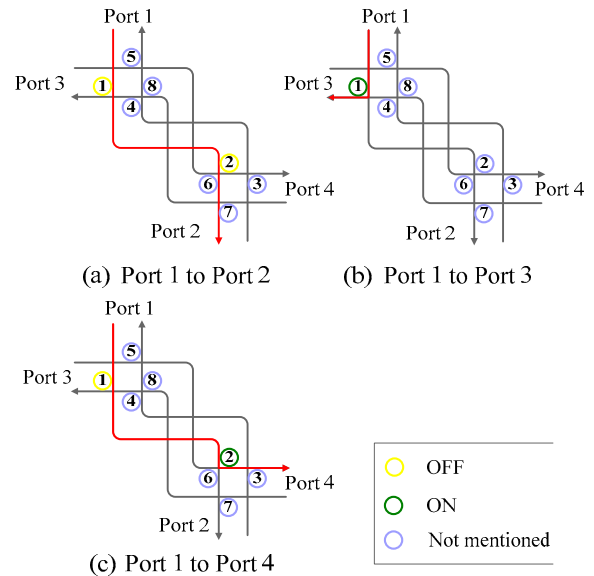
Before building the interconnection networks, we should design the node architecture first. Switch architecture is the key component in the node and implements the routing and flow control function. Amid the design of optical NoC switch, internal blocking is a key problem to be solved. A 4×4 blocking switch is proposed in [1] (short for S1), which limits the performance of the networks. An improved version is proposed in [3] (short for S2), which solves the problem of blocking, but it is not symmetrical enough and the optical losses of the Straight-forward path remain high. When used in mesh/torus networks, the energy cost ascends with the average distance of the network using XY routing. An  $n \times n$  crossbar architecture can be easily obtained by arranging the microring resonator and waveguide in rows and columns evenly. It is nonblocking but at the cost of more waveguides, microring resonators and optical losses.

The proposed optical switch structure is shown in Fig.2. With this layout, the most optimized number of resonators is used to implement the non-blocking 4×4 switch architecture.



**Figure 2.** Schematic of a 4×4 Nonblocking Optical Switch

An exemplifying proof for internal strictly non-blocking when the packets are injected from Port 1 is shown in Fig.3.



**Figure 3.** Resonators 1, 2 controlling the direction of packets injected from Port 1

(a) Port 1 to Port 2, while resonator 1, 2 are under the state of OFF, other resonators are not influenced;

(b) Port 1 to Port 3, while resonator 1 is under the state of ON, resonator 2 is under unknown state (generally as OFF), other resonators are not influenced;

(c) Port 1 to Port 4, while resonator 1 is under the state of OFF, resonator 2 is under the state of ON, other resonators are not influenced.

We can deduce out of the Fig.3 that the output direction from Port 1 is controlled only by the states of resonator 1, 2(i.e. Port 1 corresponds with resonators 1, 2; Port 2 corresponds with 3, 4; Port 3 corresponds with 5, 6; Port 4 corresponds with 7, 8), which is unrelated to the other 6 resonators' states. It is the same case with other inputting ports that each output direction is controlled by the state of a couple of resonators. The four couples of resonators do not exert interruption mutually when controlling the direction of packets coming inwards. That is, no interruption occurs to other packet flows when any path of packet comes across, which can be attributed as strictly nonblocking in its internal architecture.

Basing on the assumption that the source and destination ports do not coincide and no contention exists on the output port, the speculative process regarded in the above paragraph comes to the desired conclusion.

## 2.2 Optical-loss Analysis

Energy issue concerns every chip designer. The energy consumed by the switch is determined by the ON state of the microring resonators. In the OFF state, no power will be consumed.

As for crossbar and S2, the ON state is entered at each hop of the packet in mesh/torus networks using XY routing. Hence, the average hops in the network, i.e. average distance of the networks, determine the energy consumption. As for our architecture, when the packet makes turns in the network, a resonator will enter ON state. Otherwise, the microring resonator will keep in the OFF state.

We assumed that a loss of 0.05 dB occurs in the waveguide crossing and 0.5 dB in the ON-state microring. We calculate that the average optical losses of our switch architecture sum up to 0.53 dB in any direction, and also the minimum losses count up to 0.3 dB (each Straight-forward path), respectively (shown as Tab.1). The optical losses of the new switch architecture and three other proposed architectures are calculated in Tab.2.

**Table 1.** Optical loss in each direction for the new architecture (dB)

Out In	Port1	Port2	Port3	Port4	Avg.
Port1	-	0.3	0.75	0.55	0.53
Port2	0.3	-	0.55	0.75	
Port3	0.75	0.55	-	0.3	
Port4	0.55	0.75	0.3	-	

**Table 2.** Loss comparisons (dB)

	Average	Max	Min	Straight -forward
Crossbar	0.7	0.9	0.5	0.7
S1	0.4	0.6	0.1	0.1
S2	0.5	0.7	0.25	<b>0.7</b>
New-switch	0.53	0.75	0.3	<b>0.3</b>

Tab.1 presents the optical loss in each direction of the new architecture proposed in this paper, and Tab.2 shows the comparison features with the other three switches. Evidently, crossbar architecture performs poorest on any aspect including the optical loss within the Average, Max and Straight-forward direction. Apart from the comparatively low optical loss, S1 is not often used for the existing heavy blocking. S2 is also intolerable for the

optical loss that happens mainly on the Straight-forward path within a mesh/torus network using XY routing.

