Panzer: A 6×6 photonic router for optical network on chip

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Abstract: Photonic interconnection network plays an increasingly significant role in on-chip microarchitecture. As the heart of optical network on chips, the photonic routers implement the function of routing package from input ports to output ports. In this letter, we proposed Panzer, a 6×6 optical router to meet the extension demand of on-chip network. Compared with other routers, Panzer has the lowest insertion loss and the fewest number of microring resonator. We simulated the 64-core improved mesh built with Panzer, and showed the end-to-end delay and network throughput under neighbor traffic patterns.

Keywords: optical router, photonic NoC, six ports

Classification: Optical systems

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1 Introduction

Optical network on chip (ONoC), which capitalizes on the benefits of optical interconnection, such as large channel capacity, high data transfer rate and fundamentally low energy consumption [1], has been proposed as a promising alternative to metallic interconnection for giga-scale multiprocessor system on chip (MPSoC). As the key component for ONoC, optical router [2] has the basic function of routing the signals from input ports to specific output ports.

In order to save chip area and improve utilization of scarce network resources, two CPU cores are placed in one tile with shared cache and router. For example, the Single-Chip Cloud Computer (SCC) [3] by Intel Corporation in 2009 as well as the Knights Landing, the second generation Intel Xeon Phi product revealed in 2013. The communication costs between cores in the same tile are invariably smaller than costs between cores farther away on chip. Besides, two-core-per-tile architecture achieves the best tradeoff of performance and manufacturability.

Widespread adoption of 2D mesh in commercial products usually employs the five-port optical router, which connects the core and the four routers on the north and south, east and west directions. Two-core-per-tile architecture based on 2D mesh ONoC requires an extra port for the second core. Hence, six-port optical router is needed. However, little progress has been made in the research on six-port optical router. In this letter, we proposed a 6×6 optical router taking the advantage of two-layer framework, and analyzed its performance for optical network on chip.

2 Panzer router

2.1 Router architecture

Two types of switching elements are used in Panzer, including inner-layer switching element and inter-layer switching element. They are both constructed by two waveguides and one MR (microring resonator), but the two waveguides in the inter-layer switching element are placed in two layers, which is different against the inner-layer one. For instance, an optical signal from port I_1 port O_1 is routed by inner-layer resonator MR_1 , as shown in Fig. 1(a), port I_2 communicates with port

O_2 through the inter-layer coupler MR_2 . Panzer takes the advantage of 60° or 120° crossing angle instead of the conventional 90° to reduce the crosstalk [4].

A control unit is employed to configure all the active MRs. When the MR is powered on, the incident light with resonance wavelength can be coupled to another waveguide. When the MR is powered off, the incident light will propagate along the original waveguide. In other words, the control unit can make optical signal drop or go through via the transition of MRs' On/Off states.

The 6×6 Panzer router, illustrated as both 3D structure and planar structure in Fig. 1(b) and (c), has 24 MRs and 6 waveguides with bending of 120° . Each of the six ports includes an input port and an output port. A waveguide connects one input port with one output port, while the MRs route the signal.

In this two-layer router, the waveguide W_1, W_3, W_5 and the microring resonator $R_1, R_2, R_3, R_4, R_9, R_{10}, R_{11}, R_{12}, R_{17}, R_{18}, R_{19}, R_{20}$ are in the upper layer while the other waveguides as well as the other MRs are placed in the lower layer.

If r is odd, the microring resonator R_r acts as inter-layer coupler; and if r is even, R_r acts as inner-layer coupler. In particular, the microring resonator R_r connects two layers when r is a multiple of 4.

Fig. 1. (a) the basic elements (b) 3D structure of Panzer (c) planar structure of Panzer

Six waveguides connect all the 6 ports $P_1, P_2, P_3 \dots P_6$. At any port P_m , there are input I_m connected with waveguide W_i and output O_m connected with waveguide W_j . The number of waveguide W_i , i , fulfill the basic condition $i = m$, also the relationship between W_i and W_j is applied to $j - i \equiv 2(\text{mod}6)$. The odd number of waveguides are in the upper layer, and the even ones are in the lower layer.

Overhead view the whole architecture, each waveguide is extended by the input port along the optical signal injection direction and has N crossing with other waveguides. The 120° bending is between the second crossing and the third crossing. The strictly non-blocking property of the optical router Panzer is proved by enumerating all possible cases.

2.2 Communication rules

The 6×6 Panzer is a generic non-blocking router architecture, which routes the signals according to the rules stated as follow. Assuming that one optical signal is from input port I_m to output port O_n , $m \neq n$.

Case 1: If $n - m \equiv 4(\text{mod}6)$, port I_m communicates with port O_n by the waveguide directly.