For the transmission of a packet within a mesh/torus network using XY routing, the probability of forwarding is higher than that of turning up or down. Our architecture fully utilizes this property. The loss is lowered to 0.3 dB on the Straight-forward path, decreased by 57.1% comparing with 0.7dB of S2.

We compare the total loss for the longest path in a 4×4 2D mesh network using the various switch architectures, such as S2, 4×4 Crossbar. The result shows our architecture works with the lowest optical-loss.

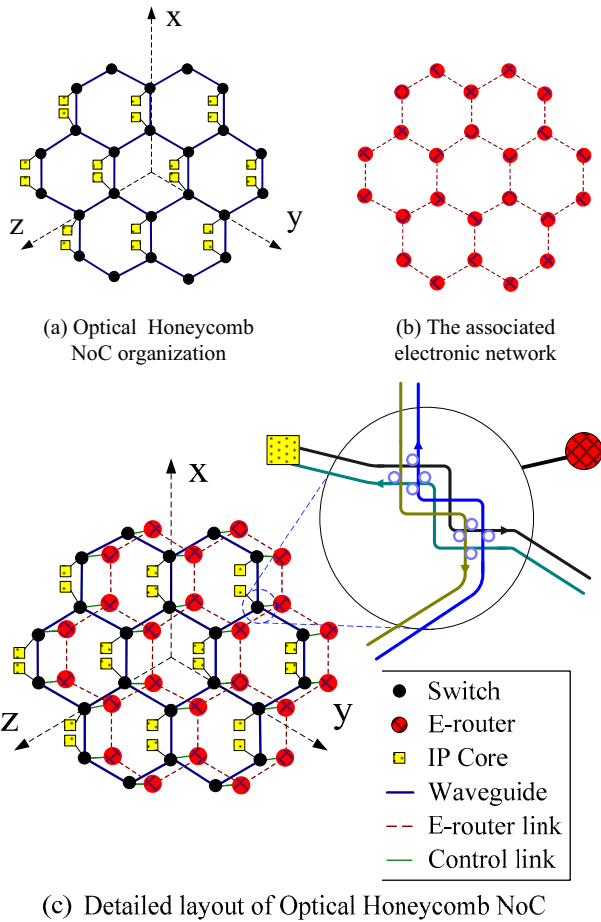
Our architecture also has some blemishes inevitably, mainly on the asymmetry feature of optical losses, which is actually a common headache.

## 3. Electro Optical NoC

With the new switch architecture, an electro optical network on chip can be built up. Fig.4 shows an electro optical network on chip which employs the proposed switch architecture. It consists of two overlapped networks, i.e. the silicon broadband optical switches are connected by waveguides to form an optical interconnection network for the transmission of high bandwidth messages. Electronic overlay control network is for small data packets and control packets. The state of the nodes in optical networks is controlled by corresponding electronic routers (shown in Fig.4 (c)). The buffering and processing problem in optical domain can be solved in this way.

As for the network topology, the popular topology for NoC can be Mesh or Torus or a 2-Dimensional planar one. But for these topologies, 5×5 switch is needed to implement local injection/ejection port. A 5×5 switch, while very simple to implement as an electronic transistor-based crossbar, is quite difficult to construct using 2×2 optical switching elements. Honeycomb network is another good candidate, as is shown in Fig.4. It has much smaller network diameter than ordinary Mesh and Torus [5]. What's more, the degree of honeycomb networks is 3, and so three of the 4×4 optical switch can be applied to connect the peripheral 3 nodes, with the remaining one especially dedicated to the injection and ejection of the local port.

Routing is the basic data communication concern for every network. As the optical and electronic networks are of the same topology, we design the same routing algorithm for them.



**Figure 4.** Electro Optical Honeycomb NoC

The routing algorithm for optical Honeycomb network (shown as Fig.4 (a)) checks at each current node which of the link directions x, y, or z (in this order) would reduce the distance to the destination, and will send the packets on that link. At last one of the link directions would lead to a node closer to the destination. Electronic network (shown as Fig.4 (b)) can also use this routing algorithm because it has the same topology as optical Honeycomb network. Through a control link, each optical switch is connected to the corresponding E-router of the electronic network with a control link.

#### 4. Conclusion

The development of NoC has ignited the flame of a new era, prompting computer network technology into a greater period. The optical NoC is further improving the bandwidth of message transmission, lowering latency and power dissipation by adding photonic medium.

On the basis of current development of optical NoC,

the optical properties of light and the integration techniques of optics, the proposed 4×4 nonblocking optical switch for optical NoC can theoretically solve the problem of internal blocking and help improve the overall performance of optical NoC. Eight resonators are applied in the architecture, and the optical losses descend to minimum on the Straight-forward path thus guaranteeing the entire architecture low optical losses in mesh/torus networks using XY routing. An electro optical honeycomb network on chip is constructed based on the new switch architecture. The new switch architecture is featured for the latter work of optical NoC.

Our future work is to prove the fine properties of the switch architecture in a mesh/torus network using XY routing and an electro optical Honeycomb NoC including low latency and high bandwidth etc. from a simulative perspective.

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