Case 2: If $n - m \neq 4(\text{mod}6)$, then the signal communicates port I_m with port O_n via the microring resonator R_r . It follows a mathematical equation that describes the relationship among the port I_m , O_n and the microring resonator R_r :

$$\begin{cases} r = (n - m) \bmod 6 + 4(m - 1), & (n - m) \bmod 6 < 3 \\ r = (n - m) \bmod 6 + 4(m - 1) - 1, & (n - m) \bmod 6 > 3 \end{cases}$$

3 Comparison and simulation

3.1 Comparison of different routers

We compare the number of MRs used and estimate insertion loss of router Panzer against several existing typical router architectures, including the traditional crossbar router, the reduced crossbar [5], the WRON [6], the λ -router [7], and the GWOR [8, 9].

Microring resonator is a significant component affecting the performance of the optical interconnection network. Reducing the number of MR not only decreases the energy consumption but also reduces the size of die. Fig. 2(a) shows that Panzer uses the lowest number of MRs as GWOR does, which leads to a smaller footprint and lower loss.

Insertion loss of an optical router influences the power consumption required by generating, modulating and detecting the optical signal, as well as determines the scalability. As given by the equation (1), it is usually expressed in decibels (dB) and calculated by adding the loss along the path together.

(a) Number of MRs Used in Different Architectures

	Crossbar	Red.Xbar	WRON	λ -router	GWOR	Panzer
6×6	36	30	30	30	24	24

Fig. 2. The comparison of Panzer and the other routers.

$$L_{\text{insert}} = \sum L_{\text{bend}} + \sum L_{\text{cross}} + \sum L_{\text{drop}} + \sum L_{\text{through}} \quad (1)$$

where $\sum L_{\text{bend}}$, $\sum L_{\text{cross}}$, $\sum L_{\text{drop}}$, $\sum L_{\text{through}}$ are the total value of the waveguide bending losses, the waveguide crossing losses, the MR drop losses and the through-losses, each of which respectively undergoes 0.013 dB, 0.05 dB, 1.5 dB, 0.01 dB [8]. In particular, 60° or 120° optical coupler has a drop-loss of 1.6 dB according to [4].

Fig. 2(b) listed the insertion loss by an optical signal communicating one input port with an output port in this six routers. Furthermore, the average insertion loss is the arithmetical mean while the maximum value is the insertion loss of the worst scenario.

Analysis shows that the average loss of 6 × 6 Panzer is reduced by 22.8%, 22.3%, 10.3%, 10.3%, 0.7% compared to the other router designs, and the worst case loss reduced by 14.8%, 14.8%, 3.2%, 3.2%, 7.3%. Thus, it can be drawn that our design has the lowest power loss, which saves energy of the entire ONoC architecture and enhances the reliability of information transmission.

3.2 Simulation result

The performance of the ONoC is measured in terms of end-to-end (ETE) delay and throughput [10].

End-to-end delay refers to the time taken for a packet to be transmitted across a network from source to destination, which is composed of path-setup time and optical signal transmission time. The network throughput is the rate of packet delivery successfully over a communication channel. It can be calculated as shown in equation (2) and usually measured in bits per second (bit/s or bps).

$$\text{Throughput} = \lambda \times N_r / N_s \quad (2)$$

In equation (2), N_r as well as N_s is defined as the number of packet received and sent. Offered load λ is the percentage of packet injection time over a period of time.

Unlike conventional mesh of 8 × 8 scale with 64 five-port routers, we built 64-core 8 × 4 mesh optical NoC using 32 Panzer, which reduces the number of routers and the area of die. In this network, one Panzer combines two core, therefore, the switching element in Panzer is used for neighbor communication and the improved ONoC mesh topology is for global interconnection.

We implement a nearest neighbor communication pattern [1], in which nodes communicate with their neighboring using different nearest neighbor rate (NNR). NNR indicates the probability that network traffic generates between cores in the same node.

It is shown that the ETE delay and the network throughput of different NNR under nearest-neighbor traffic in Fig. 3. As the offered load rises, the propagation delay-time is small before the saturation point and grows rapidly after then. And the ETE delay saturation points gradually go up with the increase of the rate.

Under the same offered load, larger rate of neighbor communication causes the shorter path and lower power consumption. The simulation of throughput in Fig. 3(b) also substantiates that the Panzer can carry the neighbor communication

Fig. 3. The simulation result of Panzer (a) ETE delay (b) Throughput

track, reducing traffic as well as congestion on the global network, which results in lower ETE delay and increased throughput.

4 Conclusion

In this letter, we proposed a six-port non-blocking photonic router called Panzer, which requires the lowest number of MRs and has the best performance in insertion loss. We simulated the 64-core improved mesh ONoC based on Panzer, and showed the ETE delay and throughput under different NNR of neighbor communication traffic. In the following research, we will design a new topology considering the characteristics of Panzer for future power-efficient optical network-on-chip.

